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 more than [50] *57* passenger motor vehicles, 56 *of which are* for replacement only, including [one] *two* law enforcement [vehicle] *vehicles*, two ambulances, and [three] *two* buses, [$4,903,710,000] *$5,121,437, 000*, to remain available until expended[: Provided, That $15,000,000 appropriated under this heading under prior appropriation Acts for the Advanced Research Projects Agency—Energy is hereby transferred to the "Advanced Research Projects Agency—Energy" account: Provided further, That, of the amount appropriated in this paragraph, $76,890,000 shall be used for the projects specified in the table that appears under the heading "Congressionally Directed Science Projects" in the joint explanatory statement accompanying the conference report on this Act]. (Energy and Water Development and Related Agencies Appropriations Act, 2010.)

Explanation of Change

Changes are proposed to reflect the FY 2011 funding and vehicle request.

Office of Science

Overview

Appropriation Summary by Program

(dollars in thousands)

	FY 2009 Current Appropriation	FY 2009 Current Recovery Act Appropriation[a]	FY 2010 Current Appropriation	FY 2011 Request
Office of Science				
Advanced Scientific Computing Research	358,772	+161,795	394,000	426,000
Basic Energy Sciences	1,535,765	+555,406	1,636,500	1,835,000
Biological and Environmental Research	585,176	+165,653	604,182	626,900
Fusion Energy Sciences	394,518	+91,023	426,000	380,000
High Energy Physics	775,868	+232,390	810,483	829,000
Nuclear Physics	500,307	+154,800	535,000	562,000
Workforce Development for Teachers and Scientists	13,583	+12,500	20,678	35,600
Science Laboratories Infrastructure	145,380	+198,114	127,600	126,000
Safeguards and Security	80,603	0	83,000	86,500
Science Program Direction	186,695	+5,600	189,377	214,437
Small Business Innovation Research (SBIR)/ Small Business Technology Transfer (STTR) (SC funding)	104,905[b]	+18,719[b]	0	0
Subtotal, Office of Science	4,681,572	+1,596,000[c]	4,826,820	5,121,437
Congressionally-directed projects	91,064	0	76,890	0
SBIR/STTR (Other DOE funding)	49,534[d]	+36,918[d]	0	0
Subtotal, Office of Science	4,822,170	+1,632,918	4,903,710	5,121,437
Use of prior year balances	-15,000	0	0	0
Total, Office of Science	4,807,170	+1,632,918	4,903,710	5,121,437
Advanced Research Projects Agency-Energy (ARPA-E)	6,300[e]	0	0	0
Total, Science Appropriation	4,813,470	+1,632,918	4,903,710	5,121,437

[a] The Recovery Act Current Appropriation column reflects the allocation of funding as of September 30, 2009 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 funding reprogrammed within the Science total to support the SBIR and STTR programs.
[c] $4,000,000 of the original $1,600,000,000 Recovery Act appropriation has been transferred to Departmental Administration for management and oversight.
[d] Reflects funding transferred from other DOE appropriation accounts to support the SBIR and STTR programs.
[e] $15,000,000 was appropriated in FY 2009 in the Science account for ARPA-E. The FY 2010 appropriation directed that this $15,000,000 be transferred to the Energy Transformation Acceleration Fund (ARPA-E). $8,700,000 has been transferred to date. Remaining balances of $6,300,000 will also be transferred during FY 2010.

Preface

The Office of Science request for Fiscal Year (FY) 2011 is $5,121,437,000, an increase of $217,727,000, or 4.4%, over the FY 2010 appropriation; and is $294,617,000, or 6.1%, over the FY 2010 appropriation excluding congressionally-directed projects.

Fundamentally new approaches to technologies for energy production, storage, and use are essential. 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 21st century.

The FY 2011 budget request supports the President's Plan for Science and Innovation, which encompasses the entire Office of Science budget, as part of a strategy to double overall basic research funding at select agencies. As part of this plan, the FY 2011 request supports the training of students and researchers in fields critical to our national competitiveness and innovation economy, and supports investments in areas of research critical to our clean energy future and to making the U.S. a leader on climate change. The FY 2011 request also supports the President's priorities for the U.S. Global Change Research Program, the National Nanotechnology Initiative, and Networking and Information Technology Research and Development.

The Office of Science supports research programs in condensed matter and materials physics, chemistry, biology, climate and environmental sciences, applied mathematics, computational science, high energy physics, nuclear physics, 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.

The Office of Science supports investigators from more than 300 academic institutions and from all of the DOE laboratories. The FY 2011 budget request will support about 27,000 Ph.D.'s, graduate students, undergraduates, engineers, and technicians. Nearly 26,000 researchers from universities, national laboratories, industry, and international partners are expected to use the Office of Science scientific user facilities in FY 2011.

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.

The Office of Science has ten programs: Advanced Scientific Computing Research (ASCR), Biological and Environmental Research (BER), Basic Energy Sciences (BES), Fusion Energy Sciences (FES), High Energy Physics (HEP), Nuclear Physics (NP), Workforce Development for Teachers and Scientists

(WDTS), Science Laboratories Infrastructure (SLI), Safeguards and Security (S&S), and Science Program Direction (SCPD).

Mission

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.

Benefits

The Office of Science accomplishes its mission by supporting:

- *Science for Discovery* focused on unraveling nature's mysteries—from the study of subatomic particles, atoms, and molecules that make of the materials of our everyday world to DNA, proteins, cells, and entire biological systems;
- *Science for National Need* focused on advancing a clean energy agenda through basic research on energy production, storage, transmission, and use; and advancing our understanding of the Earth's climate through basic research in atmospheric and environmental sciences and climate change; and
- *National Scientific User Facilities*, the 21st century tools of science, engineering, and technology—providing the Nation's researchers with the most advanced tools of modern science including accelerators, colliders, supercomputers, light sources and neutron sources, and facilities for studying the nanoworld.

Performance

The Office of Science activities target the Secretary's Innovation goal (*Lead the world in science, technology, and engineering)*, and those activities underlie progress on the Secretary's Energy goal (*Build a competitive, low-carbon economy and secure America's energy future*) and Security goal (*Reduce nuclear dangers and environmental risks*). Each of the Office of Science research programs support fundamental, innovative, peer-reviewed research to create new knowledge in areas important to Office of Science 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.

Program Overview

The *Advanced Scientific Computing Research* program 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 partnerships (Scientific Discovery through Advanced Computing, or SciDAC); research and evaluation prototypes; and the operation of high performance computing systems and networks. In FY 2011, ASCR continues research efforts in the SciDAC, applied mathematics, and computer science programs. The FY 2011 request supports continued operations of the Leadership Computing Facilities at the Oak Ridge and Argonne National Laboratories, and the operations of the National Energy Research Scientific Computing (NERSC) facility, which reaches approximately one petaflop capacity in FY 2010, at Lawrence Berkeley National Laboratory. The Energy Sciences network (ESnet) will deliver 100–400 gigabit per second connections among the Office of Science laboratories in FY 2011.

The *Basic Energy Sciences* program supports research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels. 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, and efficiency. 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 2011, investments continue to support the Energy Frontier Research Centers (EFRCs), focused on accelerating fundamental energy sciences, as well as single investigator and small group awards. BES also takes part in the Department's multi-disciplinary Energy Innovation Hubs program. In FY 2011, BES-supported Hubs will focus on Fuels from Sunlight and Batteries and Energy Storage, and BES will support additional EFRCs focused on discovery and development of new materials and energy applications in areas such as carbon capture and advanced nuclear energy systems.

The *Biological and Environmental Research* program 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 to 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 2011, BER continues research in systems biology, radiochemistry, climate science, and subsurface biogeochemistry. Support is provided for the three Bioenergy Research Centers, the Joint Genome Institute, and the Environmental Molecular Sciences Laboratory. The FY 2011 request includes investment in climate science research to more rapidly integrate existing and new knowledge into next-generation climate and Earth system prediction models that systematically reduce the uncertainties in predictions of decade to century climate change and increase the availability and usability of climate predictions to address the critical DOE mission to provide energy security to the Nation in a sustainable way. BER will also continue support for simulations and analyses needed for part of the Intergovernmental Panel on Climate Change Fifth Assessment.

The *Fusion Energy Sciences* program 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 leads the U.S. participation 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 2011 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—will continue to focus on providing solutions to high-priority technical issues and build a firm physics basis for ITER design and operation. Support for the Fusion Simulation Program computational initiative ramps up in FY 2011 as the program transitions from its planning phase to the full program. FES also continues to support the joint program in high energy density laboratory plasmas with the National Nuclear Security Administration.

The *High Energy Physics* program supports research to understand how the universe works at its most fundamental level. This is accomplished by discovering the most elementary constituents of matter and energy, probing the interactions among them, and exploring the basic nature of space and time itself. 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. The Tevatron Collider at Fermi National Accelerator Laboratory continues operations during FY 2011. Support for Large Hadron Collider (LHC) detector operations, maintenance, computing, and R&D continues in FY 2011 in order to maintain a U.S. leadership role in the LHC program. Construction continues for the Neutrinos at the Main Injector (NuMI) Off-Axis Neutrino Appearance (NOνA) project to enable key measurements of neutrino properties. Project engineering and design begins for two new experiments using the NuMI beam and other auxiliary beamlines: the Long Baseline Neutrino Experiment (LBNE) and the Muon to Electron (Mu2e) experiment. Several projects to pursue questions in dark matter, dark energy, and neutrino properties continue in FY 2011, 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 and for experiments that may be located in the National Science Foundation's proposed Deep Underground Science and Engineering Laboratory (DUSEL). HEP also continues support for advanced accelerator and detector R&D.

The *Nuclear Physics* program 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 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 2011 request supports near optimal levels of operations at the four NP 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 do activities for the proposed Facility for Rare Isotope Beams (FRIB). The request also supports several ongoing major items of equipment to address compelling scientific opportunities. In FY 2011, the Isotope Development and Production for Research Applications Program will focus on production of isotope needed by stakeholders and research isotope priorities identified by the Nuclear Science Advisory Committee and community input.

The *Workforce Development for Teachers and Scientists* program supports a range of activities for science, technology, engineering, and mathematics (STEM) students and educators, including the DOE Office of Science Graduate Fellowship program, undergraduate research programs that place students in world class research environments at the DOE laboratories, mentorship programs for K–12 teachers and undergraduate faculty who teach STEM subjects, and nation-wide competitions at the middle school and high school levels, such as the National Science Bowl®. In FY 2011, the Office of Science will initiate a research program to assess the effectiveness of investments in science, consistent with the federal interagency Science of Science Policy initiative.

Office of Science Early Career Research Program

In July 2009, the Office of Science announced the establishment of the Office of Science Early Career Research Program to support outstanding scientists early in their careers in the disciplines supported by the Office of Science. This program provides competitively selected 5-year research awards to researchers who have received a Ph.D. within the past ten years and who are untenured, tenure-track assistant professors in U.S. academic institutions or full-time employees in DOE national laboratories. Early career researchers may apply to any of the Office of Science research programs. Proposed research topics must fall within the Office of Science programmatic priorities, which are provided in annual program announcements. This program addresses recommendations from multiple Committee of Visitors' reviews and reports such as the National Academies' 2005 study, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*.

FY 2010 is the first year of this program with support for approximately 65 research awards provided through Recovery Act funds. Proposals, which will be merit reviewed by external panels of experts, were due September 1, 2009, and awards are expected to be announced by May 2010. Beginning in FY 2011, the Office of Science will issue an annual solicitation, and the Office of Science research programs will support awards through annual appropriated funds. Approximately 60 new research awards to university and DOE laboratory researchers are expected to be awarded in FY 2011 based on this open, competitive process. Office of Science program offices with existing early career research award programs, such as the Outstanding Junior Investigator awards programs, will gradually integrate these programs into the Office of Science Early Career Research Program.

Isotope Development, Production, and Research

Isotope production at the Department of Energy is primarily the responsibility of the Office of Science with two exceptions: plutonium-238 production by the Office of Nuclear Energy (NE) and molybdenum-99 production supported by NNSA's Global Threat Reduction Initiative (GTRI).

The Isotope Development and Production for Research and Applications (Isotope) program located in SC's Nuclear Physics program offers more than 120 stable and radioactive isotopes for use in basic research and in medical diagnostic, medical treatment, national security, energy, and industrial applications. The Isotope program produces isotopes only where there is no U.S. private sector capability or where other production capacity is insufficient to meet U.S. needs. Isotope production for commercial use or repackaging is on a full-cost recovery basis, while isotopes produced solely for non-proprietary research purposes are provided at below cost. The Isotope program works in close collaboration with other federal agencies and the isotope-using communities to develop priorities for production. This past year, the Nuclear Science Advisory Committee issued its report establishing priorities for the production of research isotopes in April 2009. A long-term strategic plan for the program came out in November 2009. Both reports were developed with federal, commercial, and research community input. A current priority is the production of helium-3, used in neutron detection and cryogenics. Historically, helium-3 has been a by-product of tritium production for the U.S. weapons program. With the reduction in nuclear weapons, tritium production is at a low level and current demand for helium-3 has drawn down supplies. U.S. and international efforts are underway to address the helium-3 supply shortfall.

For nearly 50 years, NE's Space and Defense Power Systems program has supported the design, development, production, and safety of plutonium-238 radioisotope power systems. Science missions to explore the solar system and other government applications use plutonium-238 power systems. With a limited existing plutonium-238 stockpile, NE is working to re-establish domestic plutonium-238 production in order to assure continued availability of these power systems.

Molybdenum-99, or moly-99, is widely used in medical diagnosis and has been produced commercially with reactors using highly enriched uranium (HEU) fuel. Because of the nonproliferation mission to remove HEU from use, NNSA's GTRI program has the lead for moly-99. As part of its nuclear nonproliferation mission, and in light of the current moly-99 supply shortage, GTRI is working to demonstrate moly-99 production without the use of HEU. GTRI is implementing projects to demonstrate the viability of non-HEU based technologies for large-scale commercial moly-99 production, including accelerator technology, low-enriched uranium (LEU) target technology, LEU solution reactor technology, and neutron capture technology.

High-Risk, High-Reward Research[a]

The Office of Science programs incorporate high-risk, high-reward 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-reward 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-reward 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 program portfolios triennially to assess, among other things, the balance and impact of the portfolios, including an assessment of high-risk, high-reward research.

The fraction of high-risk, high-reward activities is not easy to quantify, because such research is integrated within program portfolios. However, several mechanisms are used to identify and develop "high-reward" research topics, including Federal advisory committees, program and topical workshops, interagency working groups, National Academy of Sciences studies, and special Office of Science program solicitations. These activities have identified opportunities for new, compelling research. As examples, some of these opportunities are captured in the following reports: *Isotopes for the Nation's Future—A Long Range Plan*, by NSAC (2009); *New Science for a Secure and Sustainable Energy Future*, by the Basic Energy Sciences Advisory Committee (2008); *Identifying Outstanding Grand Challenges in Climate Change Research* workshop report (2008); *U.S. Particle Physics: Scientific Opportunities, A Strategic Plan for the Next Ten Years*, by the High Energy Physics Advisory Panel; and *The Frontiers of Nuclear Science*, by NSAC (2007).

Basic and 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 to effectively integrate R&D by the science and technology communities (e.g., national laboratories, universities, and private companies) that support the DOE mission. Efforts

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

have focused on improving communication and collaboration between federal program managers and increasing opportunities for collaborative efforts targeted at the interface of scientific research and technology development to ultimately accelerate DOE mission and national goals. 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 and Small Business Technology Transfer programs. Additionally, co-funding research activities and facilities at the DOE laboratories and funding mechanisms that encourage broad partnerships (e.g., Funding Opportunity Announcements) are also means by which the Department facilitates greater communication and research integration within the basic and applied research communities.

American Recovery and Reinvestment Act

The Office of Science received $1,632,918,000 under the American Recovery and Reinvestment Act of 2009. The Office of Science based Recovery Act funding decisions on two of the primary goals articulated in the Recovery Act's statement of purpose: to provide investments needed to increase economic efficiency by spurring technological advances in science, and to preserve and create jobs and promote economic recovery. The Office of Science's Recovery Act projects have the characteristics of being "shovel-ready," enhancing research infrastructure, supporting high-priority R&D, and minimizing outyear mortgages. Recovery Act projects include acceleration of ongoing line-item construction projects, acceleration of major items of equipment, upgrades to Office of Science scientific user facilities, laboratory general plant projects, and scientific research. More information on Office of Science Recovery Act supported activities can be found at the Department of Energy Recovery Act website (http://www.energy.gov/recovery/).

Energy Innovation Hubs

The Office of Science takes part in the Department's multi-disciplinary Energy Innovation Hubs, which will address topic areas that present the most critical barriers to achieving national energy and climate goals while proving the most resistant to solution by usual R&D enterprise structures. The Hubs are designed to accelerate the pace of scientific discovery and technology development to revolutionize how the U.S. produces, distributes, and uses energy. By the same token, they are intended to strengthen the Nation's competitiveness by building the expertise needed to lead our transition to a clean energy economy.

The Department's first three Energy Innovation Hubs, initiated in FY 2010, will explore Fuels from Sunlight, Energy Efficient Building Systems Design, and Modeling and Simulation for Nuclear Reactors. The Department already funds some promising R&D in these areas, and the Hubs will be able to build upon the new knowledge from these and other advances to reach the critical mass of R&D and engineering integration needed to accelerate major breakthroughs in these energy technologies. Each Hub will exist for a finite length of time and will focus on a single topic, but with work spanning the gamut from basic research, through engineering development, to facilitating commercialization by industry. Each Hub will be comprised of a highly collaborative team utilizing multiple scientific disciplines, engineering fields, and technology areas, working largely under one roof. By bringing together top talent across the full spectrum of R&D performers—including universities, private industry, non-profits, and government laboratories—each Hub is expected to conduct world-leading R&D in its topical area.

The Hubs are a central component of the Secretary of Energy's strategy to achieve the President's goals to reduce our dependence on foreign oil and our greenhouse gas emissions. The Hubs also embody the Secretary's goal to improve coordination between basic research and technology development. BES will support two Hubs in FY 2011, one focused on Fuels from Sunlight and a new Hub for Batteries and

Energy Storage. The primary objective in selecting the Hubs is to award the proposals that have the best chance to deliver transformative energy breakthroughs. The Hubs will therefore be selected on the basis of a competitive merit review; there are no preconceived goals for specific locations or geographical distribution of the Hubs. Universities, national laboratories, and the private sector—or partnerships among those groups—will be eligible to apply, similar to the DOE Bioenergy Research Center solicitation. Proposals will be selected based on external merit review and awards will provide support for research activities, not construction of new buildings. Additional information on the Hubs can be found at http://www.energy.gov/hubs/index.htm.

Scientific Workforce

The Office of Science, through its six research programs, 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. Office of Science programs also support the development of individual research programs of outstanding scientists early in their careers to stimulate research careers in disciplines supported by the Office of Science.

In addition, the Office of Science research programs support modest activities targeted towards undergraduate and graduate students, postdoctoral researchers, 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; create the skilled scientific and technical workforce needed to develop solutions to our energy and environmental challenges in the 21st century; and enable the U.S. to continue to be the leader in science and innovation.

Undergraduate activities include intensive research training internships in specific areas such as geophysics, radiochemistry, nuclear science, computer science and computational-based sciences, plasma and fusion energy sciences, and climate science, and short courses in emerging areas in the physical sciences and engineering, including opportunities for groups underrepresented in the physical sciences. Graduate student level activities include support for short courses and lecture series as part of scientific professional society meetings; summer courses, lecture series, and experimental training courses in areas such as neutron and x-ray scattering, high energy physics, and genomic sciences; summer graduate research internships in targeted areas such as genomic science, radiochemistry, accelerator physics, and nuclear physics; and graduate research fellowships to support graduate study and research in areas of basic science and engineering important to the DOE mission. Opportunities directed towards K–12 educators include workshops, classroom presentations, and summer training programs that provide educators with content knowledge, materials, and activities related to the physical sciences and mathematics to use in the classroom.

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 Science Laboratories Infrastructure program.

In FY 2009, the Office of Science began an Infrastructure Modernization initiative to revitalize Office of Science laboratories over ten years, with the goal of providing the modern laboratory infrastructure needed to deliver advances in science the Nation requires to remain competitive in the 21st century. Through this initiative, we are ensuring the laboratories have state-of-the-art facilities and utilities that are flexible, reliable, and sustainable, with environmentally stable research space and high performance computing space needed to support scientific discovery. New and renovated buildings and utilities will include the latest temperature and humidity controls, clean power, and isolation from vibration and electromagnetic interference where needed. Facility designs will consider human factors to ensure collaborative and interactive work environments and allow for the integration of basic to applied research and development. The 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. The investments will not only improve the Office of Science's mission readiness but will also reduce deferred maintenance backlog thereby improving the overall Asset Condition Index.

Means and Strategies

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.

Office of Science programs ensure effective management processes for cost-effective investments and timely delivery of projects and 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 program is coordinated with the activities of other programs within the Office of Science, with programs of the DOE applied technology offices and the National Nuclear Security Administration, and with programs of other Federal agencies. The Office of Science also promotes the transfer of basic research results 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.

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 2009	FY 2010	FY 2011
Ames Laboratory			
Advanced Scientific Computing Research	1,597	900	450
Basic Energy Sciences	21,485	19,563	19,563
Biological and Environmental Research	675	675	675
Workforce Development for Teachers and Scientists	463	240	556
Safeguards and Security	1,067	980	1,007
Total, Ames Laboratory	25,287	22,358	22,251
Ames Site Office			
Science Program Direction	536	585	621
Argonne National Laboratory			
Advanced Scientific Computing Research	53,721	54,570	68,205
Basic Energy Sciences	198,855	198,665	209,147
Biological and Environmental Research	28,627	29,266	28,913
Fusion Energy Sciences	125	125	125
High Energy Physics	17,113	13,422	13,568
Nuclear Physics	27,650	28,164	28,775
Workforce Development for Teachers and Scientists	1,916	466	2,012
Science Laboratories Infrastructure	10,000	8,000	15,000
Safeguards and Security	9,787	8,742	8,985
Total, Argonne National Laboratory	347,794	341,420	374,730
Argonne Site Office			
Science Program Direction	3,166	3,418	4,308
Berkeley Site Office			
Science Program Direction	3,685	4,462	4,586

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Brookhaven National Laboratory			
Advanced Scientific Computing Research	970	780	360
Basic Energy Sciences	201,326	235,186	247,915
Biological and Environmental Research	23,182	19,954	14,094
High Energy Physics	55,108	47,818	44,284
Nuclear Physics	176,957	179,418	192,981
Workforce Development for Teachers and Scientists	890	589	1,069
Science Laboratories Infrastructure	14,882	44,387	15,000
Safeguards and Security	11,824	11,632	11,955
Total, Brookhaven National Laboratory	485,139	539,764	527,658
Brookhaven Site Office			
Science Program Direction	3,930	5,120	5,445
Chicago Office			
Advanced Scientific Computing Research	54,656	53,611	27,917
Basic Energy Sciences	264,195	265,299	309,219
Biological and Environmental Research	167,669	160,043	161,632
Fusion Energy Sciences	149,054	152,083	151,342
High Energy Physics	142,626	134,504	133,068
Nuclear Physics	76,653	81,595	69,297
Workforce Development for Teachers and Scientists	135	164	5,000
Science Laboratories Infrastructure	756	0	0
Safeguards and Security	1,222	1,222	0
Science Program Direction	29,971	29,092	33,560
Congressionally Directed Projects	69,537	74,737	0
SBIR/STTR	154,439	0	0
Total, Chicago Office	1,110,913	952,350	891,035

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Fermi National Accelerator Laboratory			
Advanced Scientific Computing Research	910	790	180
High Energy Physics	389,043	397,273	408,705
Nuclear Physics	661	72	0
Workforce Development for Teachers and Scientists	294	105	637
Science Laboratories Infrastructure	0	0	7,524
Safeguards and Security	2,024	2,169	3,486
Total, Fermi National Accelerator Laboratory	392,932	400,409	420,532
Fermi Site Office			
Science Program Direction	2,112	2,363	2,700
Golden Field Office			
Workforce Development for Teachers and Scientists	869	176	722
Idaho National Laboratory			
Basic Energy Sciences	2,125	260	260
Biological and Environmental Research	2,238	1,717	1,304
Fusion Energy Sciences	2,272	2,172	2,222
Workforce Development for Teachers and Scientists	79	135	135
Congressionally Directed Projects	2,429	0	0
Total, Idaho National Laboratory	9,143	4,284	3,921
Lawrence Berkeley National Laboratory			
Advanced Scientific Computing Research	100,869	94,886	92,895
Basic Energy Sciences	163,071	139,607	143,183
Biological and Environmental Research	112,627	123,120	126,252
Fusion Energy Sciences	4,941	4,841	4,806
High Energy Physics	70,123	54,031	47,117
Nuclear Physics	28,151	27,136	21,271
Workforce Development for Teachers and Scientists	746	475	947
Science Laboratories Infrastructure	29,956	34,027	20,103
Safeguards and Security	5,529	5,059	5,201
Total, Lawrence Berkeley National Laboratory	516,013	483,182	461,775

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Lawrence Livermore National Laboratory			
Advanced Scientific Computing Research	14,652	13,929	7,632
Basic Energy Sciences	5,290	3,717	3,717
Biological and Environmental Research	25,362	14,891	11,503
Fusion Energy Sciences	13,886	10,744	13,145
High Energy Physics	1,552	794	793
Nuclear Physics	1,746	1,027	1,308
Workforce Development for Teachers and Scientists	130	89	294
Total, Lawrence Livermore National Laboratory	62,618	45,191	38,392
Los Alamos National Laboratory			
Advanced Scientific Computing Research	5,621	4,932	3,981
Basic Energy Sciences	41,050	33,287	35,208
Biological and Environmental Research	25,059	10,819	9,894
Fusion Energy Sciences	4,594	5,076	5,464
High Energy Physics	388	298	255
Nuclear Physics	12,064	10,014	15,128
Workforce Development for Teachers and Scientists	270	144	270
Congressionally Directed Projects	11,098	0	0
Total, Los Alamos National Laboratory	100,144	64,570	70,200
National Energy Technology Laboratory			
Workforce Development for Teachers and Scientists	782	586	1,150
National Renewable Energy Laboratory			
Advanced Scientific Computing Research	581	522	379
Basic Energy Sciences	12,608	7,209	7,209
Biological and Environmental Research	1,497	1,136	1,026
Workforce Development for Teachers and Scientists	50	55	100
Total, National Renewable Energy Laboratory	14,736	8,922	8,714
Nevada Site Office			
Basic Energy Sciences	232	244	244

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
New Brunswick Laboratory			
Science Program Direction	6,132	6,132	7,015
Oak Ridge Institute for Science and Education			
Advanced Scientific Computing Research	1,024	1,000	1,000
Basic Energy Sciences	5,237	642	642
Biological and Environmental Research	5,742	5,305	3,371
Fusion Energy Sciences	2,208	1,742	1,450
High Energy Physics	945	250	250
Nuclear Physics	3,097	789	729
Workforce Development for Teachers and Scientists	3,643	2,418	17,724
Safeguards and Security	1,710	1,626	1,671
Total, Oak Ridge Institute for Science and Education	23,606	13,772	26,837
Oak Ridge National Laboratory			
Advanced Scientific Computing Research	104,435	91,125	103,753
Basic Energy Sciences	325,637	328,071	330,246
Biological and Environmental Research	70,882	65,825	59,752
Fusion Energy Sciences	142,099	151,579	97,400
High Energy Physics	123	2	0
Nuclear Physics	26,943	25,831	44,141
Workforce Development for Teachers and Scientists	100	0	0
Science Laboratories Infrastructure	25,103	0	0
Safeguards and Security	9,094	8,895	9,144
Total, Oak Ridge National Laboratory	704,416	671,328	644,436
Oak Ridge National Laboratory Site Office			
Science Program Direction	4,565	4,357	4,457

(dollars in thousands)	FY 2009	FY 2010	FY 2011
Oak Ridge Office			
Science Laboratories Infrastructure	5,079	5,214	5,260
Safeguards and Security	19,174	19,357	19,895
Science Program Direction	43,483	37,834	42,257
Total, Oak Ridge Office	67,736	62,405	67,412
Office of Scientific and Technical Information			
Advanced Scientific Computing Research	106	177	106
Basic Energy Sciences	106	344	229
Biological and Environmental Research	373	469	389
Fusion Energy Sciences	106	178	122
High Energy Physics	106	230	110
Nuclear Physics	106	196	0
Workforce Development for Teachers and Scientists	180	250	300
Science Laboratories Infrastructure	2,500	0	0
Safeguards and Security	583	490	504
Science Program Direction	9,153	8,916	8,963
Total, Office of Scientific and Technical Information	13,319	11,250	10,723
Pacific Northwest National Laboratory			
Advanced Scientific Computing Research	7,349	5,067	3,745
Basic Energy Sciences	25,366	19,574	19,574
Biological and Environmental Research	102,200	109,274	107,474
Fusion Energy Sciences	900	1,326	1,838
Workforce Development for Teachers and Scientists	1,187	613	1,211
Science Laboratories Infrastructure	52,775	0	0
Safeguards and Security	11,256	11,163	11,476
Total, Pacific Northwest National Laboratory	201,033	147,017	145,318
Pacific Northwest Site Office			
Science Program Direction	5,564	5,264	6,173

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Princeton Plasma Physics Laboratory			
Advanced Scientific Computing Research	740	758	322
Fusion Energy Sciences	71,250	72,676	76,017
High Energy Physics	230	272	237
Workforce Development for Teachers and Scientists	375	243	541
Safeguards and Security	2,242	2,178	2,237
Total, Princeton Plasma Physics Laboratory	74,837	76,127	79,354
Princeton Site Office			
Science Program Direction	1,734	1,805	2,058
Sandia National Laboratories			
Advanced Scientific Computing Research	9,831	8,169	8,436
Basic Energy Sciences	44,373	36,108	36,397
Biological and Environmental Research	6,459	1,600	520
Fusion Energy Sciences	2,730	2,290	2,490
Nuclear Physics	275	0	0
Workforce Development for Teachers and Scientists	550	21	926
Congressionally Directed Projects	4,624	0	0
Total, Sandia National Laboratories	68,842	48,188	48,769
Savannah River National Laboratory			
Basic Energy Sciences	480	435	435
Biological and Environmental Research	622	363	0
Fusion Energy Sciences	50	0	0
Workforce Development for Teachers and Scientists	0	75	75
Total, Savannah River National Laboratory	1,152	873	510

(dollars in thousands)	FY 2009	FY 2010	FY 2011
SLAC National Accelerator Laboratory			
Advanced Scientific Computing Research	200	200	200
Basic Energy Sciences	221,597	184,134	172,560
Biological and Environmental Research	5,352	4,150	4,150
High Energy Physics	91,024	88,824	87,177
Workforce Development for Teachers and Scientists	222	160	190
Science Laboratories Infrastructure	0	6,900	33,100
Safeguards and Security	2,679	2,643	2,716
Total, SLAC National Accelerator Laboratory	321,074	287,011	300,093
Stanford Site Office			
Science Program Direction	2,948	2,748	2,829
Thomas Jefferson National Accelerator Facility			
Advanced Scientific Computing Research	100	100	0
Basic Energy Sciences	900	900	0
Biological and Environmental Research	600	600	600
High Energy Physics	2,571	2,152	1,895
Nuclear Physics	119,618	112,321	129,893
Workforce Development for Teachers and Scientists	520	208	641
Science Laboratories Infrastructure	3,700	27,687	28,628
Safeguards and Security	1,504	1,432	1,470
Total, Thomas Jefferson National Accelerator Facility	129,513	145,400	163,127
Thomas Jefferson Site Office			
Science Program Direction	1,928	2,020	2,229

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Washington Headquarters			
Advanced Scientific Computing Research	1,410	62,484	106,439
Basic Energy Sciences	1,832	163,255	299,252
Biological and Environmental Research	6,010	54,975	95,351
Fusion Energy Sciences	303	21,168	23,579
High Energy Physics	1,716	70,613	91,541
Nuclear Physics	26,386	68,437	58,477
Workforce Development for Teachers and Scientists	182	13,466	1,100
Science Laboratories Infrastructure	629	1,385	1,385
Safeguards and Security	908	5,412	6,753
Science Program Direction	67,788	75,261	87,236
Congressionally Directed Projects	3,376	2,153	0
Total, Washington Headquarters	110,540	538,609	771,113
Waste Isolation Pilot Plant			
High Energy Physics	3,200	0	0
Total, Science	4,822,170	4,903,710	5,121,437

Office of Science

Major Changes or Shifts by Site

Argonne National Laboratory

- **Advanced Scientific Computing Research**: The Leadership Computing Facility will be undergoing site preparations for the 10-petaflop upgrade, while continuing to provide open high-performance computing capability with low electrical power consumption to enable scientific advances.

Fermi National Accelerator Laboratory

- **Science Laboratories Infrastructure**: The Utilities Upgrade project is initiated to upgrade the laboratory's industrial cooling water and high voltage electrical systems. Both of these systems are critical for the current and future mission at the laboratory. System components are at the end of their design life and replacement parts are no longer available.

Lawrence Berkeley National Laboratory

- **Advanced Scientific Computing Research**: The high performance computing resources at the National Energy Research Scientific Computing (NERSC) center will provide one petaflop of capacity computing to the Office of Science programs. The Energy Sciences network (ESnet) will begin deploying the 100 gigabit per second optical technologies developed through the Recovery Act funded Advanced Networking Initiative.

Oak Ridge National Laboratory

- **Advanced Scientific Computing Research**: The Leadership Computing Facility will explore hybrid architectures while providing more than two petaflops of open high-performance computing capability to enable scientific advances.

SLAC National Accelerator Laboratory

- **Basic Energy Sciences**: The Linac Coherent Light Source will begin its first full year of operations as a DOE user facility in FY 2011.
- **High Energy Physics**: In FY 2011, SLAC will begin full operations of the Facility for Accelerator Science and Experimental Test Beams (FACET) including a round of experiments in which the electron beam is accelerated by plasma wakefields (instead of the usual electromagnetic fields in a copper cavity). The ultimate goal of this effort will be demonstration of efficient accelerating structures with gradients well above 100 MeV per meter that could be incorporated into future accelerators.

Thomas Jefferson National Accelerator Facility

- **Science Laboratories Infrastructure**: The Utility Infrastructure Modernization project is initiated to upgrade the power distribution, cooling water, and communications systems to ensure the laboratory can continue to provide superconducting radio frequency expertise as well as research, development, and production of cryomodules in support of SC missions.

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 thousand gross square feet of space). The average age of the buildings is 42 years. DOE does not own the land. Ames conducts fundamental research in the physical, chemical, and mathematical sciences associated with energy generation and storage. 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.
- **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 conducts research in focused areas within chemical and biochemical sciences.
- **Safeguards and Security**: This program provides planning, policy, implementation, and oversight in the areas of program management, access control officers, and information security. In addition, the Safeguards and Security program addresses the full range of cyber, personnel security, security systems, and material control and accountability issues.

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 99 buildings (4.6 million gross square feet of space). The average age of all the buildings is 37 years.

- **Advanced Scientific Computing Research**: ANL conducts research in applied 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 556-teraflop IBM Blue Gene/P system, which make computationally intensive projects of the largest scales possible.
- **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, the Center for Nanoscale Materials, and the Electron Microscopy Center 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** develops and maintains capabilities for electron beam characterization and applies those capabilities to solve materials problems. The Center emphasizes three major areas: materials research, technique and instrumentation development, and operation as a national research facility. Research at the Center 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 Center is organized around six scientific themes: nanomagnetism, bio-inorganic hybrids, nanocarbon, complex oxides, nanophotonics, and theory and simulation.
- **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 Climate Research Facility 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 a mobile climate research 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. ANL is the task lead for developing new adjoint techniques in ocean modeling in the LBNL-led multi-lab effort on Abrupt Climate Change. 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 consortium, focusing on research to understand the processes controlling the rate of soil carbon accretion.

- **Fusion Energy Sciences**: ANL contributes a small effort in basic plasma science. In addition, ANL participates in the two-year planning study of the Fusion Simulation Program, contributing in the areas of algorithm development, code verification, software standards, and workflow needs and tools determination.
- **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 working on the ATLAS (A Large Toroidal LHC Apparatus) experiment at the Large Hadron Collider, developing new detector technologies for future experiments, advancing accelerator R&D using the Argonne Wakefield Accelerator, and partnering with Fermilab in the development of superconducting radio frequency technology for future accelerators.
  - 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, left-handed meta-materials, high-power/high-brightness electron beams, and advanced beam diagnostics.
- **Nuclear Physics**: ANL operates the Argonne Tandem Linac Accelerator System national user facility, the world's premiere stable beam facility, and supports its corresponding R&D program. ANL nuclear scientists have expertise in detector development, computational techniques and advanced accelerator technology. 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, and Relativistic Heavy Ion Collider (RHIC); development and fabrication support 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, an increasing percentage of the beams are rare isotope beams. The 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). The facility nurtures a core competency in accelerator expertise with superconducting radiofrequency cavities for heavy ions that is relevant to the next generation of high-performance proton and heavy-ion linacs, and important to the SC mission and international stable and radioactive ion beam facilities. The combination of versatile beams and powerful instruments enables about 410 users annually to conduct research in a broad program in nuclear structure and dynamics, nuclear astrophysics, and fundamental interaction studies. The capabilities are being augmented by the fabrication of the Californium Rare Ion Beam Upgrade (CARIBU), which will be completed in FY 2010, as a source to provide new capabilities in neutron-rich radioactive beams. A new instrument, the Helical Orbital Spectrometer, employs a new concept to study reactions with radioactive beams from CARIBU.

- **Science Laboratories Infrastructure**: SLI enables DOE research missions at ANL by funding line item construction to maintain the general purpose infrastructure. The SLI program is currently funding the Energy Sciences Building project, which is constructing new, environmentally stable, specialized, and flexible space to replace some of the oldest and least effective research space for energy-related sciences.

- **Safeguards and Security**: This program provides planning, policy, implementation, and oversight in the areas of program management, access control officers, and information security. In addition, the Safeguards and Security program addresses the full range of cyber, personnel security, security systems, and material control and accountability issues.

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 331 SC buildings (4.0 million gross square feet of space). The average age of the buildings is 39 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.

- **Advanced Scientific Computing Research**: BNL conducts 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.
- **Basic Energy Sciences**: BNL conducts research efforts in materials sciences with emphasis on advanced scattering techniques, chemical sciences, and physical biosciences. It is also the site of two BES supported user facilities—the National Synchrotron Light Source and the Center for Functional Nanomaterials.
  - 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. Construction of a new synchrotron light source at BNL (the National Synchrotron Light Source II) is underway.
  - 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. It includes equipment needed for laboratory and fabrication facilities for e-beam lithography, transmission electron microscopy, scanning probes and surface characterization, material synthesis and fabrication, and spectroscopy.
- **Biological and Environmental Research**: BNL operates beam lines for protein crystallography at the National Synchrotron Light Source for use by the national biological research community, research in biological structure determination, and research into new instrumentation for detecting x-rays and neutrons. BNL conducts molecular radiochemistry and imaging and instrumentation research, developing advanced technologies for biological imaging.
  - Climate change research includes the operation of the Atmospheric Radiation Measurement Climate Research Facility (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 data and simulating cloud and aerosol processes in climate models.
  - BNL is the lead for multi-institution research to address issues of model evaluation, development, and understanding of atmospheric processes.
  - 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 and is a member of the Tevatron research collaboration at Fermilab.

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 experiment at Fermilab and R&D and planning for future accelerator-based neutrino experiments, particularly the Long Baseline Neutrino Experiment.

- 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 at 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; development of future detectors for RHIC; core competencies in accelerator R&D of beam-cooling techniques aimed at increasing the RHIC beam luminosity and of importance to other SC projects; R&D and calibration efforts directed towards research with neutrinos; a theory program emphasizing RHIC heavy ion and "spin" physics; data compilation and evaluation at the National Nuclear Data Center (NNDC) that is the central U.S. site for these national and international efforts; operations of the Brookhaven Linac Isotope Producer (BLIP) which produces research and commercial isotopes in short supply; and a research and development effort of new isotope production and processing techniques.

- The **Relativistic Heavy Ion Collider** facility uses accelerators 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 and has seen signs of the same quark-gluon plasma that is believed 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 and the Pioneering High-Energy Nuclear Interacting Experiment.

- The **Alternating Gradient Synchrotron** (AGS) accelerator 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** accelerator, 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 **Electron Beam Ion Source** (EBIS) accelerator and linac system will be completed in FY 2010 and will replace the aging Tandem Van de Graaff accelerators which have served as injectors for the Booster Synchrotron. EBIS, which was supported as a joint DOE/NASA project, promises greater efficiency, greater reliability, and lower maintenance costs as well as the potential for future upgrades.
- The **National Nuclear Data Center** (NNDC) 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 Center is a resource for a very broad user community in basic nuclear science research and 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 Center's activities and responsibilities.
- The **Brookhaven Linac Isotope Producer** at BNL uses a linear accelerator that injects 200-MeV protons into the 33-GeV Alternating Gradient Synchrotron. The isotopes produced by BLIP, such as strontium-82, germanium-68, copper-67, and others, are used in medical diagnostic and therapeutic applications and other scientific research. The BLIP can operate in dedicated mode or in conjunction with RHIC operations.

- **Science Laboratories Infrastructure**: SLI funds line item construction to maintain the general purpose infrastructure and remove excess facilities. The SLI program is currently funding the Renovate Science Laboratories, Phase II project that will modernize unsuitable laboratory space in buildings 510 (Physics) and 555 (Chemistry), allowing them to continue supporting research in Basic Energy Sciences and Nuclear and High Energy Physics. SLI is also funding construction of the Interdisciplinary Science Building, Phase I project at BNL that 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.
- **Safeguards and Security**: This program provides planning, policy, implementation, and oversight in the areas of program management, protective force officers, and information security. In addition, the Safeguards and Security program addresses the full range of cyber, personnel security, security systems, and material control and accountability issues.

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 directly provides corporate support (procurement, legal, financial management, human resources, and facilities and infrastructure) to site offices responsible for program management oversight of six management and operating laboratories—the Ames, Argonne, Lawrence Berkeley, Brookhaven, Fermi, and Princeton laboratories—and one government-owned and government-operated Federal laboratory, the New Brunswick Laboratory. The administrative, business, and technical expertise of CH is shared SC-wide through the Integrated Support Center concept. CH also serves as SC's grant center, administering grants to about 300 colleges and universities in all 50 states, Washington, D.C., and Puerto Rico, as determined by the SC program offices as well as non-SC offices.

- **Advanced Scientific Computing Research**: ASCR funds research at over 70 academic institutions located in 34 states supporting over 130 principal investigators.
- **Basic Energy Sciences**: BES funds research at 170 academic institutions located in 50 states.
- **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.
- **Fusion Energy Sciences**: FES funds research grants and cooperative agreements at more than 50 colleges and universities located in approximately 30 states.
- **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 approximately 200 research grants at 90 colleges and universities located in 35 states and Washington, DC.
- **Safeguards and Security**: Program management and funding for local security interests will be transferred from the Chicago Office to the Fermi National Accelerator Laboratory in FY 2011.

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 (2.3 million gross square feet of space). The average age of the buildings is 43 years. Fermilab is the largest U.S. laboratory for research in high-energy physics and, world-wide, 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 SciDAC science application teams relevant to physics research, accelerator modeling, and distributed data. Fermilab also participates in SciDAC Centers for Enabling Technologies focusing on specific software challenges confronting users of petascale computers.
- **High Energy Physics**: Fermilab is the principal HEP experimental facility. 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 laboratory supports two Tevatron experiments, CDF and D-Zero, together home to about 1,400 physicists from Fermilab and other national laboratories, 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. NuMI provides a controlled beam of neutrinos to the Main Injector Neutrino Oscillation (MINOS) experiment located in the Soudan Mine in Minnesota and the Main Injector Neutrino ν-A (MINERνA) experiment located onsite at Fermilab. The NuMI Off-Axis Neutrino Appearance (NOνA) experiment will upgrade the

beamline and exploit the increased beam power to make further discoveries in neutrino physics. NOvA is under construction and will be in full operation in 2014.

- 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 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 and dark matter experiments.
- Fermilab also has a significant program for R&D on advanced detector components for a variety of physics applications. The laboratory also maintains and operates a fixed target beam for testing of detector elements that hosts university, national laboratory, and international R&D groups.

- **Science Laboratories Infrastructure**: SLI funds line item construction to maintain the general purpose infrastructure at Fermilab. In FY 2011, the SLI program is requesting funding for the Utilities Upgrade project to upgrade outdated industrial cooling water and high voltage electrical systems.
- **Safeguards and Security**: This program provides planning, policy, implementation, and oversight in the areas of program management, access control officers, and information security. In addition, the Safeguards and Security program addresses the full range of cyber, personnel security, security systems, and material control and accountability issues.

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 on materials sciences for nuclear fuels and the relationship of microstructure to materials properties.

- **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 gadolinium-153, an important isotope for applications such as positron emission tomography 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). The average age of the buildings is 40 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.

- **Advanced Scientific Computing Research**: LBNL conducts research in applied 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 Energy Sciences network (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.
- **Basic Energy Sciences**: LBNL is home to major research efforts in materials sciences with emphasis on nanoscience, chemical sciences, geosciences, biosciences, and solar fuels research. It is also the site of three Basic Energy Sciences supported user facilities—the Advanced Light Source (ALS), the National Center for Electron Microscopy, 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 the highest resolution electron microscope 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.

▪ **Biological and Environmental Research**: LBNL is the lead national laboratory managing the **Joint Genome Institute** (JGI); the principal goal of which is high-throughput genome sequencing and analysis 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 a systems approach to predictively understand subsurface biogeochemical processes impacting metal and radionuclide contaminant transport and remediation in subsurface environments.
- LBNL conducts research to advance fundamental understanding of DOE-relevant microorganisms and microbial communities using systems biology approaches and analyses at the whole organism level and across multiple spatial and temporal scales.
- 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. LBNL studies and quantifies the risks of abrupt climate change during the 21st century. LBNL is leading a multi-lab activity on Abrupt Climate Change Modeling through a series of linked projects that examine: dynamics of ice shelf-ocean interaction and evaluation of marine ice sheet stability, boreal/Arctic climate positive feedbacks, rapid destabilization of methane hydrates in Arctic

Ocean sediments, and mega-droughts in North America. It leads the task for examining boreal/Arctic feedbacks in this project.

- 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.

- **Fusion Energy Sciences**: LBNL has been conducting research in developing ion beams for applications to high energy density laboratory plasmas (HEDLP) and inertial fusion energy sciences. Currently the laboratory has two major experimental systems for doing this research: the Neutralized Drift Compression Experiment (NDCX) 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 is currently upgrading the Neutralized Drift Compression Experiment from its present configuration to NDCX-II. The NDCX-II facility will advance the science of drift compression of an ion beam to intensify the beam, and enhance the energy on target of the ion beam by a factor of 100. 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.

- **High Energy Physics**: LBNL has unique capabilities in the areas of superconducting magnet R&D, engineering and detector technology, 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.

  The Laser Optics and Accelerator Systems Integrated Studies group has begun work on the Berkeley Lab Laser Accelerator (BELLA) project whose goal is the development of the 10-GeV laser-wakefield accelerator module using a petawatt laser.

  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, and continues R&D for a space-based dark energy mission. LBNL operates the Microsystems Laboratory 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 Particle Data Group, which annually 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 on the low energy and heavy ion NP subprograms. These include fabrication of a next-generation gamma-ray detector system, Gamma Ray Energy Tracking In-Beam Nuclear Array (GRETINA); research with the STAR detector located at BNL's RHIC facility; and development of future detector systems for RHIC. Also included are operation of the Parallel Distributed Systems Facility aimed at heavy ion and low energy physics computation; fabrication of a detector upgrade for the A Large Ion Collider

Experiment (ALICE) detector heavy ion program at LHC; research at the KamLAND detector in Japan that is performing neutrino studies. In addition, 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; and a theory program with an emphasis on relativistic heavy ion physics are conducted. Data compilation and evaluation activities supporting the National Nuclear Data Center at BNL; and R&D of electron-cyclotron resonance ion sources for the Facility for Rare Isotope Beams are also conducted at LBNL. 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.

- **Science Laboratories Infrastructure**: SLI funds line item construction to maintain the general purpose infrastructure and the cleanup and removal of excess facilities at LBNL. The SLI program is currently funding the Seismic Life-Safety, Modernization, and Replacement of General Purpose Buildings, Phase II project at LBNL that will replace seismically-poor buildings and trailers with a new general purpose laboratory/office building supporting Life Sciences, seismically upgrading the site-wide Hazardous Waste Handling Facility, and upgrading and modernizing an existing Life Sciences building (Building 74).
- **Safeguards and Security**: This program provides planning, policy, implementation, and oversight in the areas of program management, access control officers, and information security. In addition, the Safeguards and Security program addresses the full range of cyber, personnel security, security systems, and material control and accountability issues.

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.

- **Advanced Scientific Computing Research**: LLNL conducts research in applied mathematics and computer science. 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.
- **Basic Energy Sciences**: LLNL conducts research in focused areas related to extreme environments and the limits of length and time scales within materials sciences and geosciences.
- **Biological and Environmental Research**: LLNL is one of the major national laboratory partners supporting the Joint Genome Institute (JGI), the principal goal of which is high-throughput genome sequencing and analysis.
    - LLNL conducts research including development of novel technologies to study structure and function of environmental microbial communities.
    - 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.

- LLNL is improving model representation of the main processes, clouds, aerosols and the cryosphere, that drive the rapid decrease in Arctic ice cover as well as examining the implications of those decreases on future climate. It also is the task lead for studying the clathrate hypothesis in the LBNL-led multi-laboratory effort on Abrupt Climate Change.
- LLNL also supports the ARM Climate Research Facility through the development and support of data sets designed for modelers.
- LLNL supports subsurface biogeochemistry research on the fate and transport of plutonium and other actinide contaminants in the environment.
- LLNL is a partner in the LBNL-led Joint BioEnergy Institute.

▪ **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 high energy density laboratory plasmas and inertial fusion energy sciences. It also conducts research on fast ignition concepts for applications in research on high energy density physics and inertial fusion energy sciences. 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.

▪ **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 LHC, in nuclear data and compilation activities, in R&D for neutrino-less double beta decay experiments, nuclear structure with radioactive ion beams, research on super heavy nuclei, and in theoretical studies in the areas of nuclear structure studies, low energy nuclear reactions, and lattice QCD.

Los Alamos National Laboratory

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

▪ **Advanced Scientific Computing Research**: LANL conducts research in applied 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.

▪ **Basic Energy Sciences**: LANL is home to research efforts in materials sciences to control functionality, chemical sciences, and geosciences.

  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.

▪ **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 genome sequencing and analysis. One of LANL's roles in the JGI involves the production of high quality "finished" DNA sequence.

- LANL conducts research on the genomic analysis of complex microbial communities from environmental soil samples.
- Activities in structural biology include the operation of an experimental station for protein crystallography at LANSCE for use by the national biological research community.
- In support of BER's climate change research, LANL manages the day-to-day operations at the Tropical Western Pacific Atmospheric Radiation Measurement 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 improving representation of the main processes, clouds, aerosols and the cryosphere, that drive the rapid decrease in Arctic ice cover as well as examining the implications of those decreases on future climate.
- LANL leads a SciDAC effort for simulating subsurface biogeochemical processes impacting uranium transport in groundwater using high performance computers and is the task lead for developing ice-sheet models in the LBNL-led multi-laboratory effort on Abrupt Climate Change.

▪ **Fusion Energy Sciences**: LANL has developed a substantial experimental system for research in magnetized target fusion, an important innovative confinement concept, 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 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.

- **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. These activities include a research and development effort in relativistic heavy ions using the PHENIX detector at RHIC and development of next generation instrumentation for RHIC. Research on 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 R&D directed at future studies of the properties of neutrinos are also conducted. Participation in 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; a modest program of neutron beam research that utilizes beams from the LANSCE facility for fundamental physics measurements are also conducted at LANL. A broad program of theoretical research, nuclear data, and compilation activities as part of the U.S. Nuclear Data program; operations of the Isotope Production Facility, which produces research and commercial isotopes in short supply; and a research and development effort of new isotope production and processing techniques are conducted as well.
  - At LANL, the 100-MeV **Isotope Production Facility (IPF)** produces various radioactive isotopes, including 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). The IPF is dependent on LANSCE and operates in parallel to LANSCE.

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.

- **Advanced Scientific Computing Research**: NREL participates in SciDAC science application teams including efforts focused on computational nanoscience and computational biology.
- **Basic Energy Sciences**: NREL conducts fundamental research in the chemical sciences, biosciences, and materials sciences, which are primarily devoted to the conversion of solar energy to electricity and fuels.
- **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), located at the Argonne National Laboratory in Illinois, 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. NBL consists of one 58 year-old building (85 thousand gross square feet of space).

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 179-acre site in Oak Ridge, Tennessee. ORISE has 12 buildings (116 thousand gross square feet of space). The average age of all the buildings is 53 years. 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.

- **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.
- **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.
- **Biological and Environmental Research**: ORISE coordinates activities associated with the peer review of research proposals and applications.
- **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.
- **High Energy Physics**: ORISE provides support 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. ORISE also provides support to the NP program in the area of merit peer review.
- **Workforce Development:** ORISE manages the DOE-National Science Foundation (NSF) program supporting graduate students to attend the Lindau Meeting of Nobel Laureates.
- **Safeguards and Security**: This program provides planning, policy, implementation, and oversight in the areas of program management, access control officers, and information security. In addition, the Safeguards and Security program addresses the full range of cyber, personnel security, security systems, and material control and accountability issues.

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 237 buildings (3.7 million gross square feet of space). The average age of all the buildings is 40 years.

- **Advanced Scientific Computing Research**: ORNL conducts research in applied 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 at ORNL is operating the world's most powerful high performance computer, a two-petaflop Cray Baker system which makes computationally intensive projects of the largest scales possible.
- **Basic Energy Sciences**: ORNL is home to major research efforts in materials and chemical sciences emphasizing fundamental understanding of materials behavior and interfacial phenomena with additional programs in geosciences. 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 User Facility, and the Center for Nanophase Materials Sciences.
    - 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 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 12 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 a wide diversity of user research focused on atomic scale correlation of structure, chemistry, and properties in a wide range of metallic, ceramic, and other structural materials including 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, nanoscale magnetism and transport, catalysis and nano building blocks, and nanofabrication.
- **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 experiment which facilitates research on terrestrial carbon processes and the development of terrestrial carbon cycle models.
- ORNL, in conjunction with ANL, PNNL, and six universities, plays a principle role in the Carbon Sequestration in Terrestrial Ecosystems consortium which is focusing on research to enhance the capacity, rates, and longevity of carbon sequestration in terrestrial ecosystems.
- ORNL houses the Carbon Dioxide Information Analysis Center and Atmospheric Radiation Measure Climate Research Facility (ACRF) archive, providing data to carbon cycle and atmospheric system research scientists respectively.
- ORNL has an active research program to improve climate predictions and enhance scientific understanding of climate impacts and adaptation opportunities through strengthening the coupling between Earth System Models and Integrated Assessment Models. 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 on mercury biogeochemical studies. ORNL also manages a field site for environmental research to advance an understanding and predictive capability of coupled hydrologic, geochemical, and microbiological processes that control the mobility of radionuclides across a range of scales in the environment.
- ORNL is one of the major national laboratory partners that support the JGI, the principal goal of which is high-throughput genome sequencing and analysis. One of ORNL's roles in the JGI involves the annotation (assigning biological functions to genes) of completed genomic sequences.
- ORNL conducts microbial systems biology research as part of Genomic Science.
- The **BioEnergy Science Center** 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.

- **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. 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 project.
- **Nuclear Physics**: NP supports a diverse program of research at ORNL. These activities include: the research, development, and operations of the Holifield Radioactive Ion Beam Facility (HRIBF) that is operated as a national user facility; a relativistic heavy ion group that is involved in a research program using the PHENIX detector at RHIC and ALICE at LHC. The development of and research with the Fundamental Neutron Physics Beamline (FNPB) at the Spallation Neutron Source,

including the lead role of the prime experiment for FNPB, the neutron electric dipole moment experiment MIE; a theoretical nuclear physics effort that emphasizes investigations of nuclear structure and astrophysics; and nuclear data and compilation activities that support the national nuclear data effort are also conducted. In additiona, accelerator core competencies in rare isotope beam development and high power targets; research on the possible existence of super heavy nuclei; R&D efforts in development of next-generation neutrino-less double beta decay experiments; isotope processing capabilities; R&D efforts associated with radioisotope and stable isotope production and processing; and the operations of the National Isotope Data Center are provided for. Enriched stable isotopes are processed at ORNL materials and chemical laboratories and radioactive isotopes are chemically processed and packaged in hot cells in a radiochemical laboratory and the Radiochemical Engineering Development Center.

- The **Holifield Radioactive Ion Beam Facility** is the only radioactive nuclear beam facility in the U.S. to use the Isotope Separator On-Line method and is used annually by about 260 scientists for studies in nuclear structure, dynamics, and astrophysics using radioactive beams. HRIBF accelerates secondary radioactive beams of fission fragments to higher energies (up to 10 MeV per nucleon) than any other facility in the world with a broad selection of ions. HRIBF conducts accelerator R&D on targets and ion sources and low energy ion transport for radioactive beams. The fabrication of a second source and transport beam-line for radioactive ions will improve efficiency and reliability when it begins commissioning in FY 2010.
- The **Fundamental Neutron Physics Beamline** at the Spallation Neutron Source, which is scheduled to be completed in FY 2010, will provide 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. ORNL staff plays the lead role in the fabrication of the neutron electric dipole moment experiment, which could lead to the discovery of new physics beyond the Standard Model.
- The **National Isotope Data Center** (NIDC) is located at ORNL and is a virtual full service organization that supports all isotope development and production sites in the community supported by NP. NIDC coordinates the production, sales, and distribution of isotopes across the Nation, and the development and coordination of a suite of community outreach efforts.

▪ **Science Laboratories Infrastructure**: SLI funds line item construction to maintain the general purpose infrastructure at ORNL. SLI is currently funding construction of a new chemical and material sciences facility under the Modernization of Laboratory Facilities project. Final funding for this project was provided in FY 2009.

▪ **Safeguards and Security**: This program provides planning, policy, implementation, and oversight in the areas of program management and information security. In addition, the Safeguards and Security program addresses the full range of cyber, personnel security, security systems, and material control and accountability issues. Protective force services are provided under a contract with the Oak Ridge Office.

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 (procurement, legal, financial management, human resources, and facilities and infrastructure) to site offices responsible for program management oversight of four major management and operating laboratories—ORNL, PNNL, SLAC, and TJNAF. 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. 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 thousand square feet). The average age of all the buildings is 50 years.

- **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**: This program provides planning, policy, implementation, and oversight in the areas of program management, protective force officers, and information security. In addition, the Safeguards and Security program addresses the full range of cyber, personnel security, and security systems. This program includes funding for SCs only category I, special nuclear materials facility, 3019.

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. OSTI consists of one 63 year-old building (135 thousand gross square feet of space).

- **Science Laboratories Infrastructure**: SLI funds line item construction to maintain the general purpose infrastructure at OSTI.
- **Safeguards and Security**: This program provides planning, policy, implementation, and oversight in the areas of program management, access control officers, and information security. In addition, the Safeguards and Security program addresses the full range of cyber, personnel security, security systems, and material control and accountability issues.

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 thousand square foot national scientific user facility constructed by DOE.

- **Advanced Scientific Computing Research**: PNNL conducts research in applied 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.

- **Basic Energy Sciences**: PNNL supports research in interfacial and surface chemistry, inorganic molecular clusters, analytical chemistry, geosciences, and applications of theoretical chemistry. Materials research emphasizes synthesis science, mechanical properties, and radiation effects.

- **Biological and Environmental Research**: PNNL is home to EMSL, a national scientific user facility that provides integrated experimental and computational resource for discovery and technological innovation in the environmental molecular sciences. EMSL provides more than 50 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.

  PNNL conducts a wide variety of subsurface biogeochemical research, with emphasis on the fate and transport of uranium, technetium, and plutonium. The research focuses on an integrated understanding of the coupled geochemical, microbiological, and hydrological processes that impact contaminant transport across scales in the environment. The research integrated computer modeling with experimentation to advance a predictive understanding of processes impacting contaminant mobility in the environment. PNNL manages two large field sites for integrated, multidisciplinary research on contaminant transport and leads a SciDAC effort to address computational challenges to linking models of biogeochemical processes impacting contaminant mobility at different scales.

  The Atmospheric Radiation Measurement 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. The technical office is responsible for the development of new data products, measurement system engineering, and the conduct of aerial and ground-based field campaigns.

  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. PNNL manages the Atmospheric Radiation Measurement Aerial Facility 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, ORNL, and six universities, plays an important role in the Carbon Sequestration in Terrestrial Ecosystems (CSiTE) consortium, focusing on the role of soil microbial processes in carbon sequestration. PNNL also conducts research on the integrated assessment of global climate changes. It also is the task lead for studying mega-droughts in the LBNL-led multi-laboratory effort on Abrupt 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 the development of high-throughput approaches for characterizing all of the proteins (the proteome) being expresses 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. 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. NP also supports R&D efforts towards a next generation detector to search for neutrinoless double beta decay.
- **Science Laboratories Infrastructure**: SLI funds line item construction to maintain the general purpose infrastructure at PNNL. The SLI program is currently funding construction of the new Physical Sciences Facility. Funding for this project was completed in FY 2009.
- **Safeguards and Security**: This program provides planning, policy, implementation, and oversight in the areas of program management, and information security. In addition, the Safeguards and Security program addresses the full range of cyber, personnel security, security systems, and material control and accountability issues. Protective force services are provided under a memorandum of understanding with the Department's Office of Environmental Management.

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 thousand gross square feet of space). The average age of the buildings is 36 years.

- **Advanced Scientific Computing Research**: PPPL participates in SciDAC science application teams related to fusion science.
- **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. Research is focused on developing the scientific understanding and innovations required for an attractive fusion energy source. PPPL is a partner with ORNL in the U.S. Contributions to ITER Project with responsibility for design and fabrication of various plasma diagnostics and ITER's steady-state electric power system. PPPL scientists are also involved in several basic plasma science experiments, ranging from magnetic reconnection to plasma processing. PPPL 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 230 Ph.D. graduates since its founding in 1951.

- **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.
- **Safeguards and Security**: This program provides planning, policy, implementation, and oversight in the areas of program management, access control officers, and information security. In addition, the Safeguards and Security program addresses the full range of cyber, personnel security, security systems, and material control and accountability issues.

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, with additional sites in Livermore, California and Tonopah, Nevada.

- **Advanced Scientific Computing Research**: SNL conducts research in applied 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.
- **Basic Energy Sciences**: SNL is home to significant research efforts in materials and chemical sciences with additional programs in geosciences. SNL has a historic emphasis on electronic components needed for the Office of 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 SNL and LANL, 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.
- **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 to support new dynamical cores and improve its scalability for implementation on high-system computing systems. SNL is a partner in the LBNL-led Joint BioEnergy Institute.
- **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. The laboratory is a partner with ORNL in the U.S. Contributions to ITER Project with responsibility for design and fabrication of ITER's tokamak exhaust processing system.

- **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 multipurpose laboratory for photon science, accelerator and particle physics research and astrophysics. SLAC operates the final third of its two mile linear accelerator for the Linac Coherent Light Source (LCLS). SLAC consists of 161 buildings (1.9 million gross square feet of space). The average age of all the buildings is 30 years.

- **Basic Energy Sciences**: SLAC is home to research activities in materials and chemical sciences that build on ultrafast and advanced synchrotron techniques and include an emphasis on materials for energy. It is the site of two user facilities—the Linac Coherent Light Source (LCLS) and the Stanford Synchrotron Radiation Light source (SSRL).
  - 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 producing short pulses (from a few to 200 femtoseconds long) in the hard and soft x-ray regions. The x-ray laser light is utilized at several instruments located at six hutches to perform experiments in many areas of physics, chemistry, and biology.
- 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. **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 environmental science user community.

SLAC also investigates the fundamental molecular scale mechanisms controlling the stability and fate of metal and radionuclide contaminants in the subsurface at DOE sites.

- **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 collaboration is engaged in the analysis of the full data set collected at the B-factory over its nine years of operations. High precision results on CP violation, the parameters of the Standard Model, and the masses and properties of new heavy quark states are being accumulated and published. 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 LHC, 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 for several years. 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. HEP 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 funds line item construction to maintain the general purpose infrastructure and remove excess facilities at SLAC. The SLI program is currently funding the Research Support Building and Infrastructure Modernization project at SLAC to replace substandard modular buildings and trailers that are well beyond their intended useful life, and to modernize key existing buildings onsite.

- **Safeguards and Security**: This program provides planning, policy, implementation, and oversight in the areas of program management, access control officers, and information security. In addition, the Safeguards and Security program addresses the full range of cyber, personnel security, security systems, and material control and accountability issues.

SLAC Site Office

The SLAC 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 Nuclear Physics 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 (685 thousand gross square feet of space). The average age of the buildings is 18 years.

- **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 biological 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 1,430 researchers. Polarized electron beams with energies of 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. 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 radiofrequency accelerator technology. Their expertise is being used in the construction of the 12 GeV CEBAF Upgrade Project, which started construction in FY 2009 and received funding to mitigate project risks under the Recovery Act. In addition to upgraded capability at the existing Halls A, B, and C, the project will construct a new Hall D, and will provide researchers with the opportunity to study quark confinement, one of the greatest mysteries of modern physics.
- **Science Laboratories Infrastructure**: SLI funds line item construction to maintain the general purpose infrastructure and remove excess facilities at TJNAF. The SLI program currently funds two projects at TJNAF. The first is the Technology and Engineering Development Facility project that will construct new industrial assembly, laboratory, and office space, and renovate existing space in the Test Lab Building. The second, the Utility Infrastructure Modernization project, will upgrade the power distribution, cooling water, and communications systems.
- **Safeguards and Security**: This program provides planning, policy, implementation, and oversight in the areas of program management, access control officers, and information security. In addition, the Safeguards and Security program addresses the full range of cyber, personnel security, security systems, and material control and accountability issues.

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, is responsible for the Federal funds awarded to about 300 universities, all 17 DOE national laboratories, and private research institutions. HQ Program and Project Managers are responsible for scientific program development and management across a broad spectrum of scientific disciplines and program offices, as well as oversight of the design, construction, and operation of large-scale scientific user facilities at laboratories and universities. Program management and oversight includes regular rigorous evaluation of research programs, facilities, and projects by external peer review. Additional HQ policy, technical, and administrative support staff are 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.

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.

Advanced Scientific Computing Research

Funding Profile by Subprogram

(dollars in thousands)

	FY 2009 Current Appropriation	FY 2009 Current Recovery Act Appropriation[a]	FY 2010 Current Appropriation	FY 2011 Request
Advanced Scientific Computing Research				
Mathematical, Computational, and Computer Sciences Research	150,373	+37,130	163,792	165,091
High Performance Computing and Network Facilities	208,399	+124,665	230,208	260,909
Total, Advanced Scientific Computing Research	358,772[b]	+161,795	394,000	426,000

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 (DOE). 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 through time to observe Earth's global climate as it changes. Scientists today can 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 history, as we have strived to comprehend the mysteries of the universe, mathematics has been an essential tool. It allowed Pythagoras 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 gain new insights into societal concerns such as Alzheimer's disease and climate change. ASCR and its predecessor programs have led these advances for the past thirty years.

[a] The Recovery Act Current Appropriation column reflects the allocation of funding as of September 30, 2009.
[b] Total is reduced by $10,048,000: $8,972,000 of which was transferred to the Small Business Innovation Research (SBIR) program and $1,076,000 of which was transferred to the Small Business Technology Transfer (STTR) program.

In FY 2009, ASCR 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—an international conference on high performance computing with about 11,000 participants and a technical program that has included breakthroughs in many areas and inspired new and innovative areas of computing. At SuperComputing09, ASCR's Oak Ridge Leadership Computing Facility topped the list of the "Top 500" computers in the world and added another Gordon Bell prize. Since the machines are open to all on a competitive basis, the scientific applications span a variety of topics such as: flame simulation to guide design of fuel-efficient clean engines, high temperature superconductivity, supernova shock wave instability, designing proteins at atomic scale, and creating enzymes.

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, there is a growing demand for the development of tools that will help inform decision makers on the options for addressing and adapting to a changing climate. Waiting for the observation and recording of the impacts of increasing concentrations of greenhouse gases is not sufficient. With computation and simulation, scientists can model what is known about the Earth's systems, identify uncertainties of the models, and determine the observational data and experiments needed to further refine and improve the models. Improved climate models will allow scientists to predict, with greater confidence, future changes in the climate under various scenarios. These modeling efforts can help identify potential mitigation strategies.

ASCR supports basic research in both applied mathematics and computer science focused in areas relevant to high performance computing. The results of this research are brought to the broader scientific communities through the Scientific Discovery through Advanced Computing (SciDAC) program. SciDAC facilitates the transfer basic research efforts into computational science applications through direct partnerships between ASCR-supported applied mathematicians and computer scientists, and domain experts in a specific discipline supported by other Office of Science (SC) programs, such as climate, astrophysics, materials, or fusion. These partnerships have been spectacularly successful with documented improvements in code performance in excess of 10,000 percent.

Researchers have a need to communicate with each other, exchange large data sets, and run complex calculations and experiments in remote scientific user facilities. To facilitate the best collaborations for science, ASCR has had a leading role in driving development of the networks connecting these researchers. 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 will continue to be guided by science needs as it develops computers and networks at the leading edge of technology. The ASCR approach of integrating research results across disciplines and with forefront facilities has been the key to its history of success in computational science. With this integrated approach ASCR will continue to deliver scientific insight to address national problems in energy and the environment.

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. 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.
- 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 simulations enable 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 SC and throughout the government, in addition to its core research program, ASCR invests in partnerships to advance use of high end computing in a wide array of disciplines important to DOE and operates the Leadership Computing Facilities as open user facilities with access determined by merit evaluation of proposals.

Many of the applications running on ASCR facilities have direct benefit to science and society at large. For example, SciDAC efforts include:

- Computational chemistry and simulation of nanomaterials is relevant to energy applications. These applications are funded in partnership with the Basic Energy Sciences program.
- The next generation Earth System Models will dramatically improve our ability to predict changes in global climate. This work is funded in partnership with the Biological and Environmental Research program. 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 viable energy source. This work is jointly funded with the Fusion Energy Sciences program.
- Computer modeling of nuclear structure has relevance for science, nuclear energy, and nuclear weapons. These applications are through partnerships with both the Nuclear Physics program and the National Nuclear Security Administration.
- Understanding the origin and fate of the universe is the goal of partnerships with the High Energy Physics program that include analyzing massive amounts of data from experiments, such as the Large Hadron Collider, and conducting simulations, such as three dimensional simulations of supernovae events, which are only possible with leadership computing resources.

- Simulations of biological systems relevant for bioenergy applications and subsurface science research characterizes and predicts changes in DOE's environmental management sites. This work also has implications for DOE's efforts in subsurface carbon sequestration. These applications are partnerships with the Biological and Environmental Research Program.

Establishing SC Leadership Computing Facilities has required partnerships with hardware vendors to develop the most appropriate architectures for scientific discovery and 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 benefits strongly 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. 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, the impact of the ASCR scientific user facilities, and 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 include annual operational reviews and requirements workshops. For example, ESnet conducts two network requirements workshops per year with individual SC 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, there were a series of workshops in 2009 to identify key science opportunities in the disciplines important to DOE—nuclear energy, materials and chemistry, high energy and nuclear physics, climate change, biology, and cross-cutting areas—and the potential role of extreme scale computing in realizing those opportunities.

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 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

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

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 high end computing 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. 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."

Basic and Applied R&D Coordination

A cornerstone of the ASCR program is coordination across disciplines and programs. Partnerships within SC are mature and continue to advance the use of high performance computing and scientific networks for science. In addition, ASCR continues to have a strong partnership with the National Nuclear Security Administration 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 technology development programs throughout DOE, a key area of mutual interest continues to be in applied mathematics for the optimization of complex systems, control theory, and risk assessment. In March 2009, a workshop was organized, in partnership with the Office of Electricity Delivery and Energy Reliability, which focused on the challenges of grid modernization efforts. 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 Offices of Environmental Management, and Fossil Energy), cyber security (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 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 2011 ASCR budget request capitalizes on the continued gains in computer hardware and in computational science and positions DOE to address scientific challenges through modeling and simulation in the next decade. Since the challenges ahead will require major advances in hardware, software, methods, and tools, the request balances investments in high performance computing facilities, advanced networks, and research and evaluation prototypes with investments in applied mathematics, computer science, next generation networks for science, and computational partnerships. This balance should allow for continued progress in a wide array of fields important to DOE's missions in FY 2011 and for years to come.

The FY 2011 budget request continues support for the Leadership Computing Facility at Oak Ridge National Laboratory (OLCF)—a 2.33 petaflop, six-core Cray Baker 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 meeting challenges associated with high performance computer systems with tens of thousands of multicore processors. Efforts at the OLCF are also expected to build experience and tools for the DARPA High Productivity Computing Systems award to Cray, supported in part through ASCR's Research and Evaluation Prototypes activity, and other anticipated architectures that will exhibit even greater complexity.

The FY 2011 budget request also continues support for the Leadership Computing Facility at Argonne National Laboratory (ALCF)—a 556 teraflop IBM Blue Gene/P system also openly available to the scientific community through INCITE. Like the OLCF, the ALCF will continue to provide access and assistance to tool and library developers and to researchers seeking to scale their applications. The FY 2011 budget request also includes site preparation and acquisition activities for a next generation machine of approximately10 petaflops. Development of this proposed machine is based on the joint ASCR-NNSA sponsored research project with IBM and the Argonne and Lawrence Livermore National Laboratories that was supported from FY 2006 to FY 2010 through the Research and Evaluations Prototypes activity.

The National Energy Research Scientific Computing Center (NERSC) facility at Lawrence Berkeley National Laboratory (LBNL) will operate at a capacity of nearly one petaflop in FY 2011 to meet ever growing demand from SC researchers. Focus will be on assisting applications to effectively utilize the potential of this facility and to move beyond NERSC to the leadership computing machines.

The FY 2011 budget request supports ESnet to continue to advance the next generation network capability that is critical to DOE applications and facilities. Building on the Recovery Act-supported Advanced Networking Initiative, ESnet will deliver 100–400 gigabit per second (Gbps) connections to SC laboratories in FY 2011, with a goal of achieving 1,000 Gbps 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 DOE's energy and environment missions.

The FY 2011 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 Leadership Computing Facilities while beginning to lay the basic research foundation necessary to realize the potential from the more complex systems on the horizon. Core research in Applied Mathematics and Computer Science for FY 2011 will continue to focus on long-term research needs. In networking, the focus will continue to be on developing the advanced tools to harness the growing capabilities and requirements of the ESnet and the SC research community.

Significant Program Shifts

The demands of some critical science applications require us to look ahead to more advanced computing architectures. In FY 2010, ASCR launched a new computer science core research effort in advanced computing architectures. The FY 2011 budget enhances this effort with new projects in the Research and Evaluations Prototypes activity that replace completed projects. These projects will provide the ASCR research community with an opportunity to experiment with cutting-edge architectures and begin to develop tools and methods for harnessing their capabilities. Physical limits to miniaturization necessitate a period of innovation and collaboration for continued progress to be realized. By actively participating in the development of these next-generation machines, ASCR can ensure that the most appropriate architecture for science is developed while researchers 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 2011, SciDAC will be expanded to include partnerships with DOE's applied technology offices such as the Office of Electricity Delivery and Energy Reliability and the Office of Nuclear Energy.

Annual Performance Targets and Results

Secretarial Priority: Innovation: Lead the world in science, technology, and engineering

GPRA Unit Program Goal: Advanced Scientific Computing Research Program Goal: 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.

Annual Performance Measure: 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 and/or libraries.

FY 2006	T: Computational effectiveness is greater than 50%. A: Goal met
FY 2007	T: Achieved computational effectiveness is 100% or greater. A: Goal met
FY 2008	T: Achieved computational effectiveness is 100% or greater. A: Goal met
FY 2009	T: Achieved computational effectiveness is 100% or greater. A: Goal met
FY 2010-FY 2015	T: Achieved computational effectiveness is 100% or greater. A: TBD

Annual Performance Measure: Focus usage of the primary supercomputer at the National Energy Research Scientific Computing Center (NERSC) on capability computing.

FY 2006	T: Percentage of the computing time used that is accounted for by computations that require at least $^1/_8$ of the total resource is at least 40%. A: Goal met

FY 2007	T: Percentage of the computing time used that is accounted for by computations that require at least $^1/_8$ of the total resource is at least 40%. A: Goal met
FY 2008	T: 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. A: Goal met
FY 2009	T: At least 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. A: Goal met
FY 2010	T: At least 30% of the computing time will be used by computations that require at least $^1/_8$ (4,096 processors) of the NERSC resource. A: TBD
FY 2011	T: At least 30% of the computing time will be used by computations that require at least $^1/_8$ of the NERSC resource. A: TBD
FY 2012	T: At least 35% of the computing time will be used by computations that require at least $^1/_8$ of the NERSC resource. A: TBD
FY 2013-FY 2015	T: At least 40% of the computing time will be used by computations that require at least $^1/_8$ of the NERSC resource. A: TBD

Mathematical, Computational, and Computer Sciences Research

Funding Schedule by Activity

	FY 2009	FY 2010	FY 2011
	(dollars in thousands)		
Mathematical, Computational, and Computer Sciences Research			
Applied Mathematics	45,161	44,792	45,450
Computer Science	30,782	46,800	47,400
Computational Partnerships	59,698	53,293	53,297
Next Generation Networking for Science	14,732	14,321	14,321
SBIR/STTR	0	4,586	4,623
Total, Mathematical, Computational, and Computer Sciences Research	150,373	163,792	165,091

Description

The Mathematical, Computational, and Computer Sciences Research subprogram supports elements of the ASCR program aimed at effectively utilizing 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 subprogram must be positioned to address scientifically challenging questions, such as:

- What new mathematics are required to more accurately model systems such as the earth's climate and 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 future?
- What innovations in computer science and algorithms are needed to increase the efficiency with which supercomputers solve problems?
- What operating systems, data management, analyses, representation model development, user interfaces, 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 2009 Accomplishments

- *ASCR Research wins R&D 100 Awards.* Winning a R&D 100 award, often dubbed the "Oscars of invention," provides a mark of excellence known to industry, government, and academia for one of the most innovative ideas of the year. In FY 2009, ASCR-supported research in mathematical libraries and software toolkits, compiler development, and operating systems garnered three of these coveted awards in the software category—PETSc, a suite of data structures and routines for the scalable (parallel) solution of partial differential equation; ROSE, a compiler infrastructure that radically changes the accessibility of compiler technologies and enables users to build their own tools and easily develop programs for today's fast changing hardware platform; and the Catamount

N-Way lightweight kernel, an operating system that leverages hardware capabilities of multicore processors to deliver significant improvements in data access performance for today's parallel computing applications. (The Catamount team is supported by ASCR and builds on work previously supported by the NNSA Advanced Simulation and Computing program.)

- *41 DOE-Affiliated Researchers Named SIAM Fellows***.** The Society for Industrial and Applied Mathematics (SIAM) announced its first class of fellows on May 1, 2009, and the group included 14 current and retired mathematicians from DOE national laboratories, as well as 27 other mathematicians supported by ASCR. This represents about 20 percent of the 200 fellows selected by the society from its international membership of more than 12,000 mathematicians.
- *New General Model for Detecting MPI Deadlocks Developed.* The Message Passing Interface (MPI) standard enables massively parallel processing by directing communications between processors. However, several usage patterns can lead to deadlocks and cause programs to fail. Deadlocks are particularly troublesome because they occur inconsistently and sporadically. They are also very hard to find and fix—especially in long and complicated programs. However, ASCR researchers have developed the first general deadlock model using a graph-based approach. This model enables visualization of MPI deadlocks and motivates the design of a new deadlock detection mechanism. Overall, the results demonstrate that the mechanism improves performance by as much as two orders of magnitude while providing precise characterization of deadlocks.
- *Scaling of Multimillion-Atom Biological Molecular Dynamics Simulation on a Petascale Supercomputer.* ASCR researchers published a strategy enabling molecular dynamics simulations of lignocellulosic biomass to scale to tens of thousands of processors at the OLCF. The strategy enabled the researchers to scale efficiently to the entire machine (140,000 processors). This work will have a significant impact on a wide array of molecular dynamics simulations. Among other applications, the strategy will be of particular importance in bioenergy research.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Applied Mathematics	**45,161**	**44,792**	**45,450**

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 DOE's mission. The research falls into eight general categories, the first five of which have been supported for a number of years while the rest 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.

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

- Optimization research for mathematical methods for minimizing energy or cost, 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 and biological systems computationally. Applied Mathematics research underpins all of DOE's modeling and simulation efforts.

In FY 2011, this activity will continue to develop new and improved applied mathematical models, methods, and algorithms to understand complex systems—including the complex computing systems on which they will run. In addition, the Computational Science Graduate Fellowship program, aimed at attracting the best graduate students in the scientific disciplines and educating them as the next generation of computational scientists, is continued at $6,000,000, and the Applied Mathematics and High Performance Computer Science graduate fellowship program is continued at $2,000,000.

Computer Science	**30,782**	**46,800**	**47,400**

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, the first four of which have been supported for a number of years and the last began 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.

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

- 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 2011, the Computer Science activity will continue to focus on the challenges of emerging extreme scale architectures containing tens of thousands to millions of multicore and/or hybrid processors.

	FY 2009	FY 2010	FY 2011
Computational Partnerships	**59,698**	**53,293**	**53,297**

The Computational Partnerships 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 SC 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 begins to resemble real-world conditions. The activities fall into four general categories:

- 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.
- Four multi-institutional SciDAC Institutes are university-led centers of excellence which complement the efforts of the SciDAC Centers 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.
- 35 multi-institutional *Science Applications Partnerships* are partnerships with other SC 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, the *SciDAC Outreach Center* ensures that SciDAC teams share information across projects and leverage taxpayer investment with other researchers. This 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.

In FY 2010, the Computational Partnerships activity began to 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.

In FY 2011, completion of several of the SciDAC projects initiated in FY 2006 will enable an expansion of these critical efforts. ASCR will also initiate new SciDAC partnerships with the Office of Electricity Delivery and Energy Reliability and/or the Office of Nuclear Energy.

	FY 2009	FY 2010	FY 2011
Next Generation Networking Research for Science	**14,732**	**14,321**	**14,321**

The Next Generation Networking Research 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:

- 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 2011, research will continue to focus on developing the software, middleware and hardware that delivers 99.999% reliability up to and beyond one petabyte per second.

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Small Business Innovative Research (SBIR)/ Small Business Technology Transfer (STTR)	**0**	**4,586**	**4,623**

In FY 2009, $3,612,000 and $432,000 were transferred to the SBIR and STTR programs respectively. The FY 2010 and FY 2011 amounts shown are the estimated requirements for continuation of the congressionally mandated SBIR and STTR programs.

Total, Mathematical, Computational, and Computer Sciences Research	**150,373**	**163,792**	**165,091**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Applied Mathematics	
This increase will support the continued development of new and improved applied mathematical models, methods, and algorithms to understand complex systems.	+658
Computer Science	
This increase will support continued focus on the challenges of emerging extreme scale architectures containing tens of thousands to millions of multicore and/or hybrid processors.	+600
Computational Partnerships	
The increase, in addition to the completion of several awards initiated in FY 2006, will support additional efforts focused on getting critical applications ready to utilize extreme scale computing resources and new partnerships with DOE applied programs.	+4
SBIR/STTR	
SBIR/STTR increases as research funding is increased.	+37
Total Funding Change, Mathematical, Computational, and Computer Sciences Research	**+1,299**

High Performance Computing and Network Facilities

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
High Performance Computing and Network Facilities			
High Performance Production Computing	53,497	55,000	56,000
Leadership Computing Facilities	116,222	123,168	158,000
Research and Evaluation Prototypes	10,387	16,124	10,052
High Performance Network Facilities and Testbeds	28,293	29,722	30,000
SBIR/STTR	0	6,194	6,857
Total, High Performance Computing and Network Facilities	208,399	230,208	260,909

Description

The High Performance Computing and Network Facilities subprogram delivers forefront computational and networking capabilities to scientists nationwide. These include the High Performance Production Computing at the National Energy Research Scientific Computing Center (NERSC) facility at LBNL and Leadership Computing Facilities at Oak Ridge (OLCF) and Argonne (ALCF) National Laboratories. These computers, and the other SC research facilities, turn out many petabytes of data each year. Moving data to the researchers who need them requires advanced scientific networks and related technologies provided through High Performance Network Facilities and Testbeds. The subprogram also invests in long-term needs through the Research and Evaluation Prototypes activity.

Computing resources are allocated through competitive processes. Up to eighty percent of the processor time on the Leadership Computing Facilities is allocated through the Innovative and Novel Computational Impact on Theory and Experiment (INCITE) program, which is open to all researchers and results in awards to a small number of projects, each requiring a substantial amount of the available resources. The high performance production computing facilities at NERSC are predominately allocated to researchers supported by SC programs. In FY 2011, all of the ASCR scientific computing facilities will also allocate ten to thirty percent of computing resources through the ASCR Leadership Computing Challenge program. This program is open year-round to scientists from the research community in academia and industry for special situations of interest to DOE with an emphasis on high-risk, high-payoff simulations in areas directly related to the DOE's energy mission, for national emergencies, or for broadening the community of researchers capable of using leadership computing resources.

FY 2009 Accomplishments

- *Oak Ridge Supercomputers Provide Understanding of the Conditions that Led to Past Abrupt Climate Changes*. Scientists at the University of Wisconsin and the National Center for Atmospheric Research (NCAR) used the OLCF to simulate abrupt climate change and shed new light on an enigmatic period of natural global warming in Earth's relatively recent history. The work was featured in the July 17, 2009 issue of the journal *Science* and provides valuable new data about the causes and effects of global climate change. The scientists used nearly a million processor hours in 2008 to run one-third of their simulation, from 21,000 years ago—the most recent glacial maximum—to 14,000 years ago—the planet's most recent major period of natural global warming.

With 4 million INCITE processor hours allocated on the OLCF for 2009-2011, they will complete the simulation, capturing climate from 14,000 years ago to the present and projecting it 200 years into the future. This research is funded by Biological and Environmental Research and the National Science Foundation through its paleoclimate program and support of NCAR.

- *Argonne Supercomputer Provides Breakthrough Computation of Thermal-Hydraulics in Nuclear Reactors.* The first simulation of the full physical configuration of 217 wire-wrapped fuel rods was run on the ALCF and achieved 80% parallel efficiency. The calculation of the pressure distribution of coolant flow exceeded 2.90 million spectral elements and used approximately 1 billion grid points. Over this three-year INCITE project many ASCR research innovations were utilized to improve scaling of the code without losing physical details. Experiments indicate that low pin count results do not extrapolate to higher pin counts because of the edge channel effects. These full scale results are allowing researchers to study coolant flow in a variety of core subassembly designs in order to optimize reactor performance.
- *National Energy Research Scientific Computing (NERSC) Helps Discover Cosmic Transients***.** An innovative new sky survey, the Palomar Transient Factory, used the unique tools and services of NERSC to uncover more than 40 supernovae, or stellar explosions, during the commissioning phase and astronomers expect to be able to annually discover thousands more of these relatively rare and fleeting cosmic events. Such events occur about once a century in the Milky Way galaxy and are visible for only a few months.
- *Energy Sciences Network (ESnet) stimulates 100 Gbps technologies for DOE*. The ever growing demand for network bandwidth from large science collaborations, such as the Large Hadron Collider, requires ESnet to push toward next generation technologies to meet demand. However, the recession seemed to have stalled development of these technologies in early 2009. As a result, Secretary Chu announced in March that the Department of Energy would use Recovery Act funding to accelerate progress and deploy a prototype 100-gigabit per second data network. Across Europe and Asia, announcements of similar demonstrations quickly followed and industry began rolling out new offerings. ESnet is managing the Recovery Act-funded research project on advanced networking that is deploying a 100 Gbps test bed to develop the tools and techniques necessary to utilize this technology in the ESnet backbone beginning in FY 2010. Because of the strong connections between ESnet and this Recovery Act project, ESnet will be upgraded seamlessly to meet the growing, complex needs of DOE and remains on a path to deliver 1 terabit per second connectivity in 2014.

Detailed Justification

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
High Performance Production Computing	**53,497**	**55,000**	**56,000**

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, high energy and nuclear physics, and biology. NERSC enables teams to prepare to use the ALCF and OLCF as well as to perform the calculations that are required by the missions of the SC programs. NERSC users are supported by SC 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.

NERSC's 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 2011 funding will support operation of the NERSC high-end capability systems (NERSC-5 and NERSC-6), lease payments, and user support. With the acquisition and operation of NERSC-6, the total capacity of NERSC in FY 2011 will be approximately one petaflop. The NERSC computational resources are integrated by a common high performance file storage system that enables users to easily migrate to any of the available resources. With approximately 60 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 2009	FY 2010	FY 2011
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	3,100	3,100	3,100

Leadership Computing Facilities	**116,222**	**123,168**	**158,000**

The Leadership Computing Facilities activity enables open scientific applications to harness the potential of leadership computing to advance science. 2009 saw the realization of that vision, with the top system in the independent international "Top 500" ranking of supercomputers and a second Gordon Bell prize for a petascale science application that provided new insights into magnetic materials. This new era of petaflop science opens significant opportunities to dramatically advance research as simulations more realistically capture the behavior of, for example, materials and ITER scale fusion devices. The success of this effort is built on the gains made in research and evaluation prototypes, the SciDAC program, and research in applied mathematics and computer science.

The costs for both the ALCF and OLCF fall into three general areas: lease payments, operations (space, power, cooling, maintenance, tapes, etc.), and operating and support staff. In FY 2011, costs are driven by increases in lease payments at both facilities in accordance with the approved baselines.

▪ **Leadership Computing Facility at ORNL (OLCF)**	**87,680**	**81,168**	**96,000**

In FY 2009, with Recovery Act funds, the OLCF's Cray XT5 system was upgraded to 2.33 petaflops—making it the most powerful computer in the world. In addition, the facility also continues to operate a 263 teraflop Cray XT4 machine for INCITE projects, ASCR Leadership Computing Challenge projects, scaling tests, and tool and library developers. The facility staff is

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

continuing to focus on assisting users to fully utilize the OLCF resources. As a result, several applications, such as combustion studies in diesel jet flame stabilization, simulations of neutron transport in fast reactor cores, and groundwater flow in porous media, are running at petascale.

In FY 2011, the request supports an increase in lease payments for the XT5 and the acquisition of an experimental prototype with a hybrid architecture—a mix of standard processors and specialized processing engines (such as a Global Processing Unit [GPU], a field-programmable gate array [FPGA], or a vector processor) that offer greater efficiency and computing power but also introduce new system and application programming challenges. The OLCF activity will also support operation and INCITE allocation of the two Cray systems and will continue to provide support to INCITE projects, pioneer applications, and tool and library developers.

	FY 2009	FY 2010	FY 2011
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	496	550	625

- **Leadership Computing Facility at ANL (ALCF)** **28,542** **42,000** **62,000**

The ALCF provides a high performance IBM Blue Gene/P with low-electrical power requirements and a peak capability of 556 teraflops. This facility provides diversity in the DOE leadership resources and supports many applications, including molecular dynamics and materials. This system is better suited to these computing needs than the OLCF and NERSC. The ALCF staff operate and maintain the computing resources and provide support to INCITE projects, ASCR Leadership Computing Challenge projects, scaling tests, and tool and library developers.

In FY 2011, the request supports increases in the lease payments on the Blue Gene/P in accordance with the approved schedule. In addition, ALCF will support site preparations for acquisition of a next generation machine. This machine is expected to be approximately 10-20 petaflops, such as the system 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 2011 and will continue to provide support to INCITE projects, pioneer applications, and tool and library developers.

(dollars in thousands)

	FY 2009	FY 2010	FY 2011

	FY 2009	FY 2010	FY 2011
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	100	200	300

	FY 2009	FY 2010	FY 2011
Research and Evaluation Prototypes	**10,387**	**16,124**	**10,052**

The Research and Evaluation Prototypes activity addresses the challenges of next generation computing systems. As computer chips approach critical physical limits, we begin an era of radical innovation. These systems will likely 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, ASCR can ensure that the most appropriate architectures for science are developed while researchers will better understand their inherent challenges and can begin to work on overcoming those challenges. The Research and Evaluation Prototype 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 2011, the Research and Evaluation Prototypes activity will complete SC's partnership with the NNSA and the Defense Advanced Research Projects Agency (DARPA) program for High Productivity Computing Systems. ASCR will continue to work cooperatively with the NNSA on new, smaller scale prototype projects to explore architectures on the path toward exascale computing (capable of an exaflop, or 10^{18} floating point operations per second). These prototype projects will be tightly coupled with research in advanced computer architectures supported by the Computer Science activity.

	FY 2009	FY 2010	FY 2011
High Performance Network Facilities and Testbeds	**28,293**	**29,722**	**30,000**

This activity supports operation and upgrades for the Energy Science network (ESnet), which 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 99.999% reliability that is required for large scale scientific data transmission.

In FY 2009, a Recovery Act supported research effort implemented a national testbed of next generation optical technologies that allow networks, such as ESnet, to gain a ten-fold increase in

(dollars in thousands)

	FY 2009	FY 2010	FY 2011

bandwidth on existing fiber. The testbed allows ASCR to develop and harden the tools necessary to ensure data integrity and network reliability with this new technology. In FY 2011, ASCR will begin to deploy this next generation technology to enable 100 Gbps per wavelength. As a result of research supported by the Recovery Act, ESnet is on a path to achieving 1,000 Gbps connectivity.

	FY 2009	FY 2010	FY 2011
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[a]	N/A	N/A	N/A

	FY 2009	FY 2010	FY 2011
Small Business Innovative Research (SBIR)/ Small Business Technology Transfer (STTR)	**0**	**6,194**	**6,857**

In FY 2009, $5,360,000 and $644,000 were transferred to the SBIR and STTR programs respectively. The FY 2010 and FY 2011 amounts shown are the estimated requirements for continuation of the congressionally mandated SBIR and STTR programs.

	FY 2009	FY 2010	FY 2011
Total, High Performance Computing and Network Facilities	**208,399**	**230,208**	**260,909**

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.	+1,000
Leadership Computing Facilities (LCFs)	
The increase covers increases in lease payments at both facilities in accordance with approved schedule. The OLCF will acquire a prototype machine with a hybrid architecture. At the ALCF, the increase supports site preparation for acquisition of a next generation machine.	+34,832

[a] The ESnet is a high performance scientific network that connects DOE facilities to researches around the world and it is therefore not possible to estimate users.

	FY 2010 vs. FY 2009 ($000)
Research and Evaluation Prototypes	
The decrease is due to final payment for the DARPA High Productivity Computing Systems project. Support is increased for new, smaller scale prototype projects to explore architecture features on the path toward exascale computing.	-6,072
High Performance Network Facilities and Testbeds	
The increase will enable ESnet to begin to deliver 100 Gbps connections in FY 2011. The increase in bandwidth is critical to meeting the growing requirements for DOE applications and facilities.	+278
SBIR/STTR	
Increase in SBIR/STTR due to increase in operating expenses.	+663
Total Funding Change, High Performance Computing and Network Facilities	**+30,701**

Supporting Information

Operating Expenses, Capital Equipment, and Construction Summary

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Operating Expenses	348,595	385,000	410,000
Capital Equipment	10,177	9,000	16,000
Total, Advanced Scientific Computing Research	358,772	394,000	426,000

Funding Summary

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Research	160,760	186,110	182,000
Scientific User Facility Operations	198,012	207,890	244,000
Total, Advanced Scientific Computing Research	358,772	394,000	426,000

Scientific User Facility Operations

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
NERSC	53,497	55,000	56,000
OLCF	87,680	81,168	96,000
ALCF	28,542	42,000	62,000
ESnet	28,293	29,722	30,000
Total, Scientific User Facility Operations	198,012	207,890	244,000

Facilities Users and Hours

	FY 2009	FY 2010	FY 2011
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	3,100	3,100	3,100

	FY 2009	FY 2010	FY 2011
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	496	550	625
ALCF			
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	100	200	300
Total			
Achieved Operating Hours	31,361	N/A	N/A
Planned Operating Hours	31,361	31,361	31,361
Optimal Hours	31,361	31,361	31,361
Percent of Optimal Hours	100%	100%	100%
Unscheduled Downtime	1%	1%	1%
Number of Users	3,696	3,850	4,025

Scientific Employment

	FY 2009 Estimated	FY 2010 Estimated	FY 2011 Estimated
# University Grants	205	210	210
Average Size	$194,000	$224,000	$232,000
# Laboratory Projects	175	180	185
# Graduate Students (FTEs)	533	563	582
# Permanent Ph.D.s (FTEs)	735	766	791
# Other (FTEs)	248	246	281

Basic Energy Sciences

Funding Profile by Subprogram

(dollars in thousands)

	FY 2009 Current Appropriation	FY 2009 Current Recovery Act Appropriation[a]	FY 2010 Current Appropriation	FY 2011 Request
Basic Energy Sciences				
Materials Sciences and Engineering	1,108,351[b]	+221,788	363,642	432,663
Chemical Sciences, Geosciences, and Energy Biosciences	281,946	+169,072	296,934	403,616
Scientific User Facilities	0[b]	0	821,684	847,121
Subtotal, Basic Energy Sciences	1,390,297	+390,860	1,482,260	1,683,400
Construction	145,468	+164,546	154,240	151,600
Total, Basic Energy Sciences	1,535,765[c]	+555,406	1,636,500	1,835,000

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"

Program Overview

Mission

The mission of the 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 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 Earth'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

[a] The Recovery Act Current Appropriation column reflects the allocation of funding as of September 30, 2009.
[b] FY 2009 funding of $771,198,000 for Scientific User Facilities is located within the Materials Sciences and Engineering subprogram. The Materials Sciences and Engineering subprogram FY 2009 total, excluding Scientific User Facilities funding is $337,153,000.
[c] Total is reduced by $36,207,000; $32,328,000 of which was transferred to the Small Business Innovation Research (SBIR) program and $3,879,000 of which was transferred to the Small Business Technology Transfer (STTR) program.

advances is the ability to create new materials using sophisticated synthetic and processing techniques, precisely define the atomic arrangements in matter, and control 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.

The BES program is one of the nation's largest sponsors of research in the natural sciences. In FY 2009, the program funded research in more than 170 academic institutions located in 50 states and in 14 DOE laboratories located in 12 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 that provide 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 are used to correlate the microscopic structure of materials with their macroscopic properties, which provides 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 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; they must be designed and fabricated to exacting standards using principles revealed by basic science.

The 20th century witnessed revolutionary advances in physical sciences, 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 nanoscale. 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 materials before they exist. 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 science-guided design of 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; and 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 and properties 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 *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 the 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.

The *Scientific User Facilities* subprogram supports the operation of a nationwide suite of major facilities that provide 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 advanced tools and instruments. The continual development and renovation of the instrumental capabilities includes 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 for 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, advances in superconductivity have been introduced commercially in a number of demonstration projects around the country. Improvements in alloy design for high temperature applications are used in commercial furnaces and in green technologies such as lead-free solder. Research in chemistry has led to 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 of 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, create an entirely new paradigm for developing new and revolutionary energy technologies.

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 21st 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 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 portfolios have been reassessed and restructured to reflect the results of these workshops.

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, the Linac Coherent Light Source, and numerous instrument fabrication projects. Recently, BESAC sponsored a workshop *Next-Generation Photon Sources for Grand Challenges in Science and Energy* to explore the scientific frontiers that could be tackled with next generation photon sources. The workshop identified new research opportunities in materials, chemistry, biology, medicine, environment, and physics for science and energy that can be addressed with diffraction, excitation, and imaging by photons. BES will build on this foundation with a workshop to assess the technical readiness of various accelerator-based techniques for 4^{th} generation light sources and the corresponding R&D needs. It is expected that the output of these workshops 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

[a] http://www.science.doe.gov/opa/PDF/revhndbk.pdf

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 BES website.[a] 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 NNSA. Many activities facilitate cooperation and coordination between BES and the applied research programs, 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 Offices 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 defense programs. 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.

[a] http://www.sc.doe.gov/bes/

Budget Overview

The FY 2011 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. A significant portion of the funding increase will be devoted to expand the research program to capture new, emerging opportunities by furthering its scientific reach and potential technological impact.

BES supports three types of research rewards—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 BES core research awards permit individual scientists and small groups to pursue their discovery-driven research interests with broad energy relevance. The dozens of EFRC awards bring together multiple investigators to address major scientific challenges necessary to solve complex energy research problems. The Hub awards 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. The core research represents over 70% of the total BES research funding and complements larger group efforts comprised of the EFRCs and the Energy Innovation Hubs.

- *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, with an emphasis on molecular science and engineering; basic architecture of matter; directed assemblies, structure, and properties; emergence of collective phenomena; energy and information on the nanoscale; and matter far beyond equilibrium. An increase in funding for ultrafast science, which deals with phenomena that occur in the range of one-trillionth of a second (one picosecond) to less than one-quadrillionth of a second (one femtosecond), is requested in FY 2011. This research has the promise of expanding our understanding of chemistry and materials sciences by allowing real-time stroboscopic investigations of the earliest stages of dynamic phenomena. Such knowledge will be critical to advancing the science frontiers in energy transduction in natural and artificial solar energy conversion systems, real-time bond breakage and formation in catalytic reactions, the dynamics of materials in extreme environments, correlation in strongly correlated electron systems, the nucleation of defects in materials that result in the degradation of their properties, and structural dynamics in complex biomolecules. Additional research will also be initiated in the area of multiscale modeling for advanced engine design.

  In FY 2011, approximately $24 million will be available to fund core research efforts in two additional categories: discovery and development of new materials that are critical to both science frontiers and technology innovations, and basic research for energy needs in a limited number of areas as shown below.

  - *Discovery and development of new materials*. Research in this category will focus on new synthesis capabilities, including bio-inspired approaches, to establish a strong foundation for science-driven materials discovery and synthesis in the U.S. This work will focus on materials broadly and will include crystalline materials, which have been highlighted recently as an essential component of the science grand challenges in the 2007 BESAC report Directing Matter and Energy: Five Challenges for Science and the Imagination. As described in the November 2009 NRC report Frontiers in Crystalline Matter: From Discovery to Technology, the U.S., once the world leader in the discovery and growth of crystalline materials, has fallen behind other nations. Single crystals are vital in understanding the characteristics and properties of new materials, and they also have applications in devices that involve semiconductors, lasers, precision timing devices, solar cells or high temperature operations and provide a natural platform to explore novel states of matter.

- *Basic research for energy needs.* Major areas of emphasis will be in fundamental sciences related to carbon capture and advanced nuclear energy systems. For carbon capture, focused areas include the rational design of novel materials and separation processes for post-combustion CO_2 capture, as well as catalysis and separation research for novel carbon capture schemes to aid the design of future power plants. For advanced nuclear energy systems, focused areas include radiation resistant materials in fission and fusion applications and separation science and heavy element chemistry for fuel cycles.

- *Energy Frontier Research Centers (EFRCs),* established in FY 2009, are multi-investigator and multi-disciplinary centers to engage the talents of the nation's researchers for the broad energy sciences. The EFRCs harness the most basic and advanced discovery research in a concerted effort to accelerate the scientific breakthroughs needed to create advanced energy technologies for the 21st century. These centers 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 subprogram and the Chemical Sciences, Geosciences, and Biosciences subprogram, who are managed centrally within BES to ensure a unified management strategy and structure. In FY 2011, approximately $40 million will be available to fund additional EFRCs. New EFRCs will be competitively solicited in the two categories described above under core reserach: discovery and development of new materials that are critical to both science frontiers and technology innovations, and basic research for energy needs in a limited number of areas that are underrepresented in the 46 original EFRC awards.

- *Energy Innovation Hubs* were initiated by the Department in FY 2010. The Hubs aim to assemble multidisciplinary teams to address basic science and technology 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. The Energy Innovation Hubs comprise a larger set of investigators spanning science, engineering, and other disciplines, but focused on a single critical national need identified by the Department. Top talent drawn from the full spectrum of R&D performers—universities, private industry, non-profits, and government laboratories—drive each Hub to become a world leading R&D center in its topical area. With robust links to industry, the highly integrated Hubs can bridge the gap between basic scientific breakthroughs and industrial commercialization. In FY 2011, BES will support the continuation of the Fuels from Sunlight Hub and will initiate a new Hub on Batteries and Energy Storage.

The FY 2011 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 3.5% increase over the FY 2010 funding level and provides near optimal support for the user operations. Funding is also provided for instrumentation to upgrade BES beamlines at the light source facilities. The Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory 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. The LCLS will begin the first full year of operations in FY 2011. 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 of the National Synchrotron Light Source II (NSLS-II) will continue at Brookhaven National Laboratory, including the largest component of the project—the building that will house the accelerator ring. The Spallation Neutron Source Instruments-Next Generation (SING-I, funding to be completed in FY 2011, and SING-II) and the Power Upgrade Project (PUP), as part of the planned upgrades to the Spallation Neutron Source at Oak Ridge National Laboratory, will be supported according to planned schedules and funding profiles.

Annual Performance Results and Targets

Secretarial Priority: Innovation: Lead the world in science, technology, and engineering

GPRA Unit Program Goal: Basic Energy Sciences Program Goal: 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.

Annual Performance Measure: Annual Performance Measure: Temporal resolution; maintain x-ray pulse of less than 100 femtoseconds in duration and containing more than 100 million (108) photons per pulse.[a]

FY 2006	T: Demonstrate an X-ray pulse of less than 100 femtoseconds in duration and containing more than 100 million photons per pulse. A: Goal met
FY 2007	T: Demonstrate an X-ray pulse of less than 100 femtoseconds in duration and containing more than 100 million photons per pulse. A: Goal met
FY 2008	T: Maintain x-ray pulses that are <100 femtoseconds in duration and have an intensity of >100 million (10^8) photons per pulse. A: Goal met
FY 2009	T: Maintain x-ray pulses that are <100 femtoseconds in duration and have an intensity of >100 million (10^8) photons per pulse. A: Goal met

[a] No further improvement is expected beyond 2008 for these measures since the current suite of instruments has met their 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 2010–FY 2015	T: Maintain x-ray pulses that are <100 femtoseconds in duration and have an intensity of >100 million (10^8) photons per pulse. A: TBD

Annual Performance Measure: Spatial Resolution; 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]

FY 2006	T: Demonstrate 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: Goal met
FY 2007	T: Demonstrate 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: Goal met
FY 2008	T: 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: Goal met
FY 2009	T: 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: Goal met
FY 2010–FY 2015	T: 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: TBD

Annual Performance Measure: Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects.

FY 2006	T: Cost and schedule variance are both less than 10% A: Goal met
FY 2007	T: Cost and schedule variance are both less than 10% A: Goal not met

[a] No further improvement is expected beyond 2008 for these measures since the current suite of instruments has met their 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 2008	T: Cost and schedule variance are both less than 10% A: Goal met
FY 2009	T: Cost and schedule variance are both less than 10% A: Goal met
FY 2010–FY 2015	T: Cost and schedule variance are both less than 10% A: TBD

Annual Performance Measure: Achieve an average operation time of the scientific user facilities as a percentage of the total scheduled annual operating time of greater than 90%.

FY 2006	T: 90% of scheduled operating time A: Goal met
FY 2007	T: 90% of scheduled operating time A: Goal met
FY 2008	T: 90% of scheduled operating time A: Goal met
FY 2009	T: 90% of scheduled operating time A: Goal met
FY 2010–FY 2015	T: 90% of scheduled operating time A: TBD

Materials Sciences and Engineering

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Materials Sciences and Engineering			
Materials Sciences and Engineering Research	392,260[a]	354,104	421,427
Facilities Operations	689,047[a]	0	0
Other Project Costs	27,044[a]	0	0
SBIR/STTR	0	9,538	11,236
Total, Materials Sciences and Engineering	1,108,351[a]	363,642	432,663

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 of 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.

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.

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. This research is guided by applications of concepts learned from the interface between physics and biology and from nano-scale understanding of synthesis and structures.

The Energy Innovation Hub focused on Batteries and Energy Storage 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.

[a] FY 2009 funding of $771,198,000 for Scientific User Facilities is located within the Materials Sciences and Engineering Research activity ($82,151,000) and the Facility Operations activity ($689,047,000). In FY 2010 and beyond, this funding is shown in the Scientific User Facilities subprogram.

Selected FY 2009 Accomplishments

- *Encoding Information at Sub-Atomic Scales.* Using state-of-the-art nanoscience instruments and novel techniques, scientists have set a record for the smallest writing, forming letters with features that are one third of a billionth of a meter or 0.3 nanometers. This sub-atomic writing was achieved by using a scanning tunnelling microscope (STM) to precisely position carbon monoxide molecules into a desired pattern on a copper surface. The electrons that move around on the copper surface act as waves that interfere with the carbon monoxide molecules and with each other, forming an interference pattern that depends on the positions of the molecules. By altering the arrangement of the molecules, specific electron interference patterns are created, thereby encoding information for later retrieval. In addition, several data sets can be stored in a single molecular arrangement by using multiple electron energies, one of the variables possible with the STM. The same STM technology can then be used to read the data that has been stored. Because the information is stored in the electron interference pattern, rather than in the individual carbon monoxide molecules or surface copper atoms, the storage density is not limited by the size of an atom. These results demonstrate the feasibility of a new approach capable of achieving sub-atomic data storage.
- *Electronic Liquid Crystal States Discovered in Parent of Iron-Based Superconductor*. In one of the first results from an Energy Frontier Research Center, new insights were gained concerning the electronic structure of iron-based, high-temperature (high-T_c) superconductors. Using a newly developed, highly sensitive scanning tunneling microscope, static nanoscale electronic structures at about eight times the distance between individual iron atoms were observed in a parent material of the iron-based superconductors. These structures were aligned along one crystal axis, reminiscent of the way molecules spatially order in a liquid crystal display. In addition, free electrons were found to move in a direction perpendicular to these aligned 'electronic liquid crystal' states. These findings are similar to observations in cuprate superconductors, a surprise because many theorists had expected the iron-based materials to act more like conventional metal superconductors. This new understanding of electronic structure provides insights to revise theories for the mechanism of high temperature superconductivity.
- *Learning from Nature to Make Tough Ceramics*. Nature generates strong materials, such as mother-of-pearl, with orders of magnitude more fracture resistance than any man-made materials, by forming hybrid composites in which a hard, brittle mineral is combined with soft, organic molecules. Recently, researchers have used sophisticated material control techniques to create a new fabrication process that mimics Nature. The results are hybrid materials composed of aluminum oxide (strong, but brittle) and polymers (soft, organic materials) with toughness 300 times higher than either component alone. To achieve this new material, researchers oriented ceramic layers and interconnected them with bridges to impose molecular control on the bonding between the polymer and ceramics. The processing involved controlled freezing of a suspension of aluminum oxide ceramic particles in water (which drives the particles into layered structures), sublimating the ice, and then infiltrating the remaining ceramic framework with a polymer. The layer orientation and spacing were designed to ensure that a crack that forms in the brittle mineral is shielded from stress and actually stops growing, thereby resulting in the combined high strength and facture resistance.
- *Real-time Observation of Graphene Reconstruction Confirms Predicted Structure.* The world's most powerful transmission electron microscope, developed in the Transmission Electron Aberration-Corrected Microscope (TEAM) project, was used to make the first-ever real-time recordings of the movements of individual carbon atoms in a graphene sheet, providing critical insights on the properties of these unique materials. Graphene is a single atomic layer of graphite that is attracting

significant attention for its unique electronic properties. For example, theory predicts that narrow strips of graphene known as nanoribbons could conduct a current in which all the electrons have the same spin and might therefore serve as the basis for nanosized spintronic devices, electronics based on spin rather than charge. However, this conduction phenomenon is predicted to occur only if the nanoribbons are oriented along a particular direction in the graphene sheet, forming so-called zig-zag edges. The advanced capabilities of the new microscope yielded unprecedented images of individual carbon atoms around the edges of a hole in a suspended graphene sheet and allowed for the real-time observation of edge reconstruction and whole growth. Careful analysis of the time-evolution of the atomic positions and edge structures confirmed that the zig-zag configuration appeared to be the most stable, bolstering optimism for development of graphene-based spintronic devices.

- *Flexible, transparent, and cheaper silicon solar cells.* A novel fabrication strategy has been developed for thin, semi-transparent, lightweight, and flexible solar cells with one-tenth the silicon in current devices and applicable to a variety of substrates including flexible polymer and glass sheets. The process involves fabrication of micron-sized cells on single-crystal silicon wafers and lifting them off using a block of rubbery polymer. These are then printed, or transferred, to the desired substrate; a process that can be repeated many times to build a macro-scale cell. The technique has been used to print cells on flexible, rollable plastic sheets. Respectable solar energy conversion efficiencies of about 12% have been achieved for silicon with thicknesses of 15 microns, thinner than a human hair and less than a tenth the thickness of wafers used in current-generation solar cells. In addition to lower potential cost, this novel solar cell allows unprecedented design characteristics including bendability, lighter weight, and partial transparency, none of which are possible with today’s silicon devices.
- *Efficient Solar Hydrogen Production by a Hybrid Photo-Catalyst System.* Inorganic catalyst systems have been used to generate hydrogen from water by use of sunlight, but the efficiency is low because they can only use the UV portion of the solar radiation. Natural photosynthetic systems such as photosystem I (PS-I) can absorb about 45% of the solar spectrum, but are indirectly and inefficiently coupled to a non-robust, oxygen-sensitive hydrogenase enzyme to generate hydrogen. A novel bio-inspired hybrid system for faster and efficient generation of hydrogen from sunlight was developed. The new hybrid system uses a cleverly designed synthetic molecular wire to covalently link PS-I with gold or platinum nanocatalysts. The molecular wire provides a rapid, efficient pathway for shuttling photo-generated electrons to the inorganic nanocatalyst, with electron-transfer rates approaching 75% of the rates in plants. When exposed to sunlight, this new hybrid system generates hydrogen at up to 1,700 times the current benchmark.
- *Large Area, High Density Arrays of Nanopillars Achieved.* Control of the chemical interactions during the self-assembly of arrays of polymer nanopillars has resulted in perfectly ordered arrays over extremely large areas. Researchers controlled the formation of the polymer nano-cylinders, each with unprecedentedly small about 3 nm diameter normal to the substrate during synthesis, the attraction and repulsion between the segments in a block copolymer are balanced against their interaction with the zigzagged surface of the patterned substrate. The new insight was to control the features and the relationships among the substrate pattern, film thickness, and polymer nanopillars. By controlling these relationships, an ordered array of polymer nanopillars was produced with densities in excess of 10^{12} per square inch, more than an order of magnitude greater than previously possible. In a novel application of synchrotron x-ray scattering, the ordering and orientation of the pillars were confirmed to be maintained over the entire surface. This guided synthesis should be applicable to different substrates and block copolymers with built-in electron and optical properties,

opening a versatile route toward ultrahigh density arrays that could be used in photovoltaics, electronics, and information storage applications.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Materials Sciences and Engineering Research	**392,260**	**354,104**	**421,427**
▪ **Experimental Condensed Matter Physics**	**43,584**	**48,264**	**45,966**

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 property 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 technologies for energy generation, conversion, storage, delivery, and use. Specifically, research efforts in understanding the fundamental mechanisms of 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 2011, funding will be provided for research in the area of complex and emergent behavior. The research activities will emphasize investigations of emergent behaviors that arise from the collective, cooperative behavior of individual components of a system such as atoms or electrons that lead to physical phenomena as diverse as phase transitions, high temperature superconductivity, colossal magnetoresistance, random field magnets, and spin liquids and glasses. Additional investments will be made for the study of ultracold, atomic Fermi gasses as a means to study interaction effects that are relevant to the understanding of correlation effects in the condensed phase. These phenomena are expected to impact a wide range of energy relevant technologies.

▪ **Theoretical Condensed Matter Physics**	**27,498**	**28,932**	**29,641**

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

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

perform complex calculations dictated by fundamental theory or to perform complex system 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 2011, this activity will increase the support of collaborative research activities focused on enhancing the understanding of 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.

	FY 2009	FY 2010	FY 2011
▪ **Mechanical Behavior and Radiation Effects**	**17,830**	**20,666**	**25,172**

This activity supports basic research to understand defects in materials and their effects on the 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 in energy relevant materials. 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 microstructural analysis, 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 robust energy storage systems; 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 may be 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 2011, 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, and 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. Additional research will be initiated to focus on understanding the complex interactions of radiation-induced defects with microstructure, and their effects on the functionalities of materials under extreme conditions, including those that exist in nuclear reactor environments. The research will focus on understanding, modeling, and designing radiation-resistant materials that maintain all of the required physical properties after prolonged exposure. In situ experiments will be closely integrated with theoretical/computational efforts to develop a fundamental understanding of degradation mechanisms and kinetics over multiple length and time scales, from atomistic to micron and nanoseconds to decades.

	FY 2009	FY 2010	FY 2011
▪ **Physical Behavior of Materials**	**30,579**	**32,888**	**34,034**

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 to establish 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 the 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 2011, this activity will support research on the fundamental science of photon-matter interactions, which is likely to play a significant role in the development of metamaterials and nano-plasmonics—materials that are expected to be extremely important for the development of technologies that enable low cost power conversion. The research will also 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 photo-conversion efficiencies. This activity also includes funding for the U.S.-India Clean Energy Research Center.

	FY 2009	FY 2010	FY 2011
▪ **Neutron and X-ray Scattering**	**44,619**	**38,678**	**42,266**

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

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

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.

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 2011, 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. Increased emphasis will be placed on expansion of ultrafast materials science research to take advantage of new x-ray and neutron sources to perform research designed to understand dynamic phenomena in real-time, including the physics of strongly correlated systems, such as high temperature superconductors and magnetic materials with colossal magnetoresistance.

	FY 2009	FY 2010	FY 2011
▪ **Electron and Scanning Probe Microscopies**	**22,199**	**26,811**	**27,468**

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

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

activity is relevant to hydrogen research through the structural determination of nanostructured materials for hydrogen storage and solar hydrogen generation.

In FY 2011, 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 at the femtosecond time scale. Ultrafast electron scattering will be developed as a companion tool to ultrafast photon probes.

▪ **Experimental Program to Stimulate Competitive Research (EPSCoR)**	**16,755**	**21,623**	**8,635**

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, nuclear 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 2011 efforts will continue spanning DOE missions in the Office of Science and science underpinning a number of technology programs including Fossil Energy, Nuclear Energy, and Energy Efficiency and Renewable Energy and enhancing collaboration between programs and collaboration with DOE user facilities. The FY 2011 request will continue basic research related to DOE mission areas and will enhance collaborative efforts with DOE user facilities. The FY 2011 request reflects a decrease due to the additional funding provided by Congress in FY 2010 (-$13,103,000), and provides a funding increase for EPSCoR base amount at the same rate as BES core research (+$115,000). Additional funds provided in FY 2010 were used, to the extent possible, to fully fund grants and minimize outyear mortgages.

The following table shows EPSCoR distribution of funds by state.

EPSCoR Distribution of Funds by State

Alabama	1,305	0	585
Alaska	810	0	0
Arkansas	0	0	0
Delaware	1,861	0	0
Hawaii	0	0	0
Idaho	1,445	0	0

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Iowa[a]	0	0	0
Kansas	0	0	0
Kentucky	700	650	0
Louisiana	490	300	0
Maine	700	0	0
Mississippi	0	0	0
Montana	410	450	0
Nebraska	825	0	0
Nevada	0	0	0
New Hampshire	646	0	0
New Mexico	272	750	0
North Dakota	1,200	0	0
Oklahoma	1,175	0	0
Puerto Rico	400	450	0
Rhode Island	0	0	0
South Carolina	1,670	0	0
South Dakota	0	0	0
Tennessee	204	314	0
U.S. Virgin Islands	0	0	0
Utah[b]	0	0	0
Vermont	0	0	0
West Virginia	1,605	0	600
Wyoming	405	0	0
Technical Support	632	250	400
Other[c]	0	18,459	7,050

[a] Iowa became eligible in FY 2009.
[b] Utah became eligible in FY 2009.
[c] Uncommitted funds in FY 2010 and FY 2011 will be competed among all EPSCoR states.

	FY 2009	FY 2010	FY 2011
(dollars in thousands)			
▪ **Synthesis and Processing Science**	**19,473**	**22,220**	**32,764**

This activity supports basic research for developing new techniques to synthesize 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 materials 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 of this activity 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. Capital equipment funding is provided for crystal growth apparatus, heat treatment furnaces, lasers, chemical vapor deposition 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 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 2011, research will seek to develop novel design rules for synthesizing nanostructured materials and assemblies for applications including solid-state lighting, solar energy conversion, hydrogen storage and electrical energy storage. Research on advanced materials for electrical energy storage will include studies on the fundamental electrochemical characteristics of nanoscale building blocks with varying size and shape and in confined geometry. The development of new capabilities for synthesis will be emphasized including novel crystal growth techniques that will expand our ability to discover needed materials for advanced energy technologies, as well as to facilitate our understanding of new phenomena in energy generation and transport, including superconductivity, photovoltaics, and energy storage.

▪ **Materials Chemistry and Biomolecular Materials**	**52,373**	**52,265**	**63,461**

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 exploratory 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 scanning probe 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 2011, 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 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. Expanded research to understand carbon capture phenomena will be initiated, including investigation of novel chemical and biomimetic approaches for efficient carbon capture and release. Kinetics for both carbon capture and release will be investigated in environments that include the contaminants found in flue gases. Nanoscale hybrid materials and advances in the understanding 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. In addition, an increased emphasis will be on bio-inspired materials discovery—linking physical and chemical synthesis with the synthesis strategies of biology, which can be extended to create new materials *in vitro* with altered morphologies and desired materials properties. Biological self-assembly occurs on both spatial and temporal scales, controlled to provide function that can change dynamically. In addition, biological self-assembly can be reversible and result in complex structures that are far from equilibrium, opening new avenues to materials with emergent behaviors. The challenge is to understand the biological self-assembly and translate these into new methods for physical and chemical growth of materials.

	FY 2009	FY 2010	FY 2011
▪ **Energy Frontier Research Centers (EFRCs)[a]**	**58,000**	**58,000**	**78,000**

The 46 EFRCs established in late FY 2009 are multi-investigator and multi-disciplinary centers that foster, encourage, and accelerate basic research to provide the basis for transformative energy technologies of the future.[b] The EFRCs represent an important new research modality for BES, bringing 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. The scope and unique nature of the EFRC program requires special oversight, which is accomplished through a BES-wide, dedicated EFRC management team.

[a] A complimentary set of EFRCs is also included in the Chemical Sciences, Geosciences, and Energy Biosciences subprogram. This set includes ongoing EFRCs as well as new awards to be initiated in FY 2011.
[b] 16 of the 46 EFRCs were forward funded for the five-year initial award period under the American Recovery and Reinvestment Act of 2009.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

This team has the direct management responsibility over all EFRCs and also coordinates EFRC research with the complementary research conducted within the BES core research areas.

This activity supports those EFRCs that are best coordinated with and most suitably complement the ongoing core research activities within the Materials Science and Engineering subprogram. In general terms, these EFRCs are focused on the design, discovery, synthesis, and characterization of novel, solid-state materials that improve the conversion of solar energy and heat into electricity; that improve the conversion of electricity to light; that can be used to improve electrical energy storage; 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; that optimize energy flow to improve energy efficiency; and that are tailored at the atomic level for catalytic activity.

In FY 2011, new EFRCs will be solicited in two categories: discovery and development of new materials that are critical to both science frontiers and technology innovations, and basic research for energy needs in a limited number of areas that are underrepresented in the 46 original EFRC awards.

For the discovery and development of new materials, the emphasis will be on new synthesis capabilities, including advanced crystal growth techniques that will expand our ability to discover new materials for advanced energy technologies, as well as to drive our understanding of new phenomena in energy generation and transport, including superconductivity, photovoltaics, and energy storage. The expansion of synthesis capabilities in the EFRC modality will enable the development of a stronger culture of discovery-based research, and enhance the scientific and intellectual manpower in this critical area for science and technology. BES will foster this community to link the synthesis of materials with experimental research to discover new phenomena and to solve energy-related challenges, as well as integrating materials synthesis with advanced theoretical research to model and predict materials behavior, accelerating the rate of materials discovery.

For research for energy applications, areas of emphasis include: fundamental science of carbon capture, including the rational design of novel materials and separation processes for post-combustion CO_2 capture and fundamental science for advanced nuclear energy systems, e.g., radiation resistant materials in fission and fusion applications. EFRC research will focus on interdisciplinary team approaches to develop the scientific understanding to enable new, low energy routes to carbon capture/release including the discovery of new chemical, bioinspired, and materials approaches. For nuclear energy systems, EFRC research will couple understanding of radiation effects with other extreme conditions and will establish a greater breadth in multiscale modeling of physical behavior at a systems level.

▪ **Energy Innovation Hub—Batteries and Energy Storage**	**0**	**0**	**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; 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 affect 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.

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.
- 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.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

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

▪ **General Plant Projects (GPP)**	**4,243**	**3,757**	**0**

GPP funding is provided for the Stanford Institute for Materials and Energy Sciences (SIMES) project. This GPP project will renovate space for SIMES. Phase I prepares currently vacant space in Building 40 for build-out by upgrading the area to current ADA compliance and construction of common space. Phase II builds out the SIMES laboratories and renovates SIMES office and interaction space in Building 40. The TEC for this project is $8,000,000. No funds are requested in FY 2011.

▪ **Electron-beam Microcharacterization**	**11,313**	**0**	**0**

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).

Beginning in FY 2010, this research is budgeted for in a separate subprogram, within the Basic Energy Sciences program, entitled “Scientific User Facilities.”

▪ **Accelerator and Detector Research**	**9,794**	**0**	**0**

This activity supports basic research in accelerator physics and x-ray and neutron detectors. Accelerator research is the corner stone for the development of new technologies that will improve performance of our light sources and neutron spallation facilities. This research will explore new areas of science and technologies that will facilitate the construction of our next generation accelerator-based user facilities. Detector research is a crucial, but often overlooked, component in the optimal utilization of our user facilities. This research program is investing aggressively in research leading to a new and more efficient generation of photon and neutron detectors.

Beginning in FY 2010, this research is budgeted for in a separate subprogram, within the Basic Energy Sciences program, entitled “Scientific User Facilities.”

▪ **Spallation Neutron Source Instrumentation I (SING I)**	**12,000**	**0**	**0**

Funds support a Major Item of Equipment to fabricate five instruments for the Spallation Neutron Source (SNS).

Beginning in FY 2010, this research is budgeted for in a separate subprogram, within the Basic Energy Sciences program, entitled “Scientific User Facilities.”

▪ **Spallation Neutron Source Instrumentation II (SING II)**	**7,000**	**0**	**0**

Funds support a Major Item of Equipment to fabricate four instruments to be installed at the SNS.

Beginning in FY 2010, this research is budgeted for in a separate subprogram, within the Basic Energy Sciences program, entitled “Scientific User Facilities.”

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
▪ **Linac Coherent Light Source Ultrafast Science Instruments (LUSI)**	**15,000**	**0**	**0**

Funds support a Major Item of Equipment 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. The project is fully funded as of FY 2009.

Facilities Operations	**689,047**	**0**	**0**

This activity supports the operation of the BES scientific user facilities, which consist of light sources, neutron sources, nanoscience centers, and the Linac Coherent Light Source Free Electron Laser at SLAC.

Beginning in FY 2010, Facilities Operations is budgeted for in a separate subprogram, within the Basic Energy Sciences program, entitled "Scientific User Facilities." The number of users and operating hours for the synchrotron radiation sources and neutron scattering facilities are shown in the Scientific User Facilities subprogram.

▪ **Synchrotron Radiation Light Sources**	**338,755**	**0**	**0**
Advanced Light Source, LBNL	55,728	0	0
Advanced Photon Source, ANL	116,440	0	0
National Synchrotron Light Source, BNL	40,154	0	0
Stanford Synchrotron Radiation Light Source, SLAC	33,412	0	0
Linac Coherent Light Source (LCLS), SLAC	3,000	0	0
Linac for LCLS, SLAC	90,021	0	0
▪ **High-Flux Neutron Sources**	**249,802**	**0**	**0**
High Flux Isotope Reactor, ORNL	58,000	0	0
Intense Pulsed Neutron Source, ANL	4,000	0	0
Manuel Lujan, Jr. Neutron Scattering Center, LANL	11,302	0	0
Spallation Neutron Source, ORNL	176,500	0	0
▪ **Nanoscale Science Research Centers (NSRCs)**	**100,490**	**0**	**0**
Center for Nanophase Materials Sciences, ORNL	19,900	0	0
Center for Integrated Nanotechnologies, SNL/LANL	19,950	0	0

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Molecular Foundry, LBNL	20,000	0	0
Center for Nanoscale Materials, ANL	20,640	0	0
Center for Functional Nanomaterials, BNL	20,000	0	0
Other Project Costs	**27,044**	**0**	**0**

Other Project Costs (OPC) are associated with line-item construction or major item of equipment projects and include all project costs that are not identified as Total Estimated Cost costs. Total Estimated Cost includes project costs incurred after Critical Decision-1 such as costs associated with the acquisition of land and land rights; engineering, design, and inspection; direct and indirect construction/fabrication; and the initial equipment necessary to place the plant or installation in operation. Generally, OPC are costs incurred during the project's initiation and definition phase for planning, conceptual design, research and development, and during the execution phase for research and development, startup and operation. Other Project Costs are always operating funds.

	FY 2009	FY 2010	FY 2011
▪ Advanced Light Source User Support Building, LBNL	4	0	0
▪ Linac Coherent Light Source, SLAC	17,000	0	0
▪ National Synchrotron Light Source-II, BNL	10,000	0	0
▪ Photon Ultrafast Laser and Science and Engineering Building Renovation, SLAC	40	0	0
SBIR/STTR	**0**	**9,538**	**11,236**

In FY 2009, $25,592,000 and $3,071,000 were transferred to the SBIR and STTR programs, respectively. The FY 2010 and FY 2011 amounts shown are the estimated requirements for the continuation of the congressionally mandated SBIR and STTR program.

	FY 2009	FY 2010	FY 2011
Total, Materials Sciences and Engineering	**1,108,351**	**363,642**	**432,663**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($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 (+$1,104,000). No direct funding is planned in FY 2011 for pension payments at ORNL and LBNL (-$3,402,000).	-2,298
▪ **Theoretical Condensed Matter Physics**	
Increased funding is provided for enhanced research to support multi-investigator projects in theory and modeling and simulation.	+709

	FY 2011 vs. FY 2010 ($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.	+4,506
▪ **Physical Behavior of Materials**	
Increased funding is provided for enhanced research on the fundamental science of photon-matter interactions.	+1,146
▪ **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 (+$1,088,000). Increased emphasis will be placed on expansion of ultrafast materials science research to take advantage of new x-ray and neutron sources to perform research on dynamic phenomena in real-time (+$2,500,000).	+3,588
▪ **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.	+657
▪ **Experimental Program to Stimulate Competitive Research (EPSCoR)**	
The FY 2011 decrease is a result of the additional funding provided by Congress in FY 2010 (-$13,103,000); EPSCoR, funding increases at the same rate as BES core research (+$115,000). Additional funds provided in FY 2010 were used, to the extent possible, to fully fund grants and minimize outyear mortgages.	-12,988
▪ **Synthesis and Processing Science**	
Increased funding is provided to develop novel design rules for synthesizing nanostructured materials and assemblies for use-inspired technologies including solid state lighting, solar energy conversion, hydrogen storage, and electrical energy storage.	+10,544
▪ **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 those inspired by biology for new three-dimensional nanostructured architectures that can be precisely tailored for advanced energy storage and novel chemistries and materials for carbon capture.	+11,196

	FY 2011 vs. FY 2010 ($000)
▪ **Energy Frontier Research Centers**	
Increased funding is provided for research in discovery and development of new materials and energy related research topics.	+20,000
▪ **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
▪ **General Plant Projects (GPP)**	
No GPP funding is requested in FY 2011. The SIMES project is complete in FY 2010.	-3,757
Total, Materials Sciences and Engineering Research	**+67,323**
SBIR/STTR	
Increased funding in SBIR/STTR funding because of an increase in total operating expenses.	+1,698
Total Funding Change, Materials Sciences and Engineering	**+69,021**

Chemical Sciences, Geosciences, and Energy Biosciences

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Chemical Sciences, Geosciences, and Energy Biosciences			
Chemical Sciences, Geosciences, and Energy Biosciences Research	281,946	288,978	393,131
SBIR/STTR	0	7,956	10,485
Total, Chemical Sciences, Geosciences, and Energy Biosciences	281,946	296,934	403,616

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 and direct molecular, dynamics, and chemical reactions.

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.

In chemical transformations, research themes include the characterization, control, and optimization of chemistry in many forms, including catalysis; separations and analysis; 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.

The 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 2009 Accomplishments

- *Controlling x-rays with light.* The advent of x-ray free electron lasers and laser-based x-ray sources is enabling a rapidly expanding frontier of ultrafast x-ray science. A central application of these new sources is the visualization of atomic, molecular, and electronic dynamics, as triggered by an ultrafast light pulse, on atomic time and length scales. In such studies, visible light is used to modify the target and x-rays are used to monitor the response. Researchers have demonstrated for the first time that visible light pulses can also be used for a fundamentally different purpose—to control x-ray interactions with matter. Through an effect known as electromagnetically induced transparency, intense visible light can be used to induce transparency in a material that normally is opaque to x-ray radiation due to resonant x-ray absorption. The induced transparency is ultrafast and reversible and functions as an ultrafast x-ray switch. The ability to control x-ray/matter interactions with visible light will create new research opportunities at current and next-generation x-ray light sources. These results will also form a foundation for planned experiments at the Linac Coherent Light Source, in which intense x-rays will be used to both control and probe matter.
- *New tools for understanding interfacial chemistry*. The interactions of atoms and molecules at gas-solid and liquid-solid interfaces are critical in areas including heterogeneous catalysis, electrical energy storage, and solar energy conversion. The study of chemical interactions at surfaces at the molecular level is profoundly difficult because of the small amount of material available for study, the small spatial scales in which the interactions occur, and the ultrafast time scales over which they take place. Recent advances in low-temperature scanning tunneling microscopy (STM) have been combined with temporally and spatially resolved spectroscopic tools such as ultrafast, two-photon photoemission, to enable important new discoveries. New, long-lived electronic surface states have been discovered that could lead to new ways to induce and control electronic excitation at surfaces. Positioning the tip during STM measurements of light emission from single molecules with sub-nanometer resolution yields an unprecedented view of the coupling of electronic and vibrational motion within a single molecule. These new experimental tools are being combined with modern theoretical and computational methods to provide unprecedented capability to predict, monitor, and control the flow of energy and chemical reactivity at interfaces.
- *Understanding the Earth's geochemistry at the nanoscale.* Minerals and mineral composites coexist in the environment with a variety of inorganic and organic molecules, naturally buffering the chemistry of the natural environment. The behavior of water molecules surrounding nanoparticles in subsurface environments is thought to be an important influence on their growth and may account for the strong variation in surface chemistry with particle size. New research demonstrates that the size and shape of mineral particles controls the structure of the first few layers of water on their surfaces, profoundly influencing geochemical reactivity. The residence time of water molecules near the surface is shorter for smaller, less-crystalline nanoparticles than for larger nanoparticles or for the bulk mineral surface. Particles with facets or low curvature tend to preferentially stabilize the water network and in some cases cause faceting within the water layer itself. Molecular dynamics simulations of iron-oxide (hematite) particles show that water ordering around the particle decreases with decreasing particle size. These results show that nanophase structures formed by geochemical reactions can modify the interfacial forces present in aqueous solution near a surface. By mapping these interfacial forces, more sophisticated and accurate models can be developed to understand and

predict processes affecting contaminant immobilization and bacterial attachment on mineral surfaces under natural conditions.

- *Sub-nanometer catalysts are remarkably effective.* Heterogeneous catalysts are central to the conversion of natural resources into about 80% of all chemicals used by humankind. The scarcer and more expensive resources demand attainment of ever higher selectivity and energy efficiency in chemical catalysis, which imposes strict requirements for the control of catalyst structure. A new frontier has recently been achieved through the synthesis of sub-nanometer metal particles (clusters) containing only a few atoms that maintain their size throughout the stages of a chemical reaction, which is critical to attaining high activity and selectivity. Cluster size stability was achieved through delicate control over the structure of and reaction with the catalyst support, typically a mixed metal oxide. Clusters containing only 8–10 atoms of platinum bound to aluminum oxide films display 40–100 times higher catalytic activity and thousands time more chemical selectivity than conventional catalysts. Achieving this feat required synergistic efforts in the synthesis of atomically-layered, ordered oxides, leaving reaction sites open to bind certain metal clusters; soft landing and reaction of metal clusters of the selected size; synchrotron x-ray diagnostics to demonstrate cluster stability; and quantum chemical calculations for the prediction of catalytic activity as a function of cluster size.

- *New promise for plastic solar cells*. Plastic solar cells hold great promise for the conversion of solar energy into electricity because they are flexible, lightweight, inexpensive, and made from abundant organic materials. But current plastic solar cells have poor conversion efficiencies. New research on the polymers in plastic solar cells has revealed that the speed of electron transport and excitation diffusion through the polymer is much faster than was previously assumed. The new experiments used pulsed radiolysis to place electrons at the end of polymer chain tens of nanometers in length and then monitored the time it took for the electron or excitation to fall into a trap at the end of the chain. The results showed that electrons and optical excitations created in the polymers can wend their way through the chains in a matter of 10^{-10} seconds. Current, low-efficiency plastic solar cells are designed and engineered with the assumption that this transport of charge and energy down the polymer is intrinsically much slower. The discovery of more rapid transport paves the way toward more efficient plastic solar cells.

- *Nature's most efficient light harvesting system revealed.* Certain photosynthetic bacteria have evolved a sophisticated antenna complex, called the chlorosome, which allows them to thrive in an extremely light-limited environment. Unlike other natural antenna systems, chlorosomes lack a protein matrix supporting the photosynthetic pigments of up to 250,000 individual chlorophyll molecules. Structural analysis shows that the chlorophyll molecules inside the chlorosome are arranged as densely packed nanotubes in helical spirals. A recent study of the antenna protein that transfers energy absorbed by the chlorosome to the main photosynthetic reaction center determined that the protein is oriented so that the side containing the pigment with the lowest potential energy is nearest to the reaction center, consistent with theoretical predictions. These studies have begun to reveal how chlorophyll organization and chlorosome structure can increase the efficiency of photosynthesis. The relatively simple interactions between chlorophylls in the chlorosome provide promising new leads for the rational design of artificial photosynthetic systems. Similarly, the increased understanding of how energy transfer occurs through the relay protein from the antenna to the reaction centers may lead to new approaches for funneling energy through artificial photosynthetic systems.

Detailed Program Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Chemical Sciences, Geosciences, and Energy Biosciences Research	**281,946**	**288,978**	**393,131**
▪ **Atomic, Molecular, and Optical Science**	**25,129**	**22,717**	**26,118**

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 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.

In FY 2011, there is an increase for the development and application 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.

▪ **Chemical Physics Research**	**47,658**	**53,509**	**75,632**

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 coupling of complex chemistry and turbulent flow has long challenged predictive combustion 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 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 2011, a significant effort will be initiated in the area of multiscale models for advanced engine design. High-fidelity models of combustion processes will be critical to enabling the transition from hardware-intensive, experience-based engine design to simulation-intensive, science-based design, accommodating new fuel types and engine combustion systems. Scientific challenges posed by advanced engine systems include complex interactions among multiphase fluid mechanics, thermodynamic properties, heat transfer, and chemical kinetics over a vast range of spatial and temporal scales. Numerical and algorithm advances will be required to develop new combustion models that exploit the capabilities of the most advanced large-scale computers. Successful resolution of these scientific and computational challenges would provide new fundamental understanding of, and models for, the conditions and fuels that will be relevant for next-generation engines (+$20,000,000). In FY 2011, there will also 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.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
▪ **Solar Photochemistry**	**38,385**	**36,985**	**38,453**

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 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.

In FY 2011, continued emphasis will be placed on studies of semiconductor/polymer interfaces, multiple charge generation within semiconductor nanoparticles, dye-sensitized solar cells, inorganic/organic donor-acceptor molecular assemblies, and the use of nanoscale materials in solar photocatalytic generation of chemical fuels. This activity also includes funding for the U.S.-India Clean Energy Research Center.

▪ **Photosynthetic Systems**	**16,809**	**18,499**	**19,233**

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 2011, 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.

	FY 2009	FY 2010	FY 2011
▪ **Physical Biosciences**	**16,148**	**17,780**	**18,486**

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.

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 2011, 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 2011, 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.

	FY 2009	FY 2010	FY 2011
▪ **Catalysis Science**	**42,401**	**46,603**	**48,510**

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-

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

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, and 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 2011, 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 sites. Research on catalytic cycles involved in electrochemical energy storage and solar photocatalytic fuel formation will receive increased emphasis.

	FY 2009	FY 2010	FY 2011
▪ **Separations and Analysis**	**17,150**	**15,881**	**16,511**

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 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 2011, separations research will focus on fluid flow in nanoscale membranes and the formation of macroscopic separation systems via self-assembly of nanoscale building blocks. Special additional emphasis will be placed on the development of new materials and methods for separation and capture of CO_2 from post-combustion gas streams and oxygen from air prior to oxy-combustion. Research will include experimental and theoretical/computational studies of how weak intermolecular forces can be understood and controlled to achieve separations with high selectivity and capture with only modest energy requirements for subsequent release. Chemical analysis research will emphasize the development of techniques with high spatial, temporal, and chemical resolution; and simultaneous application of multiple analytical techniques.

	FY 2009	FY 2010	FY 2011
▪ **Heavy Element Chemistry**	**11,033**	**11,729**	**12,195**

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 determining 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 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 2011, 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.

	FY 2009	FY 2010	FY 2011
▪ **Geosciences Research**	**22,028**	**22,432**	**50,839**

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

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

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 2011, new research will be initiated in theory, multi-scale modeling, and field/experimental investigations of the geochemistry and geophysics of CO_2—rock/mineral interactions and other related topics (+$5,000,000). Additional research will support high-resolution geophysical and geochemical investigations. The objective will be to develop robust, broadly applicable measurement approaches to verify the effectiveness of CO_2 sequestration and other geological greenhouse gas mitigation measures. Specific emphasis will be on physical and chemical approaches for measuring properties and concentrations of chemical species in large-scale systems. The research will produce new tools and techniques that derive from longstanding BES capabilities in optical and physico-chemical diagnostics related to geosciences (+$5,000,000). In FY 2011 emphasis will also 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 the ability to integrate multiple data types in predictions of subsurface processes and properties.

In FY 2011, Basic Energy Sciences will initiate a new research program in gas hydrates (+$17,517,000). Gas hydrates are naturally occurring combinations of methane and water that form at low temperatures and high pressure. This program will study fundamental scientific questions surrounding methane hydrates: How do they form? What is their role in the global carbon cycle? What is their role in seafloor ecological systems? How extensive are they? How stable are they? For the next 24 months, the program will also study hydrates via controlled *in situ* depressurization and physical, thermal, and chemical stimulation in the Arctic with supporting laboratory and numerical modeling to enable interpretation and extrapolation of results. Existing core sample data from the Arctic hydrate formations will provide the scientific information of how the hydrate structure sits in the pore space at various depths. The planned tests in the Gulf of Mexico in FY 2011 will take *in situ* core samples at various depths and locations for evaluation. Computer simulations will be compared with data from previous *in situ* tests. This activity will also support theory, multi-scale modeling and

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

simulation, and experimental research in areas such as the intermolecular forces that govern the structure and properties of gas hydrates and studies of gas hydrates in the natural environment.

▪ **Energy Frontier Research Centers (EFRCs)[a]**	**42,000**	**42,000**	**62,000**

The 46 EFRCs established in late FY 2009 are multi-investigator and multi-disciplinary centers that foster, encourage, and accelerate basic research to provide the basis for transformative energy technologies of the future.[b] The EFRCs represent an important new research modality for BES, bringing 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. The scope and unique nature of the EFRC program requires special oversight, which is accomplished through a BES-wide, dedicated EFRC management team. This team has the direct management responsibility over all EFRCs and also coordinates EFRC research with the complementary research conducted within the BES core research areas.

This activity supports those EFRCs that are best coordinated with and most suitably complement the ongoing core research activities within the Chemical Sciences, Geosciences and Energy Biosciences subprogram. In general terms, these EFRCs are focused on the design, discovery, synthesis, and characterization of novel, solid-state materials that improve the conversion of solar energy and heat into electricity; that improve the conversion of electricity to light; that can be used to improve electrical energy storage; 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; that optimize energy flow to improve energy efficiency; and that are tailored at the atomic level for catalytic activity.

In FY 2011, new EFRCs will be solicited in two categories: discovery and development of new materials that are critical to both science frontiers and technology innovations and basic research for energy needs in a limited number of areas that are underrepresented in the 46 original EFRC awards.

For the discovery and development of new materials, the emphasis will be on new synthesis capabilities, particularly bio-inspired approaches, to establish a strong foundation for science-driven materials discovery and synthesis in the U.S. Emphasis will be placed on understanding the mechanisms by which biological systems manipulate and exchange energy and information on the nanoscale. Such information can then be used as the basis for the design and synthesis of purely artificial or bio-hybrid materials with functionalities that rival their biological counterparts. One critical application area is the development of bio-inspired catalytic materials. Lessons learned from biological catalysts, including their ability to fine tune catalytic function based on subtle, dynamic changes in the structural and electronic properties of the catalytic site, will be used to design and synthesize purely artificial or bio-hybrid catalytic materials.

For research for energy applications, areas of emphasis include fundamental science of carbon capture, including the rational design of novel materials and separation processes for post-combustion CO_2 capture and catalysis and separation research for advanced carbon capture schemes

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[a] A complimentary set of EFRCs is also included in the Materials Sciences and Engineering subprogram. This set includes ongoing EFRCs as well as new awards to be initiated in FY 2011.
[b] 16 of the 46 EFRCs were forward funded for the five-year initial award period under the American Recovery and Reinvestment Act of 2009.

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

in new power plants, and fundamental science for advanced nuclear energy systems, e.g., separation science and heavy element chemistry for fuel cycles. Advances in post-combustion CO_2 capture require experimental and theoretical/computational studies of how weak intermolecular forces can be understood and controlled to enable the design of capture materials and methods that are highly selective to CO_2 versus nitrogen but that release the captured CO_2 with minimum energy penalty. Carbon capture schemes for new power plants require research into efficient and cheaper ways of separating oxygen from air for oxy-combustion and new catalytic routes for the conversion of fossil feedstocks and biomass into cleaner burning fuels. Fundamental science for advanced nuclear fuel cycles includes 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. Complementary emphasis will be placed on the separation and analysis of molecular species containing transuranic isotopes and their radioactive decay products, which is required to characterize and treat extremely complex radioactive mixtures in new nuclear fuel systems.

	FY 2009	FY 2010	FY 2011
▪ **Energy Innovation Hub—Fuels from Sunlight**	**0**	**0**	**24,300**

After nearly 3 billion years of evolution, nature can effectively convert sunlight into energy-rich chemical fuels using the abundant feedstocks of water and carbon dioxide. All fuels used today to power vehicles and create electricity, whether from fossil or biomass resources, are ultimately derived from photosynthesis. While biofuels are renewable resources that avoid the environmental consequences of burning the sequestered carbon of fossil fuels, their scalability and sustainability are ongoing issues. Furthermore, the overall energy efficiency of converting sunlight to plant material and then converting biomass into fuels is low. The natural photosynthetic apparatus is a remarkable machine, but plants and photosynthetic microbes were not designed to meet human energy needs—much of the energy captured from the sun is necessarily devoted to the life processes of the plants. Imagine the potential energy benefits if we could generate fuels directly from sunlight, carbon dioxide, and water in a manner analogous to the natural system, but without the need to maintain life processes. The impact of replacing fossil fuels with fuels generated directly by sunlight would be immediate and revolutionary. Recognizing this, the BESAC report, *New Science for Secure and Sustainable Energy Future*, the production of fuels directly from sunlight as one its three strategic goals for which transformational science breakthroughs are urgently needed.

Basic research has already provided enormous advances in our understanding of the subtle and complex photochemistry associated with the natural photosynthetic system. Similar advances have occurred using inorganic photo-catalytic methods to split water or reduce carbon dioxide. Yet, we still lack sufficient knowledge to design solar fuel generation systems with the required efficiency, scalability, and sustainability for economic viability. The Fuels from Sunlight Hub will develop an effective solar energy to chemical fuel conversion system. The system should operate at an overall efficiency and produce fuel of sufficient energy content to enable transition from bench-top discovery to proof-of-concept prototyping. The magnitude of this challenge is daunting, but not insurmountable, and will require that this Hub draw expertise and premier scientific talent from the disciplines of chemistry, physics, materials sciences, biology, and engineering. Critical issues to be addressed include: understanding and designing catalytic complexes or solids that generate

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

chemical fuel from carbon dioxide and/or water; integration of all essential elements from light capture to fuel formation into an effective solar fuel generation system; and pragmatic evaluation of the solar fuel system under development.

The Fuels from Sunlight Hub was initiated in FY 2010 with $22,000,000 provided through the Office of Energy Efficiency and Renewable Energy. SC/BES provides programmatic oversight for the Fuels from Sunlight Hub, including management of the solicitation and its merit review process, and coordination with the two other Energy Innovation Hubs initiated in FY 2010 – Modeling and Simulation for Nuclear Reactors in the Office of Nuclear Energy and Energy Efficient Building Systems Design in the Office of Energy Efficiency and Renewable Energy. In FY 2011, BES will provide funding for the continuation of the Fuels from Sunlight Hub.

▪ **General Plant Projects (GPP)**	**3,205**	**843**	**854**

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 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 $5,000,000 in FY 2011.

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.

SBIR/STTR	**0**	**7,956**	**10,485**

In FY 2009, $6,736,000 and $808,000 were transferred to the SBIR and STTR programs, respectively. The FY 2010 and FY 2011 amounts shown are the estimated requirements for the continuation of the congressionally mandated SBIR and STTR programs.

Total, Chemical Sciences, Geosciences, and Energy Biosciences	**281,946**	**296,934**	**403,616**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Chemical Sciences, Geosciences, and Biosciences Research	
▪ **Atomic, Molecular and Optical Science**	
Increased funding is provided for the development and application of new ultrafast x-ray and optical probes of matter (+$2,500,000), and on theoretical and computation methods for interpretation of ultrafast measurements and on the use of optical fields to control and manipulate quantum mechanical systems (+$901,000).	+3,401

	FY 2011 vs. FY 2010 ($000)
▪ **Chemical Physics Research**	
Increased funding is provided to initiate a significant effort in the area of multiscale models for advanced engine design (+$20,000,000). Increased funding is also provided for additional emphasis on experimental, theoretical, and computational research aimed at developing predictive models for clean and efficient combustion of biofuels and alternative fossil fuels (+$2,123,000).	+22,123
▪ **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.	+1,468
▪ **Photosynthetic Systems**	
Increased funding is provided for solar energy conversion in biological and bio-hybrid systems and enhanced efforts in understanding defect tolerance and self-repair in natural photosynthetic systems.	+734
▪ **Physical Biosciences**	
Increased funding is provided for probing the organizational principles of biological energy transduction and chemical storage systems using advanced molecular imagining and x-ray or neutron methods for structural determination.	+706
▪ **Catalysis Science**	
Increased funding is provided for 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.	+1,907
▪ **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.	+630
▪ **Heavy Element Chemistry**	
Increased funding is provided for enhanced efforts on actinide chemistry and separations science related to advanced nuclear energy systems.	+466
▪ **Geosciences Research**	
Increased funding is provided for new research to improve understanding of the chemistry and physics of potential geophysical controls that could be used to modify effects induced by greenhouse gases (+$5,000,000) and for additional research to support high-resolution geophysical and geochemical investigations (+$5,000,000). Increased funding is also provided for continuing research in solid earth geophysics and geochemistry ($+890,000). In addition, funding is provided for the new gas hydrates research program (+$17,517,000).	+28,407

	FY 2011 vs. FY 2010 ($000)
▪ **Energy Frontier Research Centers**	
Increased funding is provided for research in discovery and development of new materials and energy related research topics.	+20,000
▪ **Energy Innovation Hub—Fuels from Sunlight**	
Funds are provided for an Energy innovation Hub focused on making fuels from sunlight. The Hub will develop a solar fuel conversion system that completely bypasses plants as the medium, drawing from the disciplines of chemistry physics, materials sciences, biology, and engineering.	+24,300
▪ **General Plant Projects (GPP)**	
Small increase for general plant projects.	+11
Total, Chemical Sciences, Geosciences and Energy Biosciences Research	**+104,153**
SBIR/STTR	
Increased funding for SBIR/STTR because of increase in operating expenses.	+2,529
Total Funding Change, Chemical Sciences, Geosciences, and Energy Biosciences	**+106,682**

Scientific User Facilities

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Scientific User Facilities			
Research	0	32,525	27,339
Major Items of Equipment	0	25,000	22,400
Facilities Operations	0	730,621	775,823
Other Project Costs	0	13,500	1,500
SBIR/STTR	0	20,038	20,059
Total, Scientific User Facilities	0[a]	821,684	847,121

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 provides 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 a very wide range of photon energies (from the infrared to hard x-rays), 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, assemble, 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 the 1990s to over 40% in 2009. 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] FY 2009 funding of $771,198,000 for Scientific User Facilities is located within the Materials Sciences and Engineering subprogram.

Selected FY 2009 Accomplishments

- *Advanced Photon Source Develops Non-Destructive Tool for Tomography.* The research technique known as synchrotron-radiation computed laminography (SRCL) has been developed at the Advanced Photon Source for surface tomography characterization. The SRCL overcomes the limitation of standard synchrotron-radiation computed tomography, which restricts the lateral dimension of an object to be studied or requires that a sample be cut from the subject. It allows high-resolution, non-destructive three-dimensional imaging of objects, such as imaging fossil specimens for paleontological studies. Due to the complex geological and environmental processes involved, many fossils exhibit laterally-extended structures. Traditionally, this type of fossil is sectioned and imaged utilizing scanning electron microscopy or visible-light microscopes. The specimens are, however, unavoidably destroyed after inspection. The successful application of this technique opens the door to the non-destructive study of laterally-extended fossils. SRCL also finds application in imaging dimensionally long objects, including printed circuit boards, a wide range of microelectronics, and the efficacy of industrial welds and solders.
- *Top-off Operation at Advanced Light Source Achieves High Current and Stable Beam.* The Advanced Light Source has recently completed a successful upgrade, making top-off operation available to user service. The top-off operational mode allows frequent injection of electron beam into the storage ring, resulting in an almost constant current while keeping the beam accessible to users at all times. This mode presents several important advantages for users. Instead of having multiple injections of a large number of electrons in a short time period followed by uninterrupted beam decay over the course of 8 hours, a small number of electrons are added to the storage ring approximately every 30–60 seconds. The near-constant beam current enhances the flux and brightness of the radiation while simultaneously improving the thermal stability of the machine and its beamlines. Compared with pre-top-off operation, top-off mode achieves a current level of 500 mA, which doubles the time-averaged current and increases the photon flux by a factor of two.
- *Nanoparticle Research at Molecular Foundry Yields Promising Results for Energy Applications.* Researchers at the Molecular Foundry have produced for the first time non-toxic magnesium oxide nanocrystals that efficiently emit blue light and could also play a role in long-term storage of carbon dioxide, a potential means of tempering the effects of global warming. This bright blue luminescence upon exposure to ultraviolet light could be an inexpensive, attractive alternative in applications such as bio-imaging or solid-state lighting. Efficient blue light emitters are difficult to produce, suggesting these magnesium oxide nanocrystals could be a bright candidate for lighting that consumes less energy and has a longer lifespan. Along with their promising optical behavior, these nanocrystals will allow researchers to probe a key pathway in carbon dioxide capture and storage. If properly stored, captured carbon dioxide pumped underground forms carbonate minerals with the surrounding rock by reacting with nanoparticles of magnesium oxide and other mineral oxides; these nanocrystals will provide a model system to mimic this process.
- *New Technique Developed at Center for Functional Nanomaterials (CFN) for Nanostructure Fabrication.* The unique phenomena that emerge when nanoscale objects, such as gold nanoparticles or quantum dots, are arranged in small clusters offer great opportunities for energy-related applications. Unfortunately, conventional solution-based reaction methods are quite limited and inefficient, e.g., producing clusters with a broad distribution of sizes and compositions. CFN researchers have developed a novel method for producing dimmers of DNA-encoded nanoparticles with remarkably high yields. The method, which incorporates two different DNA strands on a single nanoparticle, was employed to assemble both homogenous (gold-gold) and heterogeneous (gold-

silver) nanoparticle dimmers with novel nanoscale optical properties. Because this method is scalable to large quantities with more complex cluster arrangements, it may become a practical way of inexpensively fabricating predictable and reliable nanostructures with customized properties.

- *Spallation Neutron Source Set Another World Record*. On July 11, 2009, SNS researchers set a new world record by creating 155 trillion protons in a single pulse and delivering that pulse to the SNS mercury target. This test exceeds the SNS design intensity of 150 trillion protons in a pulse. If pulses of this intensity were delivered to the SNS target at the design repetition rate of 60 pulses per second, it would provide a beam power of 1.5 megawatts—0.1 megawatts more than the design beam power of 1.4 megawatts. The SNS facility has already been operated at close to the megawatt level. The test, performed at a rate of less than one pulse per second, confirms that the SNS linear accelerator and accumulator ring—two vital components that supply the proton beam pulses—will meet and exceed the 1.4 megawatt design criteria.
- *New Technique Developed at Electron Microscopy Center.* Magnetic structure in discrete particles and complex assemblages is important in a variety of fields, particularly information storage technologies. A new approach to characterize such structures has been developed, based on the energy losses of high-energy electrons when they traverse a material and interact with spin-charge structures. The technique, electron magnetic linear dichroism, has been demonstrated by mapping the temperature and angular dependence of the signal in hematite, a form of iron oxide. The approach complements similar linear dichroism approaches that have been developed and utilized at synchrotron x-ray facilities; data quality is comparable, and the new technique extends the spatial resolution of the information into the nanoscale.

Detailed Program Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Research	**0**	**32,525**	**27,339**
▪ **Electron-beam Microcharacterization**	**0**	**11,571**	**11,809**

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 2009	FY 2010	FY 2011

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 2011, full user operations continue at all three of these facilities, which are routinely available to users during normal working hours. The Transmission Electron Aberration Corrected Microscope (TEAM) instrument at the National Center for Electron Microscopy at LBNL will, in addition, be available to the research community 24 hours a day. This instrument was developed as a DOE Major Item of Equipment project and completed in FY 2009. It 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.

In FY 2009, $11,313,000 was provided for this activity in the Materials Sciences and Engineering Research Subprogram.

	FY 2009	FY 2010	FY 2011
▪ **Accelerator and Detector Research**	**0**	**13,061**	**15,530**

This activity supports basic research in accelerator physics and x-ray and neutron detectors. Accelerator research is the corner stone for the development of new technologies that will improve performance of light sources and neutron spallation facilities. This research will explore new areas of science and technologies that will facilitate the construction of next generation accelerator-based user facilities. Detector research is a crucial, but often overlooked, component in the optimal utilization of user facilities. This research program is investing aggressively in research leading to a new and more efficient generation of photon and neutron detectors. Research includes studies on creating, manipulating, transporting, and diagnosing ultra-high brightness beam behavior from its origin at a photocathode to its travel through undulators. Studies on achieving sub-femtosecond (hundreds of attoseconds) free electron laser (FEL) pulses will also be underway. Demonstration experiments will take place in advanced FEL seeding techniques, such as echo-enhanced harmonic generation and other optical manipulation to reduce the cost and complexity of seeding harmonic generation FELs. A very high frequency laser photocathode radio frequency (RF) gun using a room temperature cavity will be developed which can influence the design of linac-based FELs with megahertz rates. Research will also occur on construction and beam testing of a high current, high gradient compact superconducting linac which can serve as a prototype for future light sources. Studies will continue on 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 x-ray and neutron scattering 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

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

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 the DOE Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR) programs for the development of x-ray detectors and advanced accelerator technology.

Additional funds provided in FY 2011 will increase selected R&D activities related to light sources. These include the physics of gain mechanisms in 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.

In FY 2009, $9,794,000 was provided for this activity in the Materials Sciences and Engineering Research Subprogram.

▪ **General Plant Projects (GPP)**	**0**	**7,893**	**0**

GPP funding is provided in FY 2010 for the ORNL Guest House. The Guest House is designed to meet the needs of the guest users coming to perform research at ORNL's world class DOE scientific user facilities (SNS, CNMS, HFIR, SHaRE, etc.). No funds are requested in FY 2011.

Major Items of Equipment	**0**	**25,000**	**22,400**
▪ **Spallation Neutron Source Instrumentation I (SING I)**	**0**	**5,000**	**400**

Funds are provided to complete 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.

In FY 2009, $12,000,000 was provided for this activity in the Materials Sciences and Engineering Research Subprogram.

▪ **Spallation Neutron Source Instrumentation II (SING II)**	**0**	**18,000**	**17,000**

Funds are provided to continue 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 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 2012. The SING II instruments are in addition to the five instruments to be provided by the SING I MIE. The TPC is now approved at the Approve Performance Baseline, CD-2, for three of the four instruments. The FY 2011 request is to complete engineering design of the final instrument and to continue fabrication of the others.

In FY 2009, $7,000,000 was provided for this activity in the Materials Sciences and Engineering Research Subprogram.

	FY 2009	FY 2010	FY 2011
▪ **SNS Power Upgrade Project (PUP)**	**0**	**2,000**	**5,000**

(dollars in thousands)

Funds are provided for a Major Item of Equipment with a preliminary Total Project Cost range of $89,600,000–$96,100,000 for activities to design, build, install, and test the equipment necessary to increase the Spallation Neutron Source (SNS) proton beam energy. CD-1 was approved on January 16, 2009. 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.

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 is the first year of funding for this project. The FY 2011 request supports engineering design of the accelerator sub-systems and project management.

Facilities Operations	**0**	**730,621**	**775,823**

This activity supports the operation of the BES scientific user facilities, which consist of light sources, neutron sources, nanoscience centers, and the Linac Coherent Light Source free electron laser 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, 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 2000–2009, 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 2011, operation of these scientific user facilities is funded at a level that will permit near optimal service to users. Additional funds are provided in FY 2011 for the first year of full operation of the LCLS at SLAC 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, user support and instrumentation to upgrade beamlines at these facilities. Increases in the NSRC budgets reflect full functionality and staffing of the five NSRCs. Other project costs are provided for 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.

In FY 2009, $689,047,000 was provided for this activity in the Materials Sciences and Engineering Research Subprogram.

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

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 to maintain optimal operation at the facilities. Items include beam monitors, interlock systems, vacuum systems, beam line front end components, optical components, and new equipment at the NSRCs. A summary of the funding for the facilities is provided below.

	FY 2009	FY 2010	FY 2011
All Facilities			
Achieved Operating Hours	30,995	N/A	N/A
Planned Operating Hours	31,800	34,000	38,000
Optimal Hours	34,000	34,000	39,000
Percent of Optimal Hours	91%	100%	97%
Unscheduled Downtime	6%	<10%	<10%
Number of Users	11,509	12,780	13,560

▪ **Synchrotron Radiation Light Sources**	**0**	**366,974**	**403,613**
Advanced Light Source, LBNL	0	58,000	62,716
Advanced Photon Source, ANL	0	129,500	139,651
National Synchrotron Light Source, BNL	0	40,200	41,170
Stanford Synchrotron Radiation Light Source, SLAC	0	34,774	37,076
Linac Coherent Light Source (LCLS), SLAC	0	10,500	123,000
Linac for LCLS, SLAC	0	94,000	0

The unique properties of synchrotron radiation include its continuous spectrum, high flux and brightness, and in the case of the Linac Coherent Light Source, high coherence, which makes 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.

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

In FY 2011 funds are provided to continue operations of the synchrotron radiation light sources. Additional funding is provided in FY 2011 for research and development associated with improvements in the Advanced Photon Source storage ring for future performance enhancement. In addition, funds are provided for research and development, leading to new and improved scattering beam lines for the 3rd generation light sources. The budget also reflects a significant increase in the beam line and accelerator operations hours as well as user support at the LCLS as it ramps up its user program in its first full year of operations. Increased funding is also provided for instrumentation to upgrade BES beamlines at the light source facilities. Capital equipment is needed at the facilities for items such as beam monitors, interlock systems, vacuum transport systems, beamline front ends, optical components and detectors.

In FY 2009, $338,755,000 was funded in the Materials Sciences and Engineering Research subprogram as follows: $55,728,000 at the Advanced Light Source, LBNL; $116,440,000 at the Advanced Photon Source, ANL; $40,154,000 at the National Synchrotron Light Source, BNL; $33,412,000 at the Stanford Synchrotron Radiation Light Source, SLAC; $3,000,000 at the Linac Coherent Light Source (LCLS), SLAC; and $90,021,000 at the Linac for LCLS, SLAC.

	FY 2009	FY 2010	FY 2011
Advanced Light Source			
Achieved Operating Hours	5,278	N/A	N/A
Planned Operating Hours	5,400	5,600	5,600
Optimal Hours	5,600	5,600	5,600
Percent of Optimal Hours	94%	100%	100%
Unscheduled Downtime	3.5%	<10%	<10%
Number of Users	1,918	2,200	2,300
Advanced Photon Source			
Achieved Operating Hours	4,883	N/A	N/A
Planned Operating Hours	4,800	5,000	5,000
Optimal Hours	5,000	5,000	5,000
Percent of Optimal Hours	98%	100%	100%
Unscheduled Downtime	2.3%	<10%	<10%
Number of Users	3,537	3,700	3,800

			(dollars in thousands)
	FY 2009	FY 2010	FY 2011

	FY 2009	FY 2010	FY 2011
National Synchrotron Light Source			
Achieved Operating Hours	5,499	N/A	N/A
Planned Operating Hours	5,200	5,400	5,400
Optimal Hours	5,400	5,400	5,400
Percent of Optimal Hours	102%	100%	100%
Unscheduled Downtime	2.6%	<10%	<10%
Number of Users	2,214	2,200	2,200
Stanford Synchrotron Radiation Light Source			
Achieved Operating Hours	5,050	N/A	N/A
Planned Operating Hours	5,000	5,400	5,400
Optimal Hours	5,400	5,400	5,400
Percent of Optimal Hours	94%	100%	100%
Unscheduled Downtime	1%	<10%	<10%
Number of Users	1,361	1,400	1,400
Linac Coherent Light Source			
Achieved Operating Hours	0	0	N/A
Planned Operating Hours	0	0	4,000
Optimal Hours	0	0	5,000
Percent of Optimal Hours	0	0	80%
Unscheduled Downtime	0	0	<10%
Number of Users	0	0	250

▪ **High-Flux Neutron Sources**	**0**	**258,980**	**262,736**
High Flux Isotope Reactor, ORNL	0	60,700	61,390
Intense Pulsed Neutron Source, ANL	0	4,000	3,000
Manuel Lujan, Jr. Neutron Scattering Center, LANL	0	11,350	11,821
Spallation Neutron Source, ORNL	0	182,930	186,525

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 materials.

In FY 2011 funds are provided to continue operations of the neutron sources. Additional funds are provided in FY 2011 for new operating beamlines at the Spallation Neutron Source and the High Flux Isotope Reactor at ORNL. The Intense Pulsed Neutron Source is closed and funds are provided to continue decommissioning of the target assembly.

In FY 2009, $249,802,000 was funded in the Materials Sciences and Engineering Research subprogram as follows: $58,000,000 at the High Flux Isotope Reactor, ORNL; $4,000,000 at the Intense Pulsed Neutron Source, ANL; $11,302,000 at the Manuel Lujan, Jr. Neutron Scattering Center, LANL; and $176,500,000 at the Spallation Neutron Source, ORNL.

	FY 2009	FY 2010	FY 2011
High Flux Isotope Reactor			
Achieved Operating Hours	3,892	N/A	N/A
Planned Operating Hours	3,900	4,500	4,500
Optimal Hours	4,500	4,500	4,500
Percent of Optimal Hours	86%	100%	100%
Unscheduled Downtime	0%	<10%	<10%
Number of Users	358	500	600
Manuel Lujan, Jr. Neutron Scattering Center			
Achieved Operating Hours	2,840	N/A	N/A
Planned Operating Hours	3,500	3,600	3,600
Optimal Hours	3,600	3,600	3,600
Percent of Optimal Hours	79%	100%	100%
Unscheduled Downtime	18.1%	<10%	<10%
Number of Users	416	400	400
Spallation Neutron Source			
Achieved Operating Hours	3,553	N/A	N/A
Planned Operating Hours	4,000	4,500	4,500
Optimal Hours	4,500	4,500	4,500
Percent of Optimal Hours	79%	100%	100%
Unscheduled Downtime	19.5%	<10%	<10%
Number of Users	307	700	750

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
▪ **Nanoscale Science Research Centers (NSRCs)**	**0**	**104,667**	**109,474**
Center for Nanophase Materials Sciences, ORNL	0	20,641	21,595
Center for Integrated Nanotechnologies, SNL/LANL	0	20,790	21,748
Molecular Foundry, LBNL	0	20,833	21,792
Center for Nanoscale Materials, ANL	0	21,570	22,547
Center for Functional Nanomaterials, BNL	0	20,833	21,792

The NSRCs are DOE's premier user centers for interdisciplinary research at the nanoscale, serving as the basis for a national program that encompasses new science, new tools, and new computing capabilities. Each center has particular expertise and capabilities in selected theme areas, such as synthesis and characterization of nanomaterials; catalysis; theory, modeling and simulation; electronic materials; nanoscale photonics; soft and biological materials; imaging and spectroscopy; and nanoscale integration. The centers are housed in recently-constructed and custom-designed laboratory buildings near one or more other major BES facilities for x-ray, neutron, or electron scattering, which complement and leverage the capabilities of the NSRCs.
These laboratories contain clean rooms, nanofabrication resources, one-of-a-kind signature instruments, and other instruments not generally available except at major user facilities. These facilities are routinely made available to the research community during normal working hours. In FY 2011 funds are provided to continue operations for all five NSRCs.

In FY 2009, $100,490,000 was funded in the Materials Sciences and Engineering Research subprogram as follows: $19,900,000 at the Center for Nanophase Materials Sciences, ORNL; $19,950,000 at the Center for Integrated Nanotechnologies, SNL/LANL; $20,000,000 at the Molecular Foundry, LBNL; $20,640,000 at the Center for Nanoscale Materials, ANL; and $20,000,000 for the Center for Functional Nanomaterials, BNL.

	FY 2009	FY 2010	FY 2011
Number of Users[a]			
Center for Nanophase Materials Sciences	317	350	380
Center for Integrated Nanotechnologies	354	380	400
Molecular Foundry	209	300	350
Center for Nanoscale Materials	305	350	380
Center for Functional Nanomaterials	213	300	350

[a] Facility operating hours are not measured at user facilities that do not rely on one central machine.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Other Project Costs	**0**	**13,500**	**1,500**
National Synchrotron Light Source-II, BNL	0	2,000	1,500
Linac Coherent Light Source (LCLS), SLAC	0	11,500	0

Other Project Costs (OPC) are associated with line-item construction or major item of equipment projects and include all project costs that are not identified in the Total Estimated Cost. Total Estimated Cost includes project costs incurred after Critical Decision-1 such as costs associated with the acquisition of land and land rights; engineering, design, and inspection; direct and indirect construction/fabrication; and the initial equipment necessary to place the plant or installation in operation. Generally, OPC are costs incurred during the project's initiation and definition phase for planning, conceptual design, research and development, and during the execution phase for research and development, startup, and operation. Other Project Costs are always operating funds.

Funds are provided in FY 2011 for other project costs associated with the National Synchrotron Light Source-II, BNL.

In FY 2009, $27,044,000 was funded in the Materials Sciences and Engineering Research subprogram as follows: $17,000,000 for the Linac Coherent Light Source, SLAC, $40,000 for the Photon Ultrafast Laser Science and Engineering Building Renovation, SLAC, $4,000 for the Advanced Light Source User Support Building, LBNL and $10,000,000 for the National Synchrotron Light Source–II, BNL.

	FY 2009	FY 2010	FY 2011
SBIR/STTR	**0**	**20,038**	**20,059**

The FY 2010 and FY 2011 amounts shown are the estimated requirements for the continuation of the congressionally mandated SBIR and STTR programs.

	FY 2009	FY 2010	FY 2011
Total, Scientific User Facilities	**0**	**821,684**	**847,121**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($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.	+238
▪ **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.	+2,469

	FY 2011 vs. FY 2010 ($000)
▪ **General Plant Project**	
No GPP is requested in FY 2011. Funding for the ORNL Guest House project is completed in FY 2010.	-7,893
Total Research	**-5,186**
Major Items of Equipment	
▪ **Spallation Neutron Source Instrumentation I**	
Scheduled decrease for the Major Item of Equipment for the Spallation Neutron Source Instrumentation I.	-4,600
▪ **Spallation Neutron Source Instrumentation II**	
Scheduled decrease for the Major Item of Equipment for the Spallation Neutron Source Instrumentation II.	-1,000
▪ **SNS Power Upgrade Project**	
Scheduled increase for the Major Item of Equipment for the SNS Power Upgrade Project	+3,000
Total, Major Items of Equipment	**-2,600**
Facilities Operations	
▪ **Synchrotron Radiation Light Sources**	
• Increase for the Advanced Light Source to support accelerator operations and users and to provide instrumentation to upgrade BES beamlines.	+4,716
• Increase for Advanced Photon Source to support accelerator operations and users, for research and development associated with improvements in the APS storage ring for future performance enhancement, and to provide instrumentation to upgrade BES beamlines.	+10,151
• Increase for National Synchrotron Light Source to support accelerator operations and users, for research and development leading to new and improved scattering beam lines for the 3rd generation light sources, and to provide instrumentation to upgrade BES beamlines.	+970
• Increase for the Stanford Synchrotron Radiation Light Source to support accelerator operations and users and to provide instrumentation to upgrade BES beamlines.	+2,302
• Increase for the Linac Coherent Light Source to begin the first full year of operations in FY 2011.	+18,500
Total, Synchrotron Radiation Light Sources	**+36,639**

	FY 2011 vs. FY 2010 ($000)
▪ **High-Flux Neutron Sources**	
• Increase for High Flux Isotope Reactor for new operating beamlines and to support reactor operations.	+690
• Decrease for the Intense Pulsed Neutron Source to continue decommissioning of the target assembly.	-1,000
• Increase for the Manuel Lujan, Jr., Neutron Scattering Center to support target operations and users.	+471
• Increase for Spallation Neutron Source for new operating beamlines and to support operations and users.	+3,595
Total, High-Flux Neutron Sources	**+3,756**
▪ **Nanoscale Science Research Centers**	
• Increase for the Center for Nanophase Materials to support operations and users.	+954
• Increase for the Center for Integrated Nanotechnologies to support operations and users.	+958
• Increase for the Molecular Foundry to support operations and users.	+959
• Increase for the Center to Nanoscale Materials to support operations and users.	+977
• Increase for the Center for Functional Nanomaterials to support operations and users.	+959
Total, Nanoscale Science Research Centers	**+4,807**
Total, Facilities Operations	**+45,202**
Other Project Costs	
▪ Decrease for National Synchrotron Light Source-II per the project schedule.	-500
▪ Decrease for Linac Coherent Light Source per the project schedule.	-11,500
Total, Other Project Costs	**-12,000**
SBIR/STTR	
Increase in SBIR/STTR funding because of an increase in total operating expenses.	+21
Total Funding Change, Scientific User Facilities	**+25,437**

Construction

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Construction			
Advanced Light Source User Support Building, LBNL	11,500	0	0
Photon Ultrafast Laser Science and Engineering Building Renovation, SLAC	3,728	0	0
National Synchrotron Light Source-II, BNL	93,273	139,000	151,600
Linac Coherent Light Source, SLAC	36,967	15,240	0
Total, Construction	145,468	154,240	151,600

Description

Experiments in support of basic research require construction of state-of-the-art facilities and/or that 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 used. 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 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 2009	FY 2010	FY 2011
Advanced Light Source (ALS) User Support Building, LBNL	**11,500**	**0**	**0**

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 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.

The FY 2009 construction funding was 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 used to remobilize the

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

design-build construction contractor, erect the steel, complete exterior cladding, and commence interior construction project efforts. The combination of the FY 2009 Appropriations and the Recovery Act funds fully funds this project.

Photon Ultrafast Laser Science and Engineering Building Renovation, SLAC	**3,728**	**0**	**0**

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 is 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 was renovated to meet the new PULSE programs needs for offices, laboratories, and conference rooms. FY 2009 funding was used to complete construction of PULSE.

National Synchrotron Light Source-II (NSLS-II), BNL	**93,273**	**139,000**	**151,600**

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

In FY 2010, construction funding will be used to continue civil construction activities and advance experimental and accelerator systems.

In FY 2011, construction funding will be used to continue civil construction activities and advance experimental and accelerator systems. Additional information is provided in the construction project data sheet 07-SC-06.

Beyond the scope of the NSLS-II construction project, an instrument development program will be implemented in the near future to address new advanced experimental techniques that will go beyond the six initial instruments funded by the project.

Linac Coherent Light Source, SLAC	**36,967**	**15,240**	**0**

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

	FY 2009	FY 2010	FY 2011

(dollars in thousands)

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 2009, funding was used for installation of undulator and photon diagnostics, experimental halls, and technical hardware for x-ray transport systems. In addition, SLAC commenced a design and initiated construction of a user office builder adjacent to the near experimental hall to provide space in support of the LCLS operations in lieu of renovating of existing older buildings at SLAC. This user building adjacent to the near experimental hall provided a more cost effective and efficient solution to addressing the user office space needs than renovating old space at various buildings in SLAC. Commissioning of the facility will also continue on a phased schedule. In FY 2010, funds will complete construction and commissioning elements of the project. FY 2011 is expected to be the first full year of LCLS facility operations.

Total, Construction	**145,468**	**154,240**	**151,600**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
National Synchrotron Light Source-II (NSLS II), BNL	
Increase in funding to continue construction of the NSLS II project, as scheduled.	+12,600
Linac Coherent Light Source, SLAC	
Decrease in funding representing the completion of construction funding in FY 2010, as scheduled.	-15,240
Total Funding Change, Construction	**-2,640**

Supporting Information

Operating Expenses, Capital Equipment and Construction Summary

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Operating Expenses	1,256,023	1,334,500	1,492,137
Capital Equipment	100,916	100,068	151,637
General Plant Projects	11,848	13,992	2,364
Accelerator Improvement Projects	21,510	33,700	37,262
Construction	145,468	154,240	151,600
Total, Basic Energy Sciences	1,535,765	1,636,500	1,835,000

Funding Summary

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Research	632,758	663,114	841,006
Scientific User Facilities Operations	689,047	730,621	775,823
Major Items of Equipment	34,000	25,000	22,400
Construction Projects (includes OPC)	172,512	167,740	153,100
Other	7,448	50,025	42,671
Total, Basic Energy Sciences	1,535,765	1,636,500	1,835,000

Scientific User Facility Operations

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Light Source User Facilities			
Advanced Light Source, LBNL	55,728	58,000	62,716
Advanced Photon Source, ANL	116,440	129,500	139,651
National Synchrotron Light Source, BNL	40,154	40,200	41,170
Stanford Synchrotron Radiation Light Source, SLAC	33,412	34,774	37,076
Linac Coherent Light Source (LCLS), SLAC	3,000	10,500	123,000
Linac for LCLS, SLAC	90,021	94,000	0
Total, Light Sources User Facilities	338,755	366,974	403,613
Neutron Source User Facilities			
High Flux Isotope Reactor, ORNL	58,000	60,700	61,390
Intense Pulsed Neutron Source, ANL	4,000	4,000	3,000

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Manuel Lujan, Jr. Neutron Scattering Center, LANL	11,302	11,350	11,821
Spallation Neutron Source, ORNL	176,500	182,930	186,525
Total, Neutron Source User Facilities	249,802	258,980	262,736
Nanoscale Science Research Center User Facilities			
Center for Nanophase Materials Sciences, ORNL	19,900	20,641	21,595
Center for Integrated Nanotechnologies, SNL/LANL	19,950	20,790	21,748
Molecular Foundry, LBNL	20,000	20,833	21,792
Center for Nanoscale Materials, ANL	20,640	21,570	22,547
Center for Functional Nanomaterials, BNL	20,000	20,833	21,792
Total, Nanoscale Science Research Center User Facilities	100,490	104,667	109,474
Total, Scientific User Facility Operations	689,047	730,621	775,823

Facilities Users and Hours

	FY 2009	FY 2010	FY 2011
Advanced Light Source			
Achieved Operating Hours	5,278	N/A	N/A
Planned Operating Hours	5,400	5,600	5,600
Optimal Hours	5,600	5,600	5,600
Percent of Optimal Hours	94%	100%	100%
Unscheduled Downtime	3.5%	<10%	<10%
Number of Users	1,918	2,200	2,300
Advanced Photon Source			
Achieved Operating Hours	4,883	N/A	N/A
Planned Operating Hours	4,800	5,000	5,000
Optimal Hours	5,000	5,000	5,000
Percent of Optimal Hours	98%	100%	100%
Unscheduled Downtime	2.3%	<10%	<10%
Number of Users	3,537	3,700	3,800

	FY 2009	FY 2010	FY 2011
National Synchrotron Light Source			
Achieved Operating Hours	5,499	N/A	N/A
Planned Operating Hours	5,200	5,400	5,400
Optimal Hours	5,400	5,400	5,400
Percent of Optimal Hours	102%	100%	100%
Unscheduled Downtime	2.6%	<10%	<10%
Number of Users	2,214	2,200	2,200
Stanford Synchrotron Radiation Light Source			
Achieved Operating Hours	5,050	N/A	N/A
Planned Operating Hours	5,000	5,400	5,400
Optimal Hours	5,400	5,400	5,400
Percent of Optimal Hours	94%	100%	100%
Unscheduled Downtime	1%	<10%	<10%
Number of Users	1,361	1,400	1,400
Linac Coherent Light Source			
Achieved Operating Hours	0	0	N/A
Planned Operating Hours	0	0	4,000
Optimal Hours	0	0	5,000
Percent of Optimal Hours	0	0	80%
Unscheduled Downtime	0	0	<10%
Number of Users	0	0	250
High Flux Isotope Reactor			
Achieved Operating Hours	3,892	N/A	N/A
Planned Operating Hours	3,900	4,500	4,500
Optimal Hours	4,500	4,500	4,500
Percent of Optimal Hours	86%	100%	100%
Unscheduled Downtime	0%	<10%	<10%
Number of Users	358	500	600

	FY 2009	FY 2010	FY 2011
Manuel Lujan, Jr. Neutron Scattering Center			
Achieved Operating Hours	2,840	N/A	N/A
Planned Operating Hours	3,500	3,600	3,600
Optimal Hours	3,600	3,600	3,600
Percent of Optimal Hours	79%	100%	100%
Unscheduled Downtime	18.1%	<10%	<10%
Number of Users	416	400	400
Spallation Neutron Source			
Achieved Operating Hours	3,553	N/A	N/A
Planned Operating Hours	4,000	4,500	4,500
Optimal Hours	4,500	4,500	4,500
Percent of Optimal Hours	79%	100%	100%
Unscheduled Downtime	19.5%	<10%	<10%
Number of Users	307	700	750
Center for Nanophase Materials Sciences[a]			
Number of Users	317	350	380
Center for Integrated Nanotechnologies[a]			
Number of Users	354	380	400
Molecular Foundry[a]			
Number of Users	209	300	350
Center for Nanoscale Materials[a]			
Number of Users	305	350	380
Center for Functional Nanomaterials[a]			
Number of Users	213	300	350

[a] Facility operating hours are not measured at user facilities that do not rely on one central machine.

	FY 2009	FY 2010	FY 2011
Total, All Facilities			
Achieved Operating Hours	30,995	N/A	N/A
Planned Operating Hours	31,800	34,000	38,000
Optimal Hours	34,000	34,000	39,000
Percent of Optimal Hours	91%	100%	97%
Unscheduled Downtime	6%	<10%	<10%
Number of Users	11,509	12,780	13,560

Major Items of Equipment

(dollars in thousands)

	Prior Years	FY 2009	FY 2009 Recovery Act Approp.	FY 2010	FY 2011	Outyears	Total
Spallation Neutron Source Instrumentation I, ORNL							
TEC/TPC	51,100	12,000	0	5,000	400	0	68,500
Spallation Neutron Source Instrumentation II, ORNL							
TEC/TPC	6,500	7,000	0	18,000	17,000	11,500	60,000
Linac Coherent Light Source Instrumentation, SLAC							
TEC	6,500	15,000	33,600	0	0	0	55,100
OPC	4,900	0	0	0	0	0	4,900
TPC	11,400	15,000	33,600	0	0	0	60,000
SNS Power Upgrade Project (01VI), ORNL							
TEC/TPC	0	0	0	2,000	5,000	89,100	96,100
Total, Major Items of Equipment							
TEC/TPC		34,000	33,600	25,000	22,400		

Construction Projects

(dollars in thousands)

	Prior Years	FY 2009	FY 2009 Additional	FY 2010	FY 2011	Outyears	Total
08-SC-01 Advanced Light Source User Support Building, LBNL							
TEC	6,454	11,500	14,546	0	0	0	32,500[a]
OPC	2,480	4	136	0	0	0	2,620
TPC	8,934	11,504	14,682	0	0	0	35,120
08-SC-11 Photon Ultrafast Laser Science and Engineering Building Renovation, SLAC							
TEC	7,332	3,728	0	0	0	0	11,060[b]
OPC	100	40	0	0	0	0	140
TPC	7,432	3,768	0	0	0	0	11,200
07-SC-06, National Synchrotron Light Source-II, BNL							
TEC	32,727	93,273	150,000	139,000	151,600	224,600	791,200
OPC	47,800	10,000	0	2,000	1,500	59,500	120,800
TPC	80,527	103,273	150,000	141,000	153,100	284,100	912,000
05-R-320 Linac Coherent Light Source, SLAC							
TEC	299,793	36,967	0	15,240	0	0	352,000[c]
OPC	39,500	17,000	0	11,500	0	0	68,000
TPC	339,293	53,967	0	26,740	0	0	420,000
Total, Construction							
TEC		145,468	164,546	154,240	151,600		
OPC		27,044	136	13,500	1,500		
TPC		172,512	164,682	167,740	153,100		

[a] Includes $1,500,000 of PED included in the 07-SC-12 PED, LBNL Advanced Light source User Support Building data sheet.
[b] Includes $941,000 of PED included in the 08-SC-10 PED, Photon Ultrafast Laser Science and Engineering Building Renovation, SLAC data sheet.
[c] Includes $35,974,000 of PED included in the 03-SC-002 PED, SLAC, Linac Coherent Light Source data sheet.

Scientific Employment

	FY 2009 Estimate	FY 2010 Estimate	FY 2011Estimate
# of University Grants	1,180	1,210	1,400
Average Size per year	175,000	175,000	215,000
# Permanent Ph.D’s (FTEs)	4,560	4,670	5,590
# Postdoctoral Associates (FTEs)	1,270	1,300	1,620
# Graduate Students (FTEs)	2,000	2,050	2,570

Biological and Environmental Research

Funding Profile by Subprogram

(dollars in thousands)

	FY 2009 Current Appropriation	FY 2009 Current Recovery Act Appropriation[a]	FY 2010 Current Appropriation	FY 2011 Request
Biological and Environmental Research				
Biological Systems Science	0[b]	0	318,476	321,947
Climate and Environmental Sciences	0[b]	0	285,706	304,953
Biological Research	412,153[b]	+100,793	0	0
Climate Change Research	173,023[b]	+64,860	0	0
Total, Biological and Environmental Research	585,176[c]	+165,653	604,182	626,900

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

Background

The wonders of 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 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 of whether 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. These practical arguments and challenges are driven by a foundation of scientific knowledge and inquiry in atmospheric chemistry and physics, ecology, genetics, and subsurface science. Studies in these areas probe questions such as: 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

[a] The Recovery Act Current Appropriation column reflects the allocation of funding as of September 30, 2009.
[b] $313,688,000 of the FY 2009 funding for the Biological Research program is for activities funded in the Biological Systems Science subprogram in FY 2010 and FY 2011. $98,465,000 of the FY 2009 funding for the Biological Research subprogram and all of the $173,023,000 in the Climate Change Research subprogram is for activities funded in the Climate Change and Environmental Sciences subprogram in FY 2010 and FY 2011.
[c] Total is reduced by $16,364,000; $14,611,000 of which was transferred to the Small Business Innovation Research (SBIR) program; and $1,753,000 of which was transferred to the Small Business Technology Transfer (STTR) program.

subsurface environment? The BER program supports research addressing these questions to provide an understanding of Nature that enables DOE to discover and develop 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. BER-funded health effects research provided 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 the pursuit of an understanding of the most fundamental level of biology, DNA, and in turn led DOE's initiation of 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 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 scientific 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 the systems 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 of cells and organisms, 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 climate 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. In addition, 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, is the challenge and excitement of studying complex systems. The systems studied have their own unique complexity covering remarkable spatial and temporal scales. In living systems, 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 decades or even centuries to understand the long-term ecological impacts of a changing climate or the sustained production of specific biofuel feedstock 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. 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. Essential to BER supported research is the use of DOE's computational resources and the development of computational models that can be used to make experimentally testable predictions about climate, complex subsurface environments, or biological systems across the various spatial and temporal scales.

Major scientific goals for BER include:

- **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 systems."
- **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 2008 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 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 "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. This research is guided by an August 2009 community-based workshop, "Subsurface Complex System Science—with Relevance to Contaminant Fate and Transport."[d]

Subprograms

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

- 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

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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
[d] August 2009 workshop report to be available early 2010.

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 over 1,000 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.

- 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 to help resolve the greatest uncertainties in climate change—the role of clouds and aerosols in Earth's radiation balance. The Atmospheric Radiation Measurement (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, two mobile facilities, and an aerial vehicles program; it served 1000 users from around the world in FY 2009. Climate and Earth System Modeling supports some of the world's most powerful and sophisticated climate models that contribute to reports by the Intergovernmental Panel on Climate Change. In FY 2011, BER will initiate efforts for uncertainty quantification in climate models, incorporation of observational data sets, model development testbeds, and the development of numerical methods to enable climate models to use future computing architectures. 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 advanced scientific discovery, improved human health, and revolutionized the field of biology. 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, information that has provided unprecedented opportunities for discovering and understanding fundamental principles of life. Today, DNA sequencing is the foundation for BER research on plants and microbes with an emphasis on organisms with energy and environmental relevance leading to the discovery of novel microorganisms with unanticipated biotechnological capabilities and provided new insights into a variety of plants including trees, legumes and grasses.

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. Today, BER research has shown that biological responses to low and high doses of radiation are both quantitatively and qualitatively different, suggesting that the traditionally used linear no-threshold model for assessing radiation risk is not scientifically justified.

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. Today, 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 also provides new understanding of the biological, physical, and chemical mechanisms responsible for the natural sequestration of carbon dioxide in terrestrial ecosystems, knowledge that is useful in understanding the impacts of land use and land management decisions on carbon release or storage from various ecosystems.

Fundamental, hypothesis-driven research in both laboratories and the field has revealed new biogeochemical processes that influence the fate and transport of contaminants from a legacy of weapons production. Today, this knowledge has been translated into new strategies for cleaning up legacy contaminants based on understanding of the broad capabilities of naturally occurring subsurface microbes.

Program Planning and Management

BER uses broad input from scientific workshops and 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, National Aeronautics and Space Administration, Department of Commerce/National Oceanic and Atmospheric Administration, Environmental Protection Agency, Nuclear Regulatory Commission, Department of Agriculture, National Institutes of Health, Department of State, and Department of Defense. 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 U.S. Climate Change Technology Program.

BERAC conducts reviews of BER subprograms by COVs every three years. Results of these reviews and BER responses are posted on the Office of Science 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.

[a] http://www.science.doe.gov/SC-2/Committee_of_Visitors.htm

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 provides 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 three mission priorities: exploring the frontiers of genome-enabled biology; discovering the physical, chemical, and biological drivers and environmental impacts of climate change; and seeking the geochemical, hydrological, and biological determinants of environmental sustainability and stewardship. The BER scientific user facilities are key to supporting these mission priorities.

Genomic science research supported in FY 2011, including the DOE Bioenergy Research Centers, will continue to 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 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.

Climate sciences research supported in FY 2011 will continue to improve understanding and quantification of the role of aerosols and clouds on climate change. New ARM sites and laboratory 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). Results will be used to evaluate and improve performance of regional and global climate models. New efforts in FY 2011 will focus on uncertainty quantification in climate models, incorporation of observational data sets, and model development testbeds. Additional funding for Climate and Earth System modeling will support efforts to improve uncertainty quantification, streamline the translation of observational data sets, create model development testbeds, and develop new numerical methods to enable climate models to use future computing architectures. Efforts will continue on the development of an additional large-scale, manipulative experiment in the arctic tundra 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 focusing 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.

Significant Program Shifts

In FY 2011, BER will initiate enhanced activities in climate modeling, including improving uncertainty quantification, streamlining the translation of observational data sets, creating model development testbeds, and developing new numerical methods. These activities will help to accelerate the advance of climate models. BER research on the development of the components of an artificial retina is completed in FY 2010. The BER effort will end in FY 2011 with the final testing of the assembled 240+ electrode device. In FY 2011, BER will continue to actively work with NIH and industry to identify an appropriate transition route that will move the artificial retina project from research into early development and application.

Annual Performance Targets and Results

Secretarial Priority: Innovation: Lead the world in science, technology, and engineering

GPRA Unit Program Goal: Biological and Environmental Research (BER) Program Goal: 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 science advances in biology.

Annual Performance Measure: 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.

FY 2006	T: Develop predictive model for contaminant transport that incorporates complex biology, hydrology, and chemistry of the subsurface. Validate model through field tests. A: Goal met
FY 2007	T: Implement a field-oriented, integrated experimental research program to quantify coupled processes that control reactive transport of at least one key DOE contaminant. A: Goal met
FY 2008	T: Identify the critical redox reactions and metabolic pathways involved in the transformation/ sequestration of at least one key DOE contaminant in a field environment. A: Goal met

FY 2009	T: Test geophysical techniques that measure parameters controlling contaminant movement under field conditions in at least two distinct subsurface environments. A: Goal met
FY 2010	T: Develop a reactive transport model for a complex field site that accounts for heterogeneity and objectively evaluate against field data. A: TBD
FY 2011	T: Refine subsurface transport models by developing computational methods to link important processes impacting contaminant transport at smaller scales to the field scale. A: TBD
FY 2012	T: Perform time-lapse geophysical experiments to monitor spatial and temporal dynamics of hydrogeological and biogeochemical parameters impacting contaminant transport processes. A: TBD
FY 2013	T: Use genomics-based methods to predict the activity of subsurface microbial communities and their influence on the transport of contaminants in the subsurface. A: TBD
FY 2014	T: Use geophysical signatures to locate and define key biogeochemical zones in subsurface environments that impact contaminant transport processes. A: TBD
FY 2015	T: Integrate genomic-based methods of predicting microbial community activity into computational models describing contaminant transport. A: TBD

Annual Performance Measure: Increase by at least 10% the number 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 at least 10% the cost (billion base pair/dollar) to produce these base pairs from the previous year's actual results.[a]

FY 2007	T: Sequence 40 billion base pairs (bp) at a rate of 644 bp/$1. A: Goal not met
FY 2008	T: Sequence 42.8 billion base pairs at a rate of 785 bp/$1 A: Goal met

[a] This performance measure begins in FY 2007.

FY 2009	T: Sequence 253 billion base pairs at a rate of 4,600 bp/$1. A: Goal met
FY 2010	T: Sequence 1,100 billion base pairs at a rate of 15,942 bp/$1. A: TBD
FY 2011	T: TBD based on FY 2010 results A: TBD
FY 2012	T: TBD based on FY 2011 results A: TBD
FY 2013	T: TBD based on FY 2012 results A: TBD
FY 2014	T: TBD based on FY 2013 results A: TBD
FY 2015	T: TBD based on FY 2014 results A: TBD

Annual Performance Measure: 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 2006	T: 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 time scales of 1 to 4 days. A: Goal met
FY 2007	T: Provide new mixed-phase cloud parameterization for incorporation in atmospheric GCMs and evaluate extent of agreement between climate model simulations and observations for cloud properties in the arctic. A: Goal met
FY 2008	T: 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. A: Goal met

FY 2009	T: 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. A: Goal met
FY 2010	T: Provide a new parameterization for aerosol effects on cloud drizzle for incorporation into atmospheric models. A: TBD
FY 2011	T: Earth system model to be used in generating scenarios for the IPCC Fifth Assessment Report and provide integrated aerosol sub-model that includes direct and indirect forcing. A: TBD
FY 2012	T: Demonstrate coupled climate models at 20km resolution. A: TBD
FY 2013	T: Provide peer reviewed publications documenting effects of experimental warming on the regeneration of key plant species at a high-elevation and a high-latitude ecotone (i.e., boundary between two adjacent ecosystem types) in the United States. A: TBD
FY 2014	T: Provide a comparative analysis of measured and modeled biosphere atmosphere fluxes of carbon at the subcontinent scale using data products from the AmeriFlux Network and new versions of integrated terrestrial carbon cycle models. A: TBD
FY 2015	T: Provide progress report for scientific results from next generation ecosystem experiment. A: TBD

Annual Performance Measure: <u>The achieved operation time of the JGI scientific user facility as a percentage of the total scheduled annual operating time is greater than 98%.</u>

FY 2006	T: 98% of total scheduled operating time A: Goal met
FY 2007	T: 98% of total scheduled operating time A: Goal met
FY 2008	T: 98% of total scheduled operating time A: Goal not met

FY 2009	T: 98% of total scheduled operating time A: Goal met
FY 2010-FY2015	T: 98% of total scheduled operating time A: TBD

Annual Performance Measure: The achieved operation time of the ARM/ACRF scientific user facility as a percentage of the total scheduled annual operating time is greater than 98%.

FY 2006	T: 98% of total scheduled operating time A: Goal met
FY 2007	T: 98% of total scheduled operating time A: Goal met
FY 2008	T: 98% of total scheduled operating time A: Goal met
FY 2009	T: 98% of total scheduled operating time A: Goal met
FY 2010-FY 2015	T: 98% of total scheduled operating time A: TBD

Annual Performance Measure: The achieved operation time of the EMSL scientific user facility as a percentage of the total scheduled annual operating time is greater than 98%.

FY 2006	T: 98% of total scheduled operating time A: Goal met
FY 2007	T: 98% of total scheduled operating time A: Goal met
FY 2008	T: 98% of total scheduled operating time A: Goal met
FY 2009	T: 98% of total scheduled operating time A: Goal met
FY 2010-FY 2015	T: 98% of total scheduled operating time A: TBD

Biological Systems Science

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Biological Systems Science			
Genomic Science	0	165,626	176,891
Radiological Sciences	0	46,615	42,327
Ethical, Legal, and Societal Issues	0	5,000	5,000
Medical Applications	0	8,226	4,000
Biological Systems Facilities and Infrastructure	0	84,300	84,950
SBIR/STTR	0	8,709	8,779
Total, Biological Systems Science	0[a]	318,476	321,947

Description

Systems biology is the holistic, multidisciplinary study of complex interactions that specify the function of 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. 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.

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 and in radiochemistry and instrumentation research to develop new methodologies for real-time, high-resolution imaging of dynamic biological processes in energy- and environment-relevant contexts.

Selected FY 2009 Accomplishments

- The DOE Bioenergy Research Centers have pioneered a variety of new research and technological approaches designed to accelerate biofuels research. The Joint BioEnergy Institute combined carbohydrate arrays and nano-scale mass spectrometry to rapidly screen novel environmental microbes and identify new cellulose-degrading enzyme activities against a wide range of plant compounds. The Great Lakes Bioenergy Research Center used systems biology methods to identify microbial community interactions during biomass deconstruction in natural systems, with potential

[a] Associated FY 2009 funding of $313,688,000 is included within the previous Biological Research subprogram. Modifications were made to the budget structure to better reflect the subprogram's activities starting in FY 2010.

to augment development of novel approaches for biofuel production. Research on consolidated bioprocessing at the BioEnergy Science Center provided new insights on how microbes fine tune their enzyme systems to optimize efficiency while breaking down complex plant material. New analytical technologies were developed for characterizing biological processes in systems being studied for production of biofuels and for other DOE missions. Research in mass spectrometry enabled study of uncharged molecules, such as lipids, by state-of-the-art instrumentation and the rapid, accurate measurement of metabolites produced in essential pathways in microbial systems. Fourier Transform infrared spectromicroscopy at the Advanced Light Source (ALS) enabled continuous tracking of cellular chemistry within living microbes as they adapt to changing chemical environments. A high-throughput pipeline for small angle x-ray scattering was developed and implemented at another experimental station at the ALS that will allow the three dimensional shapes of proteins and protein complexes to be determined in large numbers. This information will provide significant insights into the function of a cell's proteins and complexes.

- The DOE Joint Genome Institute (JGI) significantly expanded its role in large-scale genome sequencing and analysis in support of DOE missions. Major accomplishments include the use of new sequencing technologies to sequence a trillion base pairs of DNA annually, the sequencing of the genome of sorghum (a major candidate biofuels crop with ability to withstand drought and prosper on marginal land), and substantial progress on sequencing the genome of a single microbial cell (critical to exploring the gene content of the huge majority of microbial species that cannot be easily cultivated). The JGI also developed enhanced data analysis tools for sequencing communities of organisms (metagenomes), providing fundamental insights into the behavior of microbes in natural environments.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Genomic Science	**0**	**165,626**	**176,891**
▪ **Foundational Genomics Research**	**0**	**33,216**	**40,081**

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 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 rhizosphere 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. Research will also support the development of novel technologies to enable multi-modal chemical and biological measurements across broad spatial and temporal ranges, to provide insight into actively-occurring environmental

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

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 2011, research is increased to advance the understanding of how complex biological system function is specified by genome organization, expression, and regulation, through the development of genomic and analytical technologies for multi-modal, dynamic measurements in actively-occurring environmental processes.

FY 2009 funding of $36,839,000 was funded in Molecular and Cellular Biology within the Biological Research subprogram.

	FY 2009	FY 2010	FY 2011
▪ **Genomics Analysis and Validation**	**0**	**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 2011, research supports innovative new approaches for the experimental validation and improvement of genome-scale annotation and gene models in microbes, plants, and complex biological systems.

FY 2009 funding of $10,000,000 was funded in Human Genome within the Biological Research subprogram.

	FY 2009	FY 2010	FY 2011
▪ **Metabolic Synthesis and Conversion**	**0**	**39,127**	**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 can enable strategies to increase biomass formation for conversion into advanced biofuels or to increase the sequestration of carbon in terrestrial ecosystems.

	FY 2009	FY 2010	FY 2011
	(dollars in thousands)		

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 2011, funds will continue to support research on carbon storage in plant biomass for conversion into advanced biofuels or for 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.

FY 2009 funding of $43,814,000 was in Molecular and Cellular Biology within the Biological Research subprogram.

	FY 2009	FY 2010	FY 2011
▪ **Computational Biosciences**	**0**	**8,283**	**12,683**

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. (see http://genomicscience.energy.gov/compbio/)

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 Office of Science's Advanced Scientific Computing Research program.

In FY 2011, funding will support ongoing SciDAC research on the modeling of whole cellular processes that incorporate models of genomic information and protein production and function with metabolic, regulatory, and cellular signaling processes. Increased funding includes support to establish a system biology modeling framework, allowing open access to researchers to biological

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

data and analytical tools. The framework will include biological database research and development, new software and algorithm research for interoperability among databases and datasets, and will develop and test predictive models for microbial systems of DOE relevance with respect to physiological properties, behavior, and whole microbe and microbial community 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 and phenotypic data. The primary microbial experimental datasets for integration will be drawn from research conducted at the DOE Bioenergy Research Centers, the Joint Genome Institute, and from within the Genomic Science activity.

FY 2009 funding of $5,094,000 was in Molecular and Cellular Biology within the Biological Research subprogram.

	FY 2009	FY 2010	FY 2011
▪ **Bioenergy Research Centers**	**0**	**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 there are 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.

Annual progress of each center is evaluated by an on-site review of science and management activities and progress against stated milestones. The external review teams are comprised of scientists from universities, DOE national laboratories, and industry, with expertise in systems biology, microbial physiology and genetics, plant genomics and bioinformatics, genomic database management and informatics, and analytical chemistry. All three centers are evaluated for progress against milestones and for the planned science programs.

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 2011, 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

	FY 2009	FY 2010	FY 2011
(dollars in thousands)			

bioengineering of new microbes and enzymes capable of degrading lignocellulose, and conversion of cellulose-derived sugars to carbon-neutral biofuels.

FY 2009 funding of $75,000,000 was in Molecular and Cellular Biology within the Biological Research subprogram.

	FY 2009	FY 2010	FY 2011
Radiological Sciences	**0**	**46,615**	**42,327**
▪ **Radiochemistry and Imaging Instrumentation**	**0**	**20,688**	**18,400**

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 2011, 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. Funding will also continue to support integrative training opportunities in radiochemistry to ensure the future availability of human resources for important radiochemistry applications. Two year activities funded in FY 2010 to develop new radiochemistry synthetic and detection methods will not require additional funding and will be completed in FY 2011.

FY 2009 funding of $22,811,000 was in the Radiochemistry and Instrumentation activity within the Biological Research subprogram.

	FY 2009	FY 2010	FY 2011
▪ **Radiobiology**	**0**	**25,927**	**23,927**

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 understanding the role of epigenetics in integrated gene function and response of biological systems to environmental conditions, including low dose radiation.

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.

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

In FY 2011, funds will support the development of models that integrate responses to low dose radiation at the tissue or whole organism level with available epidemiological and epigenetic 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. Research on DNA damage from low dose radiation exposure is completed in FY 2011, requiring no FY 2011 funding.

FY 2009 funding of $20,667,000 and $5,937,000 was in Molecular and Cellular Biology and Health Effects, respectively, within the Biological Research subprogram.

	FY 2009	FY 2010	FY 2011
Ethical, Legal, and Societal Issues	**0**	**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 the Environmental Protection Agency, National Science Foundation, and Office of Science and Technology Policy.

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 2011, 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.

FY 2009 funding of $5,000,000 was in Human Genome within the Biological Research subprogram.

	FY 2009	FY 2010	FY 2011
Medical Applications	**0**	**8,226**	**4,000**

Research continues to utilize resources of the national laboratories in material sciences, engineering, microfabrication, and microengineering to develop 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. BER research on the development of the components of the 240+ electrode artificial retina device is completed in FY 2010.

In FY 2011, BER continues to actively work with NIH and industry to identify an appropriate transition route that will move the artificial retina project from research into early development and application. Funding is provided to support device integration, quality assurance and quality control, and preparation for pre-clinical trials.

FY 2009 funding of $8,226,000 was in Medical Applications within the Biological Research subprogram.

	FY 2009	FY 2010	FY 2011
	(dollars in thousands)		
Biological Systems Facilities and Infrastructure	**0**	**84,300**	**84,950**
▪ **Structural Biology Infrastructure**	**0**	**15,300**	**15,683**

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.

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 2011 funds will continue to support biological community access to structural biology beamlines and instrumentation at DOE national user facilities.

FY 2009 funding of $15,300,000 was in Structural Biology within the Biological Research subprogram.

	FY 2009	FY 2010	FY 2011
▪ **Joint Genome Institute**	**0**	**69,000**	**69,267**

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

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

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 2011, funding will continue to support access by the scientific user community and the DOE Bioenergy Research Centers to integrative large-scale genome data acquisition and analysis of biological systems at the JGI. Funding will also support a greater emphasis on metagenome expression and sequencing of environmental microbial communities or the plant-microbe rhizosphere, improved genome annotation, and functional analysis and verification of genome-scale models.

FY 2009 funding of $65,000,000 was in Human Genome within the Biological Research subprogram.

		(estimated)	
	FY 2009	FY 2010	FY 2011
Achieved Operating Hours	8,400	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	100%	100%	100%
Unscheduled Downtime	0	N/A	N/A
Number of Users[a]	780	940	940

SBIR/STTR	**0**	**8,709**	**8,779**

FY 2010 and FY 2011 amounts shown for the SBIR and STTR programs are the estimated requirements for continuation of these congressionally mandated programs.

Total, Biological Systems Science	**0**	**318,476**	**321,947**

[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.

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Genomic Science	
▪ **Foundational Genomics Research**	
Funding is increased to advance the understanding of how complex biological system function is specified by genome organization, expression and regulation, through the development of genomic and analytical technologies for multi-modal, dynamic measurements in actively-occurring environmental processes.	+6,865
▪ **Computational Bioscience**	
Funding is increased to develop a systems biology modeling framework to integrate microbiological experimental data sets from research conducted at the DOE Bioenergy Research Centers, the Joint Genome Institute, and the Genomic Science activity.	+4,400
Total, Genomic Science	**+11,265**
Radiological Sciences	
▪ **Radiochemistry and Imaging Instrumentation**	
The decrease reflects the completion in FY 2011 of multi-year activities initiated in FY 2010 (and funded for two years) in development of new radiochemistry synthetics and detection methods.	-2,288
▪ **Radiobiology**	
Research on DNA damage from low dose radiation exposure is completed in FY 2011 and requires no FY 2011 funding.	-2,000
Total, Radiological Sciences	**-4,288**
Medical Applications	
BER funding for the components of the Artificial Retina effort is completed with integration and pre-clinical testing of a 240 electrode retinal device as a basis for fabrication of the 1,000 electrode device. In FY 2011, BER will actively work with NIH and industry to identify a transition route that will move the artificial retina project from research into early development and application.	**-4,226**

	FY 2011 vs. FY 2010 ($000)
Biological Systems Facilities and Infrastructure	
▪ **Structural Biology Infrastructure**	
In FY 2011 funds will continue to support biological community access to structural biology beamlines and instrumentation at DOE national user facilities.	+383
▪ **Joint Genome Institute**	
Funding will support a greater emphasis on metagenome expression and sequencing of environmental microbial communities or the plant-microbe rhizosphere, improved genome annotation, and functional analysis and verification of genome-scale models.	+267
Total, Biological Systems Facilities and Infrastructure	**+650**
SBIR/STTR	
▪ SBIR/STTR increases as the funding for research increases.	+70
Total Funding Change, Biological Systems Science	**+3,471**

Climate and Environmental Sciences

Funding Schedule by Activity

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Climate and Environmental Sciences			
Atmospheric System Research	0	26,452	28,396
Environmental System Science	0	82,558	81,531
Climate and Earth System Modeling	0	69,775	85,622
Climate and Environmental Facilities and Infrastructure	0	99,479	101,333
SBIR/STTR	0	7,442	8,071
Total, Climate and Environmental Sciences	0[a]	285,706	304,953

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. 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. 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. 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.

Selected FY 2009 Accomplishments

- In 2009, the ACRF hosted approximately 1,200 users, resulting in over 185 publications in the scientific literature. ACRF completed experiments in several climatically important regions including at the fixed sites (mid-continental U.S, Tropical Western Pacific, and the North Slope of Alaska) and by mobile facilities deployed at Graciosa Island in the Azores, a mountain top in Chile, and in China. Several strong collaborations with other agencies and countries were developed for the conduct of these experiments. These peer reviewed experiments addressed critical science questions including carbon cycling, marine clouds, low-altitude liquid-water clouds, and climatic effects of aerosols.

[a] Associated FY 2009 funding of $271,488,000 is included in the Biological Research ($98,465,000) and Climate Change Research ($173,023,000) subprograms.

- DOE scientists found that statistics for cloud radiative impacts are almost the same for low-level clouds whether cloud-radiative interactions are represented by one-dimensional or three-dimensional approaches. This result resolves a longstanding question, demonstrating that the simplified approach taken by state-of-the-art global climate models (GCMs) provides a realistic representation of low-level cloud properties. This is an important and useful result as climate models continue to increase in complexity and computational intensity
- Genome-scale models of microbial metabolism have been coupled with reactive transport models to better describe biogeochemical processes affecting uranium transport in groundwater. In a groundbreaking effort, BER investigators have integrated genome science with environmental science to provide a mechanistic basis on which to build a predictive understanding of environmentally relevant microbial processes influencing contaminant transport.
- The Environmental Molecular Sciences Laboratory (EMSL) enabled a multidisciplinary team of scientists to combine mass spectrometry capabilities and the computational chemistry software, NWChem, running on the EMSL supercomputer for molecular simulations to demonstrate that a very short segment of a protein fragment in the membrane of a microorganism is all that binds the microbe to a mineral surface. This finding enables scientists to understand how microbial interactions influence geochemical processes important for bioremediation.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Atmospheric System Research	**0**	**26,452**	**28,396**

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 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. Supported 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 2011, 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. Specific focus areas include life cycle of marine boundary layer clouds and their impacts on radiation; aerosol-cloud-precipitation interactions; polar clouds and their interactions with aerosols; high altitude clouds (cirrus) and their life cycles and impacts on radiation budget; and processes and atmospheric transformations involving biogenic aerosols. Analyses will continue on recent campaigns in the Azores, Alaska, Chile, and California. Research will use atmospheric measurements from laboratories, ACRF, and other sources in this effort. Research also will be coordinated with BER's Earth System Modeling activity to quickly and effectively incorporate results into climate models. In FY 2011, increased funding will use data from the new Recovery Act-funded instruments at the ARM sites to support expanded research, specifically the development of three-dimensional representation of clouds in the climate models.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

FY 2009 funding of $15,079,000 and $10,334,000 was in Atmospheric Radiation Measurement (ARM) Research and Atmospheric Science in the Climate Change Research subprogram.

Environmental System Science	**0**	**82,558**	**81,531**
▪ **Terrestrial Ecosystem Science**	**0**	**27,913**	**28,633**

The Terrestrial Ecosystem Science activity advances the fundamental science concerning 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, and improving reliability of global carbon cycle models for predicting future atmospheric concentrations of carbon dioxide.

Although climate change is expected to cause changes in many terrestrial ecosystems, 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 needed to establish cause-and-effect relationships between climate changes and effects on ecosystems. While a significant fraction of the CO_2 released to the atmosphere during fossil fuel combustion is apparently now being taken up by terrestrial ecosystems, future 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 in the global carbon cycle a high priority.

In FY 2011, the activity will continue ongoing research and initiate new research to understand important potential effects of climate change and increasing atmospheric CO_2 concentration on terrestrial ecosystems and the terrestrial carbon cycle. Continuing research will support AmeriFlux, the network of CO_2 flux measurement sites, for directly estimating net ecosystem production and carbon storage 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, continuing development of a next-generation ecosystem-climate change experiment, with a focus on an ecosystem that is of importance at the regional or global scales, is expected to be sensitive to climate change, and has been poorly studied to date. The increased funding will support the development of the novel experimental framework needed to conduct this research.

FY 2009 funding of $13,979,000 and $13,962,000 was in Ecosystem Function and Response, and Terrestrial Carbon Processes within the Climate Change Research subprogram.

▪ **Terrestrial Carbon Sequestration Research**	**0**	**4,747**	**3,000**

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

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

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 2011, the focus of this program will be to complete the research objectives of the current field research with an emphasis on the synthesis of data and knowledge collected over the history of the program. Funding is reduced with the completion of a series of research projects focused on the cycling of carbon associated with agriculture and forestry.

FY 2009 funding of $5,104,000 was in the Climate Change Research subprogram.

	FY 2009	FY 2010	FY 2011
▪ **Subsurface Biogeochemical Research**	**0**	**49,898**	**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, geochemical reactions, and physical transport processes with computational modeling to advance a predictive understanding of environmental processes. The current focus of the activity is to predict the impact of biogeochemical processes on the fate and transport of contaminants in the subsurface. This activity supports research at many scales and includes 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.

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 also will assist the Department's research on using deep geological formations to store carbon dioxide taken from the atmosphere.

In FY 2011, the activity will adopt a complex systems approach to environmental research. The approach builds on the findings of a recent workshop and frames the current scope of environmental research across scales as a broad continuum of complex interdependent processes. The approach relies on integrated, multi-disciplinary, multi-scale research efforts to advance a predictive understanding of processes controlling the mobility of radionuclides in the environment. This activity advances innovative scientific approaches to understanding environmental systems providing the basis for DOE's strategic goals for cleanup of legacy nuclear wastes and nuclear energy applications.

FY 2009 funding of $48,702,000 was in Environmental Remediation Sciences Research within the Biological Research subprogram.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Climate and Earth System Modeling	**0**	**69,775**	**85,622**
▪ **Regional and Global Climate Modeling**	**0**	**27,856**	**34,351**

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 regional to global. Core research areas are 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 Niño Southern Oscillation, Pacific Decadal Oscillation, and Northern Annular Mode) change as atmospheric greenhouse gas concentrations continue to increase.

In FY 2011, the focus will be on improving the accuracy of climate predictions at higher resolution. The results of a new set of coordinated experiments from about 20 modeling groups world-wide will be available as part of the Climate Model Intercomparison Project (CMIP5) archive. These model simulations will facilitate the continued development and improvement of the diagnostic tools and metrics used to evaluate the reliability of climate change projections and the multiscale natural modes of variability. Studies on understanding climate extremes, reducing the uncertainty in model predictions, and detection and attribution, and using the newly developed models will continue, as well as efforts to understand feedback processes—such as high latitude ocean-ice interaction and carbon cycle feedbacks—that are important for understanding climate change. The funding increases will provide for enhanced efforts to better represent the feedbacks produced by the indirect effect of aerosols and enhanced efforts in uncertainty quantification for climate model simulations and predictions. Current models have an unacceptably large range of uncertainty, due to differences in the simulation of feedbacks and insufficient information to properly constrain model parameters. Advanced methods coupled with leadership computing resources and integrated observational data sets can reduce these uncertainties.

FY 2009 funding of $34,820,000 was in Climate Change Modeling within Climate Change Research subprogram.

▪ **Earth System Modeling**	**0**	**30,596**	**39,611**

Earth System Modeling develops the components and the mechanisms needed to couple 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 schemes for aerosol, convection, ice sheets, and land surface 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 detection, understanding, 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 accurately simulate regional climate variability and change.

In FY 2011, the focus will be to continue the development of a comprehensive coupled earth system model at high resolution that will be the foundation for understanding climate change at regional and global scales. Improvement of the representation of the physical, chemical, and biogeochemical processes crucial for climate change prediction, such as cloud-aerosol and carbon cycle-climate, are an important part of this program. Development and testing of these processes and their incorporation into high resolution models will continue as part of this program. The program also continues development of software tools that enhance the ability to analyze high resolution model output and observational data in a single framework. This modeling program will also continue its support of Data Visualization which was initiated in 2010. FY 2008 multiyear research awards on abrupt climate change have been completed and no FY 2011 funding is required. In FY 2011, the funding increase will support three activities. First, enhanced research will focus on converting observational datasets into specialized, multi-variable datasets for model testing and improvement. This will seamlessly link and provide integration of existing and new data resources for the purpose of model development and evaluation and advancement. In addition, the increased funding supports establishment of model development testbeds in which model components can be rapidly prototyped and evaluated using integrated observational datasets, like those described above. Thirdly, the enhanced funding will also focus on the development of numerical methods to enable climate models to effectively use future computer architectures.

FY 2009 funding of $26,258,000 was in Climate Change Modeling within Climate Change Research subprogram.

	FY 2009	FY 2010	FY 2011
▪ **Integrated Assessment**	**0**	**11,323**	**11,660**

Integrated Assessment research provides scientific insights into options for mitigation of an 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.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

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; developing 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 2011, BER will continue research on several key research challenges identified in the Integrated Assessment Research Workshop held in November of 2008. In particular, Integrated Assessment will continue to provide 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 Integrated Assessment activity will continue to benefit from Recovery Act investments made in FY 2009 that provided the resources to develop open source, community-based approaches to modeling; improve capacity to conduct inter-model comparisons and multi-model studies; improve capacity to enhance convergence of models and collaborations across the Integrated Assessment, Earth System Modeling, and Impacts, Adaptation, and Vulnerability research communities, especially for regional-scale and multi-scale questions; and enhance transparency and accessibility for both data and models by the Integrated Assessment research community, their collaborators, and other user communities. Funding for this activity was increased significantly in FY 2010 to take full advantage of Recovery Act investments. The Recovery Act investments included software upgrade and development as well as short-term efforts to integrate the Recovery Act computing resources into the Integrated Assessment activity.

FY 2009 funding of $9,713,000 was in Integrated Assessment within Climate Change Research subprogram.

Climate and Environmental Facilities and Infrastructure	**0**	**99,479**	**101,333**
▪ **Atmospheric Radiation Measurement Climate Research Facility**	**0**	**41,809**	**45,770**

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.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

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 2011, ACRF will continue its long-term observations from the fixed sites and will provide data from the new instruments acquired under the Recovery Act funding. These new data include 3-D cloud evolution and properties, a broader geographic coverage of aerosol measurements, and enhanced surface characterization measurements. ACRF will conduct field experiments to study questions on aerosols and various cloud types—cirrus, marine, and mixed-phase (ice and water)—to improve process understanding as well improving regional and Earth System Models that simulate climate change. The first mobile facility will support an experiment in India to examine the impact of aerosols on the Indian monsoon. The second mobile facility will continue to examine liquid and mixed-phase clouds in Colorado. These measurements support research efforts designed to address the largest uncertainties in the climate models. ACRF will support a field experiment at the North Slope of Alaska site to study cloud and aerosol properties in the Arctic lower troposphere. The increased funding in FY 2011 will support operations of the new Recovery Act instruments resulting in new capabilities for users and new data for improving representation of clouds and aerosols in the climate models.

FY 2009 funding of $40,339,000 was in Atmospheric Radiation Measurement (ARM) Infrastructure within the Climate Change Research subprogram.

		(estimated)	
	FY 2009	FY 2010	FY 2011
Achieved Operating Hours	8,219	N/A	N/A
Planned Operating Hours	7,884	7,884	7,884
Optimal hours	7,884	7,884	7,884
Percent of Optimal Hours	104%	100%	100%
Unscheduled Downtime	0	N/A	N/A
Number of Users[a]	1,186	1,000	1,000

- **Environmental Molecular Sciences Laboratory** **0** **52,021** **51,340**

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

[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.

research on aerosol chemistry, biological systems, biogeochemistry, and interfacial and surface science.

EMSL encourages the use of multiple experimental systems to provide fundamental understanding of the physical, chemical, and biological processes that underlie DOE's energy and environmental mission areas, 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 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 2011, EMSL operations funding is increased to provide users with enhanced access to new EMSL capabilities obtained with the FY 2009 Recovery Act funding. 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. A multi-year effort to acquire a High Magnetic Field Mass Spectrometer, a major item of equipment with a total estimated cost of $17,500,000 was initiated in FY 2010 at $ 3,000,000 and is continued in FY 2011 at $7,250,000. This transformational instrument will enable users to undertake world-leading proteomics, metabolomics and lipidomics of plant, animal and microbial cells, communities and other complex systems that will have application to biofuels, systems biology, bioremediation, aerosol particle characterization, catalysis and fossil fuel analysis. 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.

FY 2009 funding of $48,953,000 was in the EMSL activity within the Biological Research subprogram.

(estimated)

	FY 2009	FY 2010	FY 2011
Achieved Operating Hours	4,376	N/A	N/A
Planned Operating Hours	4,365	4,352	4,365
Optimal hours	4,365	4,365	4,365
Percent of Optimal Hours	100%	100%	100%
Unscheduled Downtime	0	N/A	N/A
Number of Users[a]	750	750	750

[a] EMSL users are both onsite and remote. Individual users are counted once per year.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
▪ **Data Management and Education**	**0**	**4,199**	**2,773**

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.

BER's Global Climate Education Program (GCEP) is completed in FY 2010. BER will meet the outyear commitments for prior year awards. This program has achieved its goals of supporting graduate and undergraduate students with interest in climate change. BER will continue to support students with interest in climate change science through its on-going research at universities and DOE national laboratories. The Office of Science Graduate Fellowship program initiated in FY 2010 within the Workforce Development for Teachers and Scientists (WDTS) program supports graduate students pursuing advanced degrees in areas of research supported by the Office of Science, including climate change research. Likewise the Summer Undergraduate Laboratory Internship program supported by WDTS continues to support undergraduate research opportunities at the national laboratories in areas including climate science.

In FY 2011, the data management activity will continue to support data users with tools for 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.

FY 2009 funding of $2,013,000 and $1,422,000 was in Information and Integration, and Education within the Climate Change Research subprogram.

▪ **General Purpose Equipment (GPE)**	**0**	**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 support multi-purpose research.

FY 2009 funding of $112,000 was in Environmental Remediation Sciences Research activity within the Biological Research subprogram.

▪ **General Plant Projects (GPP)**	**0**	**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 GPP funding for ORISE. The total estimated cost of each GPP project will not exceed $5,000,000 in FY 2011.

	FY 2009	FY 2010	FY 2011
	(dollars in thousands)		

FY 2009 funding of $698,000 was in Environmental Remediation Sciences Research activity within the Biological Research subprogram.

SBIR/STTR	**0**	**7,442**	**8,071**

FY 2010 and FY 2011 amounts shown for the SBIR and STTR programs are the estimated requirements for continuation of these congressionally mandated programs.

Total, Climate and Environmental Sciences	**0**	**285,706**	**304,953**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Atmospheric System Research	
The increased funding will support the development of the next generation 3D cloud parameterizations.	**+1,944**
Environmental System Science	
▪ **Terrestrial Ecosystem Science**	
The increased funding will support development of 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.	+720
▪ **Terrestrial Carbon Sequestration Research**	
Funding is reduced with the completion of a series of research projects focused on the cycling of carbon sequestration associated with agriculture and forestry.	-1,747
Total, Environmental System Science	**-1,027**
Climate and Earth System Modeling	
▪ **Regional and Global Climate Modeling**	
Funding increases to enhance efforts to better represent the feedbacks produced by the indirect effect of aerosols and enhanced efforts in uncertainty quantification.	+6,495
▪ **Earth System Modeling**	
Funding increases to support focused efforts for converting observational datasets, the establishment of model development testbeds, and new numerical capabilities for transitioning climate models to new computing architectures.	+9,015

	FY 2011 vs. FY 2010 ($000)
▪ **Integrated Assessment**	
In FY 2011 Integrated Assessment will continue to provide 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.	+337
Total, Climate and Earth System Modeling	**+15,847**
Climate and Environmental Facilities and Infrastructure	
▪ **ARM Climate Research Facility**	
The increase will support operations of the new Recovery Act instruments resulting in new capabilities for users and new data for improving representation of clouds and aerosols in the climate models.	+3,961
▪ **Environmental Molecular Sciences Laboratory**	
Funding is held near FY 2010 levels. Operations funding increases are offset by reductions in capital equipment funding.	-681
▪ **Data Management and Education**	
Support for BER's Global Climate Education Program is completed in FY 2010. The Workforce Development for Teachers and Scientists program will support graduate climate science education in the DOE Office of Science Graduate Fellowship program.	-1,426
Total, Climate and Environmental Facilities and Infrastructure	**+1,854**
SBIR/STTR	
SBIR/STTR increases as the funding for research increases.	+629
Total Funding Change, Climate and Environmental Sciences	**+19,247**

Biological Research

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Biological Research			
Life Sciences	305,462	0	0
Medical Applications	8,226	0	0
Environmental Remediation	98,465	0	0
Total, Biological Research	412,153[a]	0	0

Description

The BER program has continued its investments in core fundamental science and technologies needed to address the interfaces between scientific disciplines such as biology, physics, chemistry, engineering, and information science. Within the Biological Research subprogram, the highest priority has been the Genomics: GTL program which develops an understanding of the fundamental principles underlying the function and control of biological systems.

Modifications were made to the budget structure to better reflect the subprogram's activities starting in FY 2010. The Conference report for the FY 2010 Energy and Water Development Appropriations Bill reflected this new structure.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Life Sciences	**305,462**	**0**	**0**
▪ **Structural Biology**	**15,300**	**0**	**0**

The Structural Biology program develops and supports access to beamlines and instrumentation at DOE's national user facilities for the Nation's structural biologists. BER coordinates, with the NIH and the 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]).

In FY 2010 and 2011, funding is shown in the Biological Systems Facilities and Infrastructure activity in the Biological Systems Science subprogram.

[a] $313,688,000 is associated with activities funded in the Biological Systems Science subprogram in FY 2010 and FY 2011, and $98,465,000 with activities funded in the Climate and Environmental Science subprogram.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
▪ **Molecular and Cellular Biology**	**191,391**	**0**	**0**
• **Carbon Sequestration Research**	**7,817**	**0**	**0**

Carbon sequestration research seeks to understand the fundamental mechanisms of carbon fixation, conversion and cycling in microbes, microbial communities, and plants. The program initiated a new focus on carbon sequestration and utilization for biofuels, with genomics-based research that will lead to the improved use of plant feedstocks for the production of carbon-neutral fuels such as ethanol or renewable chemical feedstocks.

In FY 2010 and 2011, funding is shown in the Metabolic Synthesis and Conversion activity in the Biological Systems Science subprogram.

• **Genomics: GTL**	**162,847**	**0**	**0**
► **Genomics: GTL Foundational Research**	**41,850**	**0**	**0**

The Foundational Research activity supports fundamental research and technology development that underpins all microbial and plant research conducted in the Genomics: GTL program overall and in the GTL Bioenergy Research Centers. GTL Foundational Research also develops the robust computational infrastructure needed to understand, predict, and ultimately use the genomic potential, cellular responses, biological regulation, and behaviors of complex biological systems of interest to the DOE mission.

In FY 2010 and 2011, funding is shown in the Foundational Genomics Research and Computational Biosciences activities in the Biological Systems Science subprogram.

► **Genomics: GTL Sequencing**	**10,000**	**0**	**0**

DNA sequence data underpins and is the starting point for all aspects of the Genomics: GTL program. The vast majority of high-throughput DNA sequencing of plants, microbes, and microbial communities conducted at the Joint Genome Institute (JGI) user facility is directly relevant to the Genomics: GTL program. Research continued within Genomics: GTL to generate DNA sequence data of individual genes as they are expressed, whole genomes, and metagenomes in order to provide essential information needed to formulate genetic engineering strategies for microbes and plants, to understand plant and microbe molecular machines, to determine the composition of complex microbial communities, and to dissect plant-microbe associations.

In FY 2010 and 2011, funding is shown in the Genomics Analysis and Validation activity in the Biological Systems Science subprogram.

► **Genomics: GTL Biohydrogen Research**	**15,661**	**0**	**0**

This activity supports innovative systems biology research with a specific emphasis on biological hydrogen production, such as the discovery and development of improved or oxygen-tolerant hydrogenases, characterization of specific cellular architecture to facilitate electron transfer for optimum hydrogen production, and the redirection of metabolic

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

pathways and metabolite flow into hydrogen production. While this activity draws upon the foundational research and technology development within the broader GTL portfolio, it is specifically directed towards scientific issues and challenges unique to biological hydrogen production.

In FY 2010 and 2011, funding is shown in the Metabolic Synthesis and Conversion activity in the Biological Systems Science subprogram.

► **Genomics: GTL Bioethanol Research**	**20,336**	**0**	**0**

Cellulosic ethanol is a carbon-neutral fuel that can already be used within today's energy infrastructure. Microbes or microbial processes are used to produce ethanol from residues such as corn plants left after a corn harvest or energy crops such as poplar trees that are specifically grown as biomass for energy production. While this activity draws upon the foundational research and technology development within the broader GTL portfolio it is specifically directed towards scientific issues and challenges unique to understanding the metabolic conversion of 5- and 6-carbon sugars to ethanol.

In FY 2010 and 2011, funding is shown in the Metabolic Synthesis and Conversion activity in the Biological Systems Science subprogram.

► **Genomics: GTL Bioenergy Research Centers**	**75,000**	**0**	**0**

The three DOE Bioenergy Research Centers, all involving academic, industrial, and national laboratory scientists, are designed to accomplish the GTL program objectives more effectively. The centers serve as catalysts for innovation and change, by concentrating appropriate technologies and scientific expertise to go from the genome sequence to an integrated systems understanding of the pathways and internal structures of plants and microbes most relevant to the steps required to develop bioenergy compounds.

In FY 2010 and 2011, funding is shown in the Bioenergy Research Centers within the Biological Systems Science subprogram.

• **Low Dose Radiation Research**	**20,727**	**0**	**0**

The Low Dose Radiation Research activity supports research that will help determine health risks from exposures to low levels of ionizing radiation; information critical to adequately and appropriately protecting individuals, and to making more effective use of our national resources. Information developed in this program will provide a better scientific basis for making decisions with regard to remediating 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. Some research in this program is jointly funded with NASA's Office of Biological and Physical Research.

In FY 2010 and 2011, funding is shown in the Radiobiology activity in the Biological Systems Science subprogram.

	FY 2009	FY 2010	FY 2011
	(dollars in thousands)		
▪ **Human Genome**	**70,000**	**0**	**0**
• **Joint Genome Institute, Production Genomics Facilities**	**55,000**	**0**	**0**

The Joint Genome Institute's (JGI) high-throughput DNA sequencing factory, the Production Genomics Facility (PGF) is focused on helping to meet the demand for DNA sequencing in the broader energy and environment scientific community.

In FY 2010 and 2011, funding is in Joint Genome Institute within the Biological Systems Science subprogram.

	FY 2009	FY 2010	FY 2011
• **Tools for DNA Sequencing and Sequence Analysis**	**10,000**	**0**	**0**

BER develops the tools and resources needed by the scientific, medical, and industrial sector communities to fully exploit the information contained in complete DNA sequences, from energy-relevant microbes to low dose radiation effects.

In FY 2010 and 2011, funding is in the Joint Genome Institute activity in the Biological Systems Science subprogram.

	FY 2009	FY 2010	FY 2011
• **Ethical, Legal, and Societal Issues (ELSI)**	**5,000**	**0**	**0**

BER ELSI research supports activities applicable to Office of Science issues in bioenergy, synthetic biology, and nanotechnology, including exploration of, and communication of, the societal implications arising from these programs.

In FY 2010 and 2011, funding is in the Ethical, Legal, and Societal Issues (ELSI) activity in the Biological Systems Science subprogram.

	FY 2009	FY 2010	FY 2011
▪ **Health Effects**	**5,937**	**0**	**0**

Health effects research in functional genomics provides a link between human genomic sequencing and the development of information that is useful in understanding normal human development and disease processes including susceptibility to low doses of ionizing radiation.

In FY 2010 and 2011, funding is in the Radiobiology activity in the Biological Systems Science subprogram.

	FY 2009	FY 2010	FY 2011
▪ **Radiochemistry and Instrumentation**	**22,834**	**0**	**0**

BER supports basic research that builds on unique DOE capabilities in physics, chemistry, engineering, and computational science. It supports fundamental imaging research, maintains core infrastructure for imaging research and development, including innovative imaging technology with respect to new radiochemistry and radiotracer methodologies for precise and dynamic metabolic imaging of biological organisms.

In FY 2010 and 2011, funding is in Radiochemistry and Imaging Instrumentation within the Biological Systems Science subprogram.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Medical Applications			
▪ **Artificial Retina**	**8,226**	**0**	**0**

BER utilized the resources of the national laboratories in material sciences, engineering, microfabrication, and microengineering to develop unique neuroprostheses and continue development of an artificial retina to restore sight to the blind.

In FY 2010 and 2011, funding is in the Medical Applications activity within the Biological Systems Science subprogram.

Environmental Remediation	**98,465**	**0**	**0**
▪ **Environmental Remediation Sciences Research**	**48,702**	**0**	**0**

Environmental Remediation Sciences research activities address questions of fundamental environmental remediation science at the interfaces of biology, chemistry, geology, and physics. The research will help to provide the scientific foundation for the solution of key environmental challenges within DOE's cleanup mission at scales ranging from molecular to the field, including issues of fate and transport of contaminants in the environment; novel strategies for *in situ* remediation; and long-term monitoring of remediation strategies.

In FY 2010 and 2011, Environmental Remediation Sciences Research funding is in Subsurface Biogeochemical Research within the Climate and Environmental Sciences subprogram.

▪ **General Purpose Equipment (GPE)**	**112**	**0**	**0**

GPE funding will increase to provide 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 support multi-purpose research.

In FY 2010 and 2011, GPE funding is in Climate and Environmental Facilities and Infrastructure within the Climate and Environmental Sciences subprogram

▪ **General Plant Projects (GPP)**	**698**	**0**	**0**

GPP funding continued for minor new construction, other capital alterations and additions, and for buildings and utility systems, such as replacing infrastructure 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 included stewardship GPP funding for ORISE.

In FY 2010 and 2011, GPP funding is in Climate and Environmental Facilities and Infrastructure within the Climate and Environmental Sciences subprogram.

▪ **Facility Operations**	**48,953**	**0**	**0**

The William R. Wiley Environmental Molecular Sciences Laboratory (EMSL), a national 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 to support the needs of DOE and the Nation.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
• **EMSL Operating Expenses**	**34,223**	**0**	**0**

Operating funds are used for: staff support for users; maintenance of instruments and buildings; utilities; environmental safety and health compliance activities; and communications. With over 55 leading-edge instruments and a supercomputer system, EMSL annually supports approximately 700 users. The core EMSL science team networks with the broader academic community as well as with DOE national laboratories and other agencies. EMSL users have access to unique expertise and instrumentation for environmental research, including a high performance computer; a 900 MHz nuclear magnetic resonance (NMR) spectrometer that highlights a suite of NMRs in EMSL; a collection of mass spectrometers, including an 11.5 Tesla high performance mass spectrometer; laser desorption and ablation instrumentation; ultra-high vacuum scanning, tunneling and atomic force microscopes; and controlled atmosphere environmental chambers.

In FY 2010 and 2011, funding for EMSL Operating Expenses is in EMSL Operations and Infrastructure within the Climate and Environmental Sciences subprogram.

• **Capital Equipment**	**5,987**	**0**	**0**

Capital equipment support for the EMSL enables instrument modifications needed by collaborators and external users of the facility as well as the ability to make upgrades to existing instrumentation and to provide additional capabilities in order to maintain EMSL capabilities for environmental molecular scientific research.

In FY 2010 and 2011, funding for EMSL Capital Equipment is in EMSL Operations and Infrastructure within the Climate and Environmental Sciences subprogram.

• **EMSL GPP**	**8,743**	**0**	**0**

GPP is provided to initiate development and construction of an addition to EMSL.

In FY 2010 and 2011, funding for EMSL GPP is in EMSL Operations and Infrastructure within the Climate and Environmental Sciences subprogram.

Total, Biological Research	**412,153**	**0**	**0**

Climate Change Research

Funding Schedule by Activity

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Climate Change Research			
Climate Forcing	81,727	0	0
Climate Change Modeling	61,078	0	0
Climate Change Response	25,114	0	0
Climate Change Mitigation	5,104	0	0
Total, Climate Change Research	173,023[a]	0	0

Description

BER priorities within the Climate Change Research subprogram are to develop the ability to predict climate on global and regional scales; to explore the impacts of excess atmospheric CO_2 on the Earth system; to develop strategies for its removal and sequestration from the atmosphere; and, provide the science to underpin the prediction of the impacts of climate change. These priorities will depend on the continued development of novel research tools and a close integration of experimental, observational, and computational research.

Modifications were made to the budget structure to better reflect the subprogram's activities starting in FY 2010. The Conference report for the FY 2010 Energy and Water Development Appropriations Bill reflected this new structure.

Detailed Justification

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Climate Forcing	**81,727**	**0**	**0**
▪ **Atmospheric Radiation Measurement (ARM) Research**	**15,079**	**0**	**0**

A major emphasis in the Climate Forcing area of the Climate Change Research subprogram 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 FY 2010 and 2011, funding is shown in Atmospheric System Research within the Climate and Environmental Sciences subprogram.

[a] Associated FY 2010 and 2011 activities are funded in the Climate and Environmental Sciences subprogram.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
▪ **Atmospheric Radiation Measurement (ARM) Infrastructure**	**40,339**	**0**	**0**

The ARM infrastructure activity will continue to support and upgrade the operation of the ARM Climate Research Facility (ACRF). The ACRF consists of three stationary facilities, an ARM Mobile Facility (AMF), and the ARM Aerial Vehicles Program (AAVP). The stationary sites provide scientific testbeds in three different climatic 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 AMF provides a capability to address high priority scientific questions in regions other than the stationary sites. The AAVP provides a capability to obtain *in situ* cloud and radiation measurements that complement the ground-based measurements.

In FY 2010 and 2011, funding is shown in ARM Operations and Infrastructure within the Climate and Environmental Sciences subprogram.

▪ **Atmospheric Science**	**10,334**	**0**	**0**

The Atmospheric Science Program is focused on the radiative effects of atmospheric aerosols, the greatest source of uncertainty in global radiative forcing of climate change over the last century. To enable more reliable and accurate simulations of direct and indirect aerosol climate forcing, the program conducts research on the atmospheric processes that control the formation, transport, transformations, and removal of atmospheric aerosols as these affect their distribution, radiative, and cloud nucleating properties.

In FY 2010 and 2011, funding is shown in the Atmospheric System Research activity within the Climate and Environmental Sciences subprogram.

▪ **Terrestrial Carbon Processes**	**13,962**	**0**	**0**

BER continues support of AmeriFlux, a network of research sites where the net exchange of carbon dioxide, energy, and water between the atmosphere and major terrestrial ecosystems in North America is continuously measured.

The AmeriFlux Network research sites provided extensive measurements of terrestrial carbon sink properties, including biological and soil carbon processes. This research is important for evaluating what happens to carbon dioxide emissions from combustion of fossil fuels, and provides scientific information needed for prognostic modeling of the rate of atmospheric carbon dioxide increase, which is a key forcing factor of climate.

In FY 2010 and 2011, funding is shown in Terrestrial Ecosystem Science within the Climate and Environmental Sciences subprogram.

▪ **Information and Integration**	**2,013**	**0**	**0**

The Information and Integration element of Climate Forcing research continued to store, evaluate, quality assure, and disseminate a broad range of climate change related data, especially data on atmospheric concentrations and industrial emissions of greenhouse gases, greenhouse gas fluxes from terrestrial systems, ocean CO_2 data, and air quality data. This is accomplished by supporting the Carbon Dioxide Information and Analysis Center (CDIAC). CDIAC's data holdings include records of the concentrations of carbon dioxide and other radiatively active gases in the atmosphere;

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

the role of the terrestrial biosphere and the oceans in the biogeochemical cycles of greenhouse gases; emissions of carbon dioxide to the atmosphere; long-term climate trends; the effects of elevated carbon dioxide on vegetation; and the vulnerability of coastal areas to rising sea level.

In FY 2010 and 2011, funding is shown in Data Management and Education within the Climate and Environmental Sciences subprogram.

Climate Change Modeling	**61,078**	**0**	**0**

BER's Climate Change Modeling program addresses uncertainty in simulating Regional and Global Climate Change. 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.

BER's SciDAC for Climate Change Research continued partnerships with the Advanced Scientific Computing Research program.

In FY 2010 and 2011, funding is shown in the Climate and Earth System Modeling activity within the Climate and Environmental Sciences subprogram.

Climate Change Response	**25,114**	**0**	**0**
▪ **Ecosystem Function and Response**	**13,979**	**0**	**0**

The goal of the Ecosystem Function and Response research activity is to understand the potential effects of climatic change anticipated during the coming 50-100 years on the health of important terrestrial ecosystems in the United States. The primary focus is experimental studies of the potential effects of warming on the abundance and geographic distribution of plant and animal species in several ecosystem types. The experiments will be conducted to fill specific critical knowledge gaps. In particular, experiments will determine linkages between warming and the possibility of species migrations, the expansion of species into areas that are presently too cool for their success, and the decline of species or ecosystems presently at the warm edge of their ranges.

In FY 2010 and 2011, funding is shown in Terrestrial Ecosystem Science within the Climate and Environmental Sciences subprogram.

▪ **Integrated Assessment**	**9,713**	**0**	**0**

BER's Integrated Assessment (IA) Research supports underlying research and development of the basic methods and models for estimating costs and benefits of global climate change and possible actions to mitigate such change. Understanding the underlying and complex human-earth systems dynamics are a priority for IA research.

In FY 2010 and 2011, funding is shown in Integrated Assessment within Climate and Earth System Modeling in the Climate and Environmental Sciences subprogram.

▪ **Education**	**1,422**	**0**	**0**

BER's Global Change Education Program continues to support both undergraduate and graduate studies in FY 2009 through the DOE Summer Undergraduate Research Experience (SURE) and the DOE Graduate Research Environmental Fellowships (GREF).

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

In FY 2010 and 2011, funding is shown in Data Management and Education within the Climate and Environmental Sciences subprogram.

Climate Change Mitigation	**5,104**	**0**	**0**

BER's carbon sequestration research, part of BER's support to the Climate Change Technology Program, continued to focus only on terrestrial carbon sequestration. Research continues on studies to enhance long-term sequestration processes and the stability of stored carbon in terrestrial vegetation and soils.

In FY 2010 and 2011, funding is shown in Terrestrial Carbon Sequestration Research within the Climate and Environmental Sciences subprogram.

Total, Climate Change Research	**173,023**	**0**	**0**

Supporting Information

Operating Expenses, Capital Equipment and Construction Summary

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Operating Expenses	561,792	576,818	601,786
Capital Equipment	13,943	24,164	24,414
General Plant Projects (GPP)	9,441	3,200	700
Total BER	585,176	604,182	626,900

Funding Summary

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Research	406,031	395,251	419,290
Scientific User Facilities Operations and Research	169,592	178,130	182,060
Major Items of Equipment	0	10,700	7,250
Facility related GPP	8,743	2,500	0
Other[a]	810	17,601	18,300
Total BER	585,176	604,182	626,900

Scientific User Facilities Operations and Research

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Biological Systems Science			
Structural Biology Infrastructure	15,300	15,300	15,683
Joint Genomics Institute	65,000	69,000	69,267
Total, Biological Systems Science	80,300	84,300	84,950
Climate and Environmental Sciences			
Atmospheric Radiation Measurement Climate Research Facility	40,339	41,809	45,770
Environmental Molecular Sciences Laboratory	48,953	52,021	51,340
Total, Climate and Environmental Science	89,292	93,830	97,110
Total Science User Facilities Operations and Research	169,592	178,130	182,060

[a] Includes SBIR, STTR, GPE, and non-Facility related GPP.

Facilities Users and Hours

	FY 2009	FY 2010	FY 2011
Joint Genome Institute			
Achieved Operating Hours	8,400	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	100%	100%	100%
Unscheduled Downtime	0	N/A	N/A
Number of Users[a]	780	940	940
Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF)			
Achieved Operating Hours	8,219	N/A	N/A
Planned Operating Hours	7,884	7,884	7,884
Optimal hours	7,884	7,884	7,884
Percent of Optimal Hours	104%	100%	100%
Unscheduled Downtime	0	N/A	N/A
Number of Users[b]	1,186	1,000	1,000
Environmental Molecular Sciences Laboratory			
Achieved Operating Hours	4,376	N/A	N/A
Planned Operating Hours	4,365	4,352	4,365
Optimal hours	4,365	4,365	4,365
Percent of Optimal Hours	100%	100%	100%
Unscheduled Downtime	0	N/A	N/A
Number of Users[c]	750	750	750

[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.

[c] EMSL users are both onsite and remote. Individual users are counted once per year.

	FY 2009	FY 2010	FY 2011
Total Facilities			
Achieved Operating Hours	20,995	N/A	N/A
Planned Operating Hours	20,649	20,636	20,649
Optimal hours	20,649	20,649	20,649
Percent of Optimal Hours	104%	100%	100%
Unscheduled Downtime	0	N/A	N/A
Number of Users	2,716	2,690	2,690

Structural Biology Infrastructure activities are at Basic Energy Sciences user facilities and the user statistics are included in the BES user statistics.

Major Items of Equipment

(dollars in thousands)

	Prior Years	FY 2009	FY 2009 Recovery Act	FY 2010	FY 2011	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)	0	0	3,070	0	0	0	3,070
Dual-Frequency Scanning Cloud Radar for North Slope of Alaska ARM Site							
TEC/TPC	0	0	3,070	0	0	0	3,070
Dual-Frequency Scanning Cloud Radar for Tropical Western Pacific (Manus) ARM Site							
TEC/TPC	0	0	3,070	0	0	0	3,070
Dual-Frequency Scanning Cloud Radar for ARM Mobile Facility #1							
TEC/TPC	0	0	3,070	0	0	0	3,070
Dual-Frequency Scanning Cloud Radar for ARM Mobile Facility #2							
TEC/TPC	0	0	3,070	0	0	0	3,070
Dual-Frequency Scanning Cloud Radar for Tropical Western Pacific (Darwin) ARM Site							
TEC/TPC	0	0	3,070	0	0	0	3,070

(dollars in thousands)

	Prior Years	FY 2009	FY 2009 Recovery Act	FY 2010	FY 2011	Outyears	Total
Total ACRF TEC/TPC	0	0	18,420	0	0	0	18,420
Environmental Molecular Sciences Laboratory (EMSL)							
Field Emission-Transmission Electron Microscope (FE-TEM)							
TEC/TPC	4,500	0	0	0	0	0	4,500
Standard Transmission Electron Microscope (TEM)							
TEC/TPC	0	0	2,940	0	0	0	2,940
X-ray Phototelectron Spectrometer (XPS)							
TEC/TPC	0	0	2,027	0	0	0	2,027
3-D Atom Probe							
TEC/TPC	0	0	2,280	0	0	0	2,280
Electron Microprobe							
TEC/TPC	0	0	2,250	0	0	0	2,250
700 Megahertz Wide Bore Nuclear Magnetic Resonance (NMR) Spectrometer							
TEC/TPC	0	0	2,640	0	0	0	2,640
15 Tesla Fourier Transform-Ion Cyclotron Resonance (FT-ICR) Mass Spectrometer (MS)							
TEC/TPC	0	0	2,840	0	0	0	2,840
Ultra-High Vacuum (UHV) Scanning Tunneling Microscope/Atomic Force Microscope (STM/AFM)							
TEC/TPC	0	0	2,200	0	0	0	2,200
850 Megahertz Wide Bore Nuclear Magnetic Resonance (NMR) Spectrometer							
TEC/TPC	0	0	4,830	0	0	0	4,830
3-D Microscope System							
TEC/TPC	0	0	2,250	0	0	0	2,250

(dollars in thousands)

	Prior Years	FY 2009	FY 2009 Recovery Act	FY 2010	FY 2011	Outyears	Total
Advanced Mass Spectrometry System							
TEC/TPC	0	0	2,900	0	0	0	2,900
Advanced Oxygen Plasma Assisted Molecular Beam Epitaxy system							
TEC/TPC	0	0	0	3,200	0	0	3,200
Secondary Ion Mass Spectrometer							
TEC/TPC	0	0	0	4,500	0	0	4,500
Next Generation, High Magnetic Field Mass Spectrometer							
TEC/TPC	0	0	0	3,000	7,250	7,250	17,500
Total EMSL TEC/TPC	4,500	0	27,157	10,700	7,250	7,250	56,857
Total BER TEC/TPC	4,500	0	45,577	10,700	7,250	7,250	75,277

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.

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 enable nano-meter structural and chemical characterization of complex synthesized and natural materials relevant to catalysis, fuel 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. The XPS will be used to study mineral/contaminant interactions, aging and degradation of solar cells and solid state lighting and catalytic surfaces.

3-D Atom Probe for three dimensional atomic scale imaging of complex materials including solid-solid "buried" interfaces. This system will be used for material surface studies relevant to subsurface remediation, photovoltaics and catalysis.

Electron Microprobe provides elemental composition and structural imaging of materials/minerals. This capability has relevance to radiological applications such as waste storage and processing.

700 Megahertz Wide Bore Nuclear Magnetic Resonance (NMR) Spectrometer system is used 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. This capability will enable the study of intact and modified proteins, and will 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. This system will 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 will be used to study energy-relevant materials (including catalysts) and minerals and contaminants.

3-D Microscope System 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.

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 system is designed for the growth of a wide variety of oxide materials and will be funded at $3,200,000 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 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 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. The system 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 2009 Estimate	FY 2010 Estimate	FY 2011 Estimate
# University Grants	489	475	490
Average Size per year	$320,000	$320,000	$320,000
# Laboratory Projects	377	234[a]	195
# Permanent Ph.D.s[b]	1,480	1,460	1500
# Postdoctoral Associates[c]	340	335	345
# Graduate Students[c]	485	480	495
# Ph.D.s awarded[d]	105	110	110

[a] In FY 2010, BER consolidated funding for laboratories resulting in fewer individual projects.
[b] 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.
[c] Estimated for national laboratory projects.
[d] 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.

Fusion Energy Sciences

Funding Profile by Subprogram

(dollars in thousands)

	FY 2009 Current Appropriation	FY 2009 Current Recovery Act Appropriation[a]	FY 2010 Current Appropriation	FY 2011 Request
Fusion Energy Sciences				
Science	163,479	+57,399	182,092	185,940
Facility Operations	207,649	+33,624	220,717	170,020
Enabling R&D	23,390	0	23,191	24,040
Total, Fusion Energy Sciences	394,518[b]	+91,023	426,000	380,000

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 FES mission is to expand the fundamental understanding of matter at very high temperatures and densities and to develop the scientific foundations needed to develop a fusion energy source. This is accomplished by studying plasmas and their interactions with their surroundings under a wide range of temperature and density, developing advanced diagnostics to make detailed measurements of their properties, and creating theoretical and computational models to resolve the essential physics.

Background

The physics of plasmas is at the heart of understanding how stars shine and evolve over billions of years. Plasmas, essentially hot gases of ions and electrons, are found in environments as familiar as fluorescent lighting and lightning bolts, as unimaginably harsh as the centers of stars, and as exotic as the environments surrounding super massive black holes. The science of plasma physics that describes the plasmas in these environments also describes the auroras that gently illuminate the northern and southern skies and the solar corona, where temperatures are far higher than on the sun's surface. At the scale of the very small, plasma physics and materials science combine to enable the exquisitely precise manufacture of semiconductors. Plasma science is also at the heart of advances in efficiencies in the lighting industry.

Plasma science forms the basis for research that is needed to establish our ability to harness the power of the stars in order to generate fusion energy on earth. The successful development of this science and relevant supporting sciences may have enormous implications for the future. The plasma and materials science needed to form the essential understanding required for fusion energy is both rich and far-reaching. The research central to the highest level goals of fusion research—the creation of an energy source with a virtually limitless fuel supply, with low level radioactive waste, and with no carbon emission—has a reach even broader than these ambitious goals suggest. The research required for

[a] The Recovery Act Current Appropriation column reflects the allocation of funding as of September 30, 2009.
[b] Total is reduced by $8,032,000: $7,171,000 of which was transferred to the SBIR program and $861,000 of which was transferred to the STTR program.

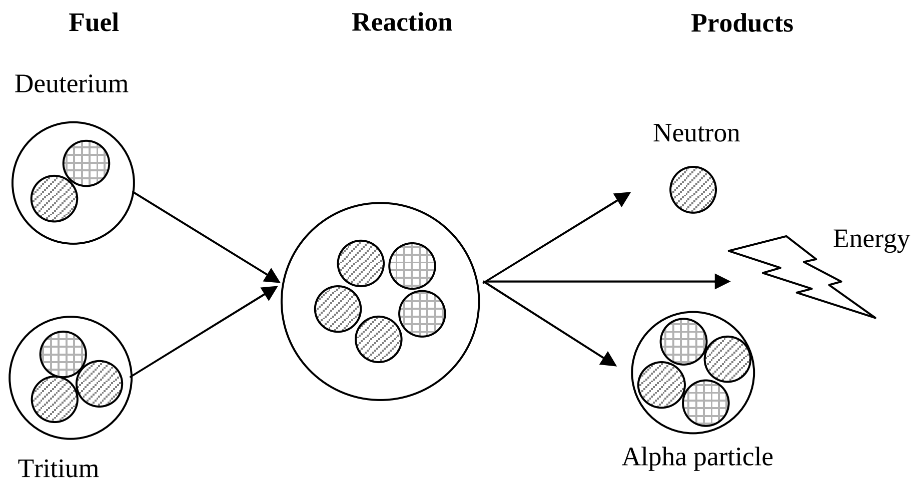
fusion energy's success is intimately tied to rich scientific questions about some of nature's most extreme environments, inside and outside of stars, and has practical implications to industry beyond energy as well.

One measure of the progress in plasma physics to date can in part be seen in the fact that the densities and temperatures required for fusion on earth are now routinely obtained in the laboratory. Scaling the results from present fusion experiments to those required for energy production, this research is providing a stronger experimental basis for future fusion. But while experimental scaling of results is encouraging and important, progress in fusion science goes beyond this. It is grounded in an increasingly deep, experimentally validated theoretical understanding that is growing in parallel with these empirical accomplishments. This validation forms the foundation of computational tools used to understand and predict the behavior of natural and man-made plasmas systems, including burning plasmas for fusion energy. From this foundation, the ever-increasing sophistication of simulation with massively parallel computing is improving our ability to predict the performance of experimental systems. Such simulation is being used as a tool for discovery in itself and is guiding experimental choices, a sign of increasing maturity of the field and increasing readiness to embrace the practical challenges of fusion energy development.

The tools developed for advancing fusion's scientific base are also being used as tools for general scientific discovery beyond the fusion realm. An example is our increasing understanding of the anomalous heating of the solar corona, where plasma physics common to both fusion energy in the laboratory and plasmas in the natural world provides the basis for unraveling this mystery. Fusion's theory-based computational tools have also recently been used to explain the unexpectedly low brightness of the accretion of plasma in the extraordinary environment surrounding super massive black holes in the center of our galaxy. Once regarded as too complex to allow anything except an empirical approach, our understanding of the fundamental laws governing the gross dynamics of plasmas, including the challenge of understanding the nonlinearly saturated state of plasmas turbulence, has undergone significant transformation in the past 20 years.

The transformation of plasma science from empirical to predictive has come from a sustained investment in flexible experiments that can explore an ever-increasing range of plasma conditions, advanced diagnostics that sample plasma phenomena at temporal and spatial scales covering many orders of magnitude, and simulation capability that also can capture these disparate scales and offers the promise of integrated, validated simulation of burning plasmas in the laboratory and in future energy producing reactors. Importantly, plasma science has also been advanced by vigorous national and international collaboration where fusion's puzzles and challenges have been addressed in joint experiments promoted by international physics activities.

Today, FES investments are focused on extending this progress into the yet unexplored regime of self-sustaining, or burning, fusion reactions. Since the earliest work on fusion energy, most fusion reactor concepts have shared a common approach—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 both the magnetic fusion energy science (MFES) and inertial fusion energy science (IFES) programs. 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 by the fusion reaction itself, primarily by the self-heating from alpha particles, energetic helium ions produced by the fusion reactions.

To sustain the fusion reactions 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 magnetic fusion energy science and in plasma science, including activities related to IFES through investigation of the fundamental science of high energy density laboratory plasmas (HEDLP).

The MFES program is now moving into the burning plasma regime through the U.S. participation in ITER, an international fusion research facility under construction in Cadarache, France, which will be the world's first magnetic fusion facility large enough to achieve a burning plasma and investigate its characteristics. 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. The 9.09% share of ITER construction 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 the U.S. contribution. In addition to ITER, the United States collaborates with these partners on current fusion research facilities and programs through International Energy Agency and bilateral agreements. The inertial fusion program within the National Nuclear Security Administration (NNSA) is also moving into the burning plasma regime with the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory.

With the initiation of the ITER project and the recent completion of NIF, plasma science research is at the threshold of new discoveries that will transform the field. Both magnetic fusion and inertial fusion sciences have progressed to the point where the fusion community has the knowledge not only to design a burning plasma device, 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 four strategic goals:

- 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 explore the feasibility of the inertial confinement approach as a fusion energy source, to better understand our universe, and to enhance national security and economic competitiveness;
- Support the development of the scientific understanding required to design and deploy the materials needed to support a burning plasma environment; and
- Increase the fundamental understanding of basic plasma science, including both burning plasma and low temperature plasma science and engineering, to enhance economic competiveness and to create opportunities for a broader range of science-based applications.

These distinct but strongly linked and synergistic goals are unified by fundamental plasma science, the scientific foundation for a fusion energy source. The goals also reflect a synthesis of input from the National Academies, the Fusion Energy Sciences Advisory Committee (FESAC), and the U.S. fusion community.

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 three decades, the development of advanced computation and simulation capability in the areas of energy transport and plasma stability needed to design a device capable of achieving a burning plasma with significant fusion energy output, and the demonstrated control of plasma states that scale favorably to burning plasmas and future fusion reactors.

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 plasmas properties, including their dynamics and their interactions with surrounding materials. The emphasis is presently weighted towards understanding the plasma state and its properties for stable magnetically confined 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. Also, plans call for extending this class of research activity, further leveraging the scientific basis established for magnetic fusion to other areas. This includes research to investigate the fundamental science of HEDLP.
- The *Facility Operations* subprogram includes efforts to build, operate, maintain, and upgrade the large facilities needed to carry out research on fusion energy science. It also includes 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 *Enabling R&D* subprogram supports research to optimize and control plasma states in the laboratory, increasing the scientific output of present experiments and the likelihood of success of future fusion facilities. Research is aimed at improving the components and systems that are used to build present and future fusion facilities, thereby enabling them to achieve improved performance and scientific output and bring us closer to the goal of achieving practical fusion energy.

Benefits

The development of plasma science 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 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 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 neutrons) 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 could cost about the same as electricity from other 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 also 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.

During 2008 and 2009, FES sponsored a series of workshops focused on providing input for a new FES strategic plan. The first workshop covered the field of low temperature plasma physics and produced the report entitled *Low Temperature Plasma Science: Not only the Fourth State of Matter but All of Them*[a] in September 2008. More recently, FES organized a community-wide effort that culminated in an MFES Research Needs Workshop (ReNeW) in June 2009 to describe the scientific research required during the ITER era to develop the knowledge needed for a practical fusion power source. The report on the results from this workshop entitled *Research Needs for Magnetic Fusion Energy Sciences*[a] was published in September 2009. Two FESAC reports, *Priorities, Gaps and Opportunities: Towards a Long-Range*

[a] The 2008/2009 reports are located at http://www.science.doe.gov/ofes/programdocuments.shtml.

Strategic Plan for Magnetic Fusion Energy (October 2007)[a] and *Report of the FESAC Toroidal Alternates Panel* (December 2008)[a], and a series of topical workshops provided the technical basis for this ReNeW workshop.

A Research Needs Workshop for HEDLP was held in November 2009 to evaluate research opportunities in fundamental high energy density plasma science and in inertial fusion energy related high energy density plasma science. A FESAC report on scientific issues and opportunities in both fundamental and mission-driven HEDLP, entitled *Advancing the Science of High Energy Density Laboratory Plasmas*, was used as the technical basis for the workshop. This report documents the issues and opportunities that can be pursued over the next decade through the joint program in HEDLP. SC and NNSA have jointly appointed FESAC as the federal Advisory Committee for the FES-NNSA joint program in HEDLP. The HEDLP ReNeW report is expected to be published in the March 2010 timeframe.

The reports from the research needs workshops will be used by FES as a major part of the input used in its strategic planning activities. The planning is aimed, in part, at accelerating work on the scientific and technical foundations for a fusion energy source. The planning activities will also describe increased FES stewardship of general plasma science as recommended by the National Research Council (NRC) report entitled *Plasma Science: Advancing Knowledge in the National Interest* [a].

To assist in the management and coordination of U.S. scientific and technical activities in support of ITER, and to prepare for the eventual participation by U.S. scientists in ITER operations and research, FES established 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 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.

FES requires the three major experimental facilities supported by the program to have Program Advisory Committees (PACs). The PACs serve an 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.

FES charges FESAC to convene a Committee of Visitors (COV) panel every three years to assess the efficacy and quality of the processes used to solicit, review, recommend, monitor, and document application, proposal, and award actions and the quality of the resulting portfolio. A new COV charge was given to FESAC in November 2008 asking FESAC to review the entire FES program and report its findings. The COV has conducted its review, meeting with the FES program staff in August 2009. The COV will present its findings to the full committee at the first FESAC meeting of 2010. The final FESAC report on this COV activity is expected to be published about one month after that FESAC meeting.

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*[a], 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 at the NNSA high energy density 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

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[a] The 2008/2009 reports are located at http://www.science.doe.gov/ofes/programdocuments.shtml.

science of high energy density plasmas is important to science-based nuclear stockpile stewardship as well as to 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 HEDLP areas funded by NNSA, including compressible and radiative hydrodynamics, laser-plasma interactions, material properties under extreme conditions, and laboratory astrophysics. FES and NNSA HEDLP research is being coordinated through the joint program, with coordinated solicitations, peer reviews, scientific workshops, and Federal Advisory Committee input.

Budget Overview

The FES program is the primary supporter of research in the field of plasma physics in the United States. The FY 2011 budget request is designed to optimize the scientific productivity of the program. The FES program funds activities involving over 1,100 researchers and students in 31 states at approximately 63 universities, 9 industrial firms, 10 national laboratories, and 2 Federal laboratories. Some of the key activities of the FES program and their status in the FY 2011 budget request follow:

- The United States will continue funding to meet our obligations in 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 emphasize the importance 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 building the predictive science needed for ITER operations and providing solutions to high-priority ITER technical issues. 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. Maintaining a high level of facility usage and upgrades so as to best exploit these investments is a priority.
- The Fusion Simulation Program (FSP) transitions from its 2-year (FY 2009-FY 2010) planning phase to the full program. 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.
- Plasma Science Centers (PSCs) support multi-institutional teams to work on some of the most important and challenging plasma science problems of our time. Recognizing this, FES will continue to provide support for the operation of three plasma science centers. The PSCs are intended to establish academic centers of excellence that will focus on fundamental issues of widely recognized importance to plasma science. In addition to the science that is fostered in this research, the education and training of plasma scientists is a major goal of this program.
- FES investments in emerging scientific opportunities in HEDLP are positioning the U.S. to assert strong leadership in this growing field of plasma science. FES and NNSA intend to expand the joint research program that was initiated in FY 2009. The Materials in Extreme Conditions (MEC) end station at the recently commissioned Linac Coherent Light Source at SLAC will permit studies of high energy states of matter with unprecedented precision. The Neutralized Drift Compression

Experiment-II (NDCX-II) will enable enhanced warm dense matter experiments relevant to the interiors of giant planets and to the high energy density science underpinning the concept of heavy ion fusion. This program will continue to explore a number of fields of research identified as priorities by both the National Academies and FESAC, including basic research on the science of fast ignition, laser-plasma interaction, magnetized high energy density plasmas, plasma jets, and warm dense matter. An increase is proposed in FY 2011 with further increases planned for future years.

- A modest increase in fusion-related materials science research is proposed in this budget. One of the clearest recommendations that comes from the magnetic fusion community from the ReNeW process and underscored by the FESAC report entitled "*Priorities, Gaps, and Opportunities*," described above, is the need to develop the materials science essential to practical fusion energy. Indeed, pursuit of this research by the United States provides an opportunity to assert leadership worldwide in this important area. Full maturation of this endeavor in the coming years will require sensible collaboration with other research programs in the Department, including those stewarded by Basic Energy Sciences.

Annual Performance Results and Targets

Secretarial Priority: Innovation: Lead the world in science, technology, and engineering.

GPRA Unit Program Goal: Fusion Energy Sciences Program Goal: 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.

Annual Performance Measure: Conduct experiments on the major fusion facilities (DIII-D, Alcator C-Mod, NSTX) leading toward the predictive capability for burning plasmas and configuration optimization.

FY 2006	T: Inject 2 MW of neutral beam power in the counter direction on DIII-D and begin physics experiments. A: Goal met
FY 2007	T: Measure and identify magnetic modes on NSTX that are driven by energetic ions traveling faster than the speed of magnetic perturbations (Alfvén speed); such modes are expected in burning plasmas such as ITER. A: Goal met
FY 2008	T: Evaluate the generation of plasma rotation and momentum transport, and assess the impact of plasma rotation on stability and confinement. Alcator-Mod will investigate rotation without external momentum input, NSTX will examine very high rotation speeds, and DIII-D will vary rotation speeds with neutral beams. The results achieved at the major facilities will provide important new data for estimating the magnitude of and assessing the impact of rotation on ITER plasmas. A: Goal met

FY 2009	T: 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. A: Goal met
FY 2010	T: 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. A: TBD
FY 2011	T: Improve the understanding of the physics mechanisms responsible for the structure of the pedestal and compare with the predictive models described in the companion theory milestone. Perform experiments to test theoretical physics models in the pedestal region on multiple devices over a broad range of plasma parameters (e.g., collisionality, beta, and aspect ratio). Detailed measurements of the height and width of the pedestal will be performed augmented by measurements of the radial electric field. The evolution of these parameters during the discharge will be studied. Initial measurements of the turbulence in the pedestal region will also be performed to improve understanding of the relationship between edge turbulent transport and pedestal structure. A: TBD
FY 2012–2015	T: TBD based on research needs and FY 2011 through 2014 results A: TBD

Annual Performance Measure: <u>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.</u>

FY 2006	T: Simulate nonlinear plasma edge phenomena using extended MHD codes with a resolution of 40 Toroidal modes. A: Goal met

FY 2007	T: Improve 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. A: Goal met
FY 2008	T: Improve the simulation resolution of ITER-relevant modeling of lower hybrid current drive experiments on Alcator C-Mod by increasing the number of poloidal modes used to 2,000 and the number of radial elements used to 1,000 using the SC's high performance computing resources. A: Goal met
FY 2009	T: Gyrokinetic edge electrostatic turbulence simulations will be carried out across the divertor separatrix with enhanced resolution down to the ion gyroradius scale. A: Goal met
FY 2010	T: Gyrokinetic simulations of turbulent transport of toroidal momentum with both kinetic and Boltzmann electrons will be carried out. These simulations will explore the Ion Temperature Gradient (ITG) and the Collisionless Trapped Electron Mode (CTEM) regimes. A: TBD
FY 2011	T: A focused analytic theory and computational effort, including large-scale simulations, will be used to identify and quantify relevant physics mechanisms controlling the structure of the pedestal. The performance of future burning plasmas is strongly correlated with the pressure at the top of the edge transport barrier (or pedestal height). Predicting the pedestal height has proved challenging due to a wide and overlapping range of relevant spatiotemporal scales, geometrical complexity, and a variety of potentially important physics mechanisms. Predictive models will be developed and key features of each model will be tested against observations, to clarify the relative importance of various physics mechanisms, and to make progress in developing a validated physics model for the pedestal height. A: TBD
FY 2012–2015	T: TBD based on research needs and FY 2011 through 2014 results A: TBD

Annual Performance Measure: <u>Average achieved operation time of the major national fusion facilities (DIII-D, Alcator C-Mod, NSTX) as a percentage of the total planned operation time is greater than 90%.</u>

FY 2006	T: 90% of scheduled operating time A: Goal met

FY 2007	T: 90% of scheduled operating time A: Goal met
FY 2008	T: 90% of scheduled operating time A: Goal met
FY 2009	T: 90% of scheduled operating time A: Goal met
FY 2010–2015	T: 90% of scheduled operating time A: TBD

Annual Performance Measure: Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%.

FY 2006	T: Cost and schedule variance are both less than 10% A: Goal met
FY 2007	T: Cost and schedule variance are both less than 10% A: Goal not met
FY 2008	T: Cost and schedule variance are both less than 10% A: Goal not met
FY 2009	T: N/A, no major construction project/MIE tracked this fiscal year.
FY 2010	T: N/A, no major construction project/MIE tracked this fiscal year.
FY 2011–2015	T: Cost and schedule variance are both less than 10% A: TBD

Science

Funding Schedule by Activity

	FY 2009	FY 2010	FY 2011
	(dollars in thousands)		
Science			
Tokamak Experimental Research	50,121	58,177	53,781
Alternative Concept Experimental Research	65,684	65,780	72,269
Theory	24,014	24,348	24,348
Advanced Fusion Simulations	9,163	11,212	13,212
General Plasma Science	14,497	14,193	14,193
SBIR/STTR	0	8,382	8,137
Total, Science	163,479	182,092	185,940

Description

The Science subprogram supports preparation for the eventual exploration of burning plasmas by developing a scientific understanding of how high temperature plasmas behave in a tokamak magnetic confinement 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 FESAC's *Scientific Challenges, Opportunities and Priorities for the Fusion Energy Sciences Program, July 2004*[a] report.

Plasmas are gases comprising of a mixture of ions and electrons that are influenced by the long range interactions with each other and by magnetic and electric fields, either externally applied or generated by the plasma itself. 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, and how do you create, confine, heat, and control a burning plasma to make fusion power a reality? These 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: to develop a predictive understanding of high temperature fusion burning plasmas in a range of confinement configurations.

The Science subprogram is actively pursuing the development of a broad range of advanced computational simulation tools, taking advantage of emerging petascale computing resources, to address and predict in an integrated manner the questions of how a burning plasma will behave. This effort will yield the computational tools needed to help fully utilize ITER and should also keep the U.S. science community in the lead in using high performance computers to advance understanding of the plasma state. Ultimately, research on ITER is expected to provide sufficient information on burning plasmas to make a definitive assessment of the scientific feasibility of fusion power.

Selected FY 2009 Accomplishments

- *Low absorption of fusion fuel by material walls in high-confinement plasma experiments*: A major concern for ITER is the need to minimize the amount of the tritium fuel absorbed into the vessel walls, as high absorption rates could shorten the lifetimes of components. A set of coordinated

[a] The 2008/2009 reports are located at http://www.science.doe.gov/ofes/programdocuments.shtml.

experiments in the DIII-D and Alcator C-Mod tokamaks demonstrated that particle absorption into the wall in the operational regime favored for ITER is very small, perhaps zero. Virtually the entire uptake of the wall materials may only occur during the short, early phase of the discharge prior to the transition to the operating regime. This finding has significant implications for ITER operations.

- *Advances in predicting plasma behavior:* The NSTX team has detected theoretically-predicted small scale density fluctuations by observing scattered microwaves launched into the plasma. This turbulence is challenging to measure because of its small scale size and amplitude, yet is of potentially high importance to determining how energy created by the fusion process diffuses to the reactor walls. Researchers at the Madison Symmetric Torus (MST) reversed-field pinch have made the first ever measurement of electromagnetic turbulence in the core of a high-temperature plasma. Using newly developed laser-based techniques they were able to simultaneously measure electron density fluctuations and magnetic field fluctuations, providing a direct glimpse into the nature of the transport of electrons in a stochastic magnetic field. This is of critical interest to magnetic fusion energy research as stochastic fields may be applied in a reactor to control undesirable pulses of heat from the plasma boundary to the reactor walls. On the DIII-D tokamak, scientists used localized microwave heating to vary the turbulence in a reproducible manner by controlling local temperature gradients. Comparison between measurement and state-of-the-art plasma simulations shows general agreement with the computed turbulence, but not with the resulting energy transport, thus motivating further improvements to the theory.
- *Improved understanding of plasma viscosity in 3D magnetic fields:* Recent advances in the theory of the coupling between plasmas and 3D magnetic field perturbations have provided new insight for controlling plasma rotational shear in tokamaks. Strong rotation improves plasma stability and strong rotational shear reduces turbulent transport, leading to high energy confinement. Recent experiments in DIII-D that measured the applied torque and resulting plasma rotation have observed a dependence on plasma collisionality as predicted by theory. Related experiments used static 3D fields to produce the high edge rotational shear needed to produce high confinement. These results have important positive implications for achieving and maintaining the required edge rotation in ITER.
- *Exploration of possible improved confinement mode for ITER*: Achieving good energy confinement without deleterious effects such as edge-localized modes (ELMs) or impurity accumulation is a critical issue for ITER. An improved energy confinement mode was discovered and is being explored on the Alcator C-Mod tokamak. The characteristics of the new mode include: normalized energy confinement at the level required by ITER, while keeping the plasma clean of impurity particles, and enabling high temperatures due to the good energy confinement. Separating energy and particle confinement, this improved confinement mode also avoids edge-localized plasma instabilities (ELMs). The possible extrapolation of this regime to ITER is currently under active investigation.
- *Fast ignition:* The first instrumented integrated fast ignition experiment in the United States has just been performed in the OMEGA Laser Facility at the University of Rochester. Preliminary assessment of the experimental data indicated that when a second (short) laser pulse was applied during inertial confinement of the target, the neutron yield was increased by two to three fold.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Tokamak Experimental Research	**50,121**	**58,177**	**53,781**

The tokamak magnetic confinement concept has been the most effective approach to date 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), U.S. tokamaks continue to give high priority to joint experiments with tokamak facilities in Europe and Japan to resolve ITER-relevant physics issues.

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 magnet 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.

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. Both programs are also closely coordinated with international tokamak research through collaborations with major foreign tokamaks in the European Union, Japan, China, and Korea. As JET and ASDEX-UG in Europe undergo hardware modifications in 2010 and 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. These will address ITER physics, steady-state physics, and technology issues that are not currently being addressed in U.S. facilities.

In FY 2011, U.S. tokamak researchers will continue to expand the frontiers of fusion science, both to address remaining ITER questions and to develop the basis for practical fusion power plants.

▪ **DIII-D Research**	**25,740**	**27,504**	**26,604**

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 plasma stability. DIII-D has been a major contributor to the world fusion program over the past two decades.

The DIII-D program is operated as a national research effort, with extensive participation from many U.S. laboratories and universities who receive direct funding from FES. The DIII-D program also plays a central role in U.S. international collaborations with the European Union, Japan, Korea, China, India, and the Russian Federation, hosting many foreign scientists, as well as sending DIII-D scientists overseas to participate in foreign experiments. 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 boundary layer physics using a magnetic divertor to control the magnetic field configuration at the edge of the plasma. These topics are integral parts of six physics groups in the DIII-D Experimental Science Division: 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 2011 experimental program on DIII-D will commence in April 2011, after a year-long shutdown from April 2010 to March 2011 for facility modifications. These modifications primarily include re-orientation of one of the neutral beam lines for off-axis current drive capability and installation of plasma control coils on the tokamak center post. The FY 2011 experimental program will exploit these new facility modifications and 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 continue to accommodate a number of joint experiments in collaboration with the international community.

	FY 2009	FY 2010	FY 2011
▪ **Alcator C-Mod Research**	**9,002**	**9,045**	**9,045**

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 2011, Alcator C-Mod will continue a strong research program, while providing support of ITER. Experiments will address issues with the generation of sheaths by radio frequency (RF) heating of the plasma discharge. A new type of ion cyclotron range of frequency antenna that better matches the geometry of the C-Mod magnetic field lines will be the primary tool in these experiments. Impurity generation via the formation of sheaths is an undesirable byproduct of RF heating in present day plasmas. Current drive experiments using a new type of microwave launcher at the lower hybrid range of frequencies will also be possible at high powers as more klystrons are currently being purchased using Recovery Act funding.

Other ITER-relevant topics that the Alcator C-Mod team will continue to focus on in FY 2011 include characterization of the H-mode pedestal at the edge of the plasma, 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 plasma edge, an activity important to both ITER and to a potential future demonstration project. C-Mod will also continue participation in many joint international experiments.

	FY 2009	FY 2010	FY 2011
▪ **International Research**	**5,487**	**4,935**	**4,935**

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 around the world. These include the world's highest performance tokamak, the Joint European Torus (JET) in England; a stellarator, the Large Helical Device in Japan; a superconducting tokamak, Tore Supra in France; the AxiSymmetric Divertor Experiment Upgrade (ASDEX-U) and Tokamak Experiment for Technology Oriented Research (TEXTOR) 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.

In FY 2011, the U.S. will continue to be a major participant in the ITPA, which identifies experimental and computational studies to resolve high priority ITER physics design needs and implements these studies through collaborative work among the world's leading experimental and theoretical research teams. These studies 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. The JET tokamak in the United Kingdom and the ASDEX-U tokamak in Germany will be restarting after year-long shutdowns in 2010 for facility modifications involving an ITER-like wall and internal control coils. The KSTAR and EAST tokamaks in Korea and China respectively will be maturing in their operational capability. All of these modifications and improvements in the international tokamaks will provide an opportunity to expand collaborations and joint experiments utilizing these new tools. To develop these collaboration options, a national committee has been assembled to identify further U.S. international research opportunities that can be developed in the coming years.

	FY 2009	FY 2010	FY 2011
▪ **Diagnostics**	**4,082**	**3,912**	**3,920**

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 2011, 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.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

A competitive peer review of the national laboratory component of the diagnostics development program will be conducted in FY 2011.

▪ **Other**	**5,810**	**12,781**	**9,277**

Funding in this category supports educational activities such as research at historically black colleges and universities, 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, and the activities of the U.S. Burning Plasma Organization and the Fusion Energy Sciences Advisory Committee. Beginning in FY 2011 new fellowships will be funded through the Office of Science Graduate Fellowship (SCGF) program, which is funded by the Workforce Development for Teachers and Scientists program. This program was initiated in FY 2010 and supports graduate students pursing advanced degrees in areas of basic research supported by the Office of Science, including fusion science.

Alternative Concept Experimental Research	**65,684**	**65,780**	**72,269**

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.

▪ **NSTX Research**	**17,104**	**17,549**	**17,549**

The National Spherical Torus Experiment (NSTX) is one of only two large research facilities 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 ST is an innovative confinement configuration that produces a plasma that is shaped like a sphere with a narrow cylindrical hole through its center. The properties of an ST plasma are significantly different from a conventional tokamak plasma, which is shaped like a donut with a large hole through the center. Results to date indicate that STs can achieve a higher plasma pressure for a given applied magnetic field 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 power plant.

NSTX is operated as a national collaborative research facility, with extensive involvement of researchers from other national laboratories, universities, and industry who receive their funding from FES via a competitive peer review process.

In FY 2011 the NSTX program will continue to explore and understand the unique physics properties of STs, exploit these unique properties to contribute to the physics basis for ITER, and advance the fundamental understanding of ST plasmas to establish attractive scenarios for future

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

fusion facilities. Using a liquid lithium divertor to confront the harsh plasma environment and new diagnostic capabilities, NSTX researchers will perform critical experiments to understand non-inductive current drive at reduced collisionality. In addition, they will investigate means to handle the large heat and particle fluxes that will fall on the divertor surface. They will also seek to understand the relation between electron energy confinement and fluctuations in the plasma density and electron temperature. This knowledge is needed to extrapolate to next-step facilities, and NSTX has unique capabilities to investigate this topic. NSTX researchers will continue studying macroscopic instabilities and will focus on sustaining high pressure plasmas and understanding disruption limits. The basic principles of error field correction and resistive wall mode control have been demonstrated, so future work will focus on developing reliable active control techniques to stabilize these modes. Plasma-wave interaction 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 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, experiments on solenoid-free start-up and current ramp-up, capabilities needed for future ST devices, will focus on reducing impurity influx during co-axial helicity injection start-up and using radio frequency waves to ramp-up the plasma current.

▪ **Experimental Plasma Research**	**16,975**	**16,765**	**16,765**

The Experimental Plasma Research activity focuses on the exploration of Innovative Confinement Concepts (ICC)—small-scale facilities that explore emerging concepts for plasma confinement and stability. Recent investments have supported construction and operation of a range of facilities, an ICC-centric theory center, and several small topic-specific investigations. The facilities built include stellarators, spheromaks, field-reversed configurations, a levitated dipole, a flow-stabilized z-pinch, centrifugally confined magnetic mirrors, and electrostatic confinement. These studies have intrinsic value to FES's plasma science and fusion energy missions since they provide unique tests and extensions to enhance the understanding of confined plasmas, complementing the larger tokamak programs and helping to establish the predictive understanding of fusion plasma behavior. The program is undergoing 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. New emphasis will be placed on the ability of some elements in this portfolio to contribute to the science needed in order to deepen our understanding of burning plasmas such as ITER.

In FY 2011, 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. Stellarators remain a top alternative confinement concept that can mitigate several of the potential deficiencies of the tokamak configuration. Research on the stellarator concept is continuing in FY 2011 within this program, such as developing knowledge of quasi-symmetric stellarator confinement as the basis for a credible, innovative approach to fusion energy.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
▪ **High Energy Density Laboratory Plasmas**	**24,753**	**24,551**	**31,040**

High energy density laboratory plasma physics is the study of ionized matter at extremely high density and temperature. According to the 2007 National Academies 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 2011, the proposed budget will allow a significant expansion of the FES HEDLP initiative launched in FY 2009. On-going research includes studies of warm dense matter driven by heavy ion beams, fast 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 SLAC National Accelerator Laboratory Linac Coherent Light Source (LCLS) with Recovery Act funding. LCLS is the world's first coherent hard 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 spatial and temporal resolution. Recovery Act funding will be used to expedite completion of the MEC instrument. Recovery Act funding is also enabling the construction of the Neutralized Drift Compression Experiment-II (NDCX-II), which will facilitate studies of warm dense matter and the high energy density physics intrinsic to the science of heavy ion fusion.

▪ **Madison Symmetrical Torus**	**6,852**	**6,915**	**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. Since 2005 this approach has led to a ten-fold increase in energy confinement time.

In FY 2011, the major plans for the MST program are to assess the confinement of energetic ions using approximately 1 megawatt neutral beam injection, advance inductive current profile control and sustainment methods using a programmable power supply for the toroidal field, and assess the

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

anisotropy of ion heating from magnetic reconnection using parallel and perpendicular charge exchange recombination spectroscopy.

Theory	**24,014**	**24,348**	**24,348**

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 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 in 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 2011 the Theory Program will focus particular attention on many important scientific issues, including:

- 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,
- a first-principles formulation of moment closures in extended magnetohydrodynamics models,
- calculations atomic and molecular collision processes of importance in fusion reactors,
- studies 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,
- understanding fast magnetic reconnection in high temperature fusion plasmas, and
- development of predictive integrated computational models for tokamak plasmas.

Developing a validated predictive capability is very important, and in FY 2011, the theory program is exploring the possibility of having, as its annual performance target, a joint theory/computational/experiment milestone aimed at understanding the physics mechanisms responsible for the structure of the pedestal and developing a predictive capability. If this happens, it will be the first time that the theory program has been joined with the experimental and computational programs in an

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

integrated joint research effort in support of an annual performance target.

Advanced Fusion Simulations	**9,163**	**11,212**	**13,212**

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).

▪ **SciDAC**	**7,163**	**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 would have been impossible using theoretical or laboratory studies alone. By taking advantage of significant recent advances in computing technologies, the SciDAC program 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 with high physics fidelity that can fully exploit the emerging capabilities of petascale computing resources.

The current FES SciDAC portfolio includes eight projects focused on the plasma science of magnetic fusion. Of these projects, 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. 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 magnetohydrodynamic instabilities, and the coupling of the edge and core regions of tokamak plasmas.

In FY 2011, following a peer review scheduled for mid-2010, the projects of the resulting FES SciDAC portfolio will continue to focus their efforts on grand challenge scientific questions of importance to burning plasmas and ITER and will also address high-priority issues identified during the recently held Research Needs Workshop (ReNeW) for the Magnetic Fusion Sciences part of the FES program.

In FY 2011, the proto-FSP Centers will continue to focus their efforts on issues of importance to burning plasmas and ITER such as using RF waves to control and mitigate performance-limiting macroscopic instabilities in fusion devices, the development of a first-principles predictive edge pedestal and edge localized modes model for ITER, and the development of advanced computational frameworks for integrated fusion simulations that enable the seamless coupling of the edge and core regions of tokamak plasmas. In addition, as the FES program starts the full Fusion Simulation Program in FY 2011 following a 2-year planning study, the proto-FSPs will work with the FSP team to coordinate their eventual integration within the larger program.

▪ **Fusion Simulation Program**	**2,000**	**4,000**	**6,000**

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

	FY 2009	FY 2010	FY 2011

(dollars in thousands)

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 developing 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 FY 2009, following 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 FSP planning team is expected to complete its design report by the end of FY 2010, which will then undergo an independent review.

In FY 2011 the increase in funding will allow FES to start implementing the plan developed by the FSP planning team. The FSP research team will begin to develop the scientific software deliverables identified and prioritized during the two-year planning study and take the first steps toward the verification and validation of these components.

General Plasma Science	**14,497**	**14,193**	**14,193**

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 complements burning plasma science and reaches beyond into 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 General Plasma Science program 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 significant 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 Center started in FY 2003 and renewed by NSF for five years in FY 2008. In FY 2009, the PSCs program was renewed following an intensive merit review process. Of the seven applications for PSC funding in FY 2009, one center was selected for funding with regular appropriations and two additional centers were selected with one fully funded for five years and the second funded for approximately three years using Recovery Act funding. In FY 2011, the third year of funding is provided for the PSC funded through regular appropriations.

SBIR/STTR	**0**	**8,382**	**8,137**

In FY 2009, $7,171,000 and $861,000 were transferred to the congressionally mandated Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, respectively. The FY 2010 and FY 2011 amounts are the estimated requirements for the continuation of these programs.

Total, Science	**163,479**	**182,092**	**185,940**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Tokamak Experimental Research	
▪ **DIII-D Research**	
The decrease in funding will shift resources to facility operations to support the completion of facility upgrade activities but still provide sufficient research support and analysis for the planned 14 weeks of experiments.	-900
▪ **Diagnostics**	
The increase in funding is for magnetic fusion energy research.	+8
▪ **Other**	
In the FY 2010 appropriation, FES received an overall increase of $5,000,000 for a total of $426,000,000. This funding element includes the $5,000,000 increase until it can be distributed among priority activities within the FES Science subprogram. Following the distribution of the $5,000,000 in FY 2010, the remaining increase of $1,228,000 will support continuation of Early Career and other post doctoral activities. FES support for new graduate fellowships in fusion science is completed in FY 2010 with the initiation of the DOE Office of Science Fellowship program funded within the Workforce Development for Teachers and Scientists program.	-3,504
Total, Tokamak Experimental Research	**-4,396**
Alternative Concept Experimental Research	
▪ **High Energy Density Laboratory Plasmas (HEDLP)**	
Increase will allow for an expansion of research activities supported by the HEDLP initiative, which was started in FY 2009.	+6,489
Advanced Fusion Simulations	
▪ **Fusion Simulation Program (FSP)**	
The increase will allow FES to start the ramp-up of the Fusion Simulation Program (FSP) funding as it transitions from the planning phase to the full program.	+2,000
SBIR/STTR	
The support for SBIR/STTR is funded at the mandated level.	-245
Total Funding Change, Science	**+3,848**

Facility Operations

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Facility Operations			
DIII-D	36,456	37,480	39,751
Alcator C-Mod	15,724	17,434	18,457
NSTX	22,536	22,150	22,024
NSTX Upgrade (MIE)	5,235	6,550	7,685
Other, GPE and GPP	3,698	2,103	2,103
U.S. Contributions to ITER (MIE TPC)	124,000	135,000	80,000
Total, Facility Operations	207,649	220,717	170,020

Description

The mission of the Facility Operations subprogram is to provide for the operation, maintenance, and minor modifications of the major fusion research facilities (Alcator C-Mod, DIII-D, and NSTX), to carry out major upgrades to existing facilities, and to construct new facilities such as ITER. Periodic facility reviews are used to ensure that the facilities are operated efficiently and in a safe and environmentally sound manner. The balance between operations, maintenance, and upgrades is judiciously adjusted to ensure safe operation of each facility; provide modern experimental tools such as heating, fueling, and exhaust systems; and provide the operating time to meet the needs of scientific collaborators.

The major FES facilities enable U.S. scientists from universities, laboratories, and industry, as well as visiting foreign scientists, to conduct world-class research funded through the Science and Enabling R&D subprograms. Upgrades of the major fusion facilities, such as installation of new diagnostics, and execution of new projects, such as ITER, help to keep U.S. scientists at the forefront of plasma and fusion research.

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. The extensive tokamak database from DIII-D has provided the major physics input to the ITER design.

Alcator C-Mod at 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 PPPL using the spherical torus confinement configuration. A major advantage of this configuration is the ability to confine a higher plasma pressure for a given magnetic field strength, which could enable the development of smaller, more economical fusion research facilities.

ITER is an important step between today's facilities designed to study plasma physics and a demonstration fusion power plant. It will be the only magnetic fusion facility in the foreseeable future to achieve burning plasmas, which is essential to demonstrate the scientific feasibility of fusion energy, and study its underlying physics. An 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.

Selected FY 2009 Accomplishments

- *DIII-D:* The installation of an additional power supply for the electron cyclotron heating system permitted the simultaneous operation of six long pulse, high power microwave tubes for the first time. The completed six tube system resulted in a DIII-D record of 13 megajoules of microwave energy injection into a plasma.
- *Alcator C-Mod:* An extensive set of new divertor and limiter heat-flux diagnostics was installed during C-Mod's recent maintenance shutdown, which is providing key information on energy deposition to main-chamber limiter and divertor surfaces and their relationship to upstream plasma parameters. The new diagnostics are providing critical data to advance our understanding of plasma-wall interaction physics in the unique power density regime in which C-Mod operates.
- *NSTX:* Using dual lithium evaporators to provide complete toroidal coverage of lithium to the lower divertor structure, the NSTX team has achieved plasma performance significantly higher than with one lithium evaporator. In addition, high-performance operation with no between-shot helium glow discharge cleaning is now possible, thus increasing the achievable shot-rate by more than 20%.
- *ITER Test Blanket Module Experiments on DIII-D*: To address a concern that the ferromagnetic materials in the structure of proposed ITER Test Blanket Modules (TBMs) might have a detrimental effect on the performance of ITER, DIII-D researchers have designed and installed a mockup module that can simulate the expected fields in ITER by varying currents in coils in the mockup module. The coils can produce fields that will be up to approximately three times the equivalent perturbation that would be produced by the TBMs in ITER. An international research team representing most of the ITER parties will carry out a series of experiments in FY 2010 to determine the effect that the localized non-resonant fields from the TBM mockup have on the DIII-D plasma.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
DIII-D	**36,456**	**37,480**	**39,751**

To carry out the research funded in the Science subprogram, support is provided for operation, maintenance, and improvement of the DIII-D facility and its auxiliary systems. The DIII-D program will complete 17 weeks of FY 2010 experimental operations (including three weeks using Recovery Act funding) in April 2010 prior to a year-long shutdown for facility modifications. The primary modifications will be to move one of the neutral beam lines for off-axis power injection, installation of internal control coils on the tokamak center post for investigation of plasma edge instabilities, and diagnostics improvements. The Recovery Act funding for the DIII-D Upgrades provided for enhanced diagnostics systems and additional electron cyclotron heating. The FY 2011 experimental operations will then start in April 2011 with plans for 14 weeks of single-shift operations. Operations will continue to support experiments addressing ITER design and operations issues and developing the

	FY 2009	FY 2010	FY 2011
(dollars in thousands)			

advanced tokamak concept for fusion energy. Experiments in FY 2011 will take advantage of the recently completed off-axis neutral beam and center post coil systems.

	FY 2009	FY 2010	FY 2011
Achieved Operating Hours	559	N/A	N/A
Planned Operating Hours[a]	520	560	560
Optimal Hours	1,000	1,000	1,000
Percent of Optimal Hours	55.9%	56.0%	56.0%
Unscheduled Downtime	85	N/A	N/A
Number of Users	220	235	235

	FY 2009	FY 2010	FY 2011
Alcator C-Mod	**15,724**	**17,434**	**18,457**

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 high temperature tungsten divertor. In FY 2010, Alcator C-Mod will be operated for 18 weeks, which includes five weeks using Recovery Act funding, focusing on ITER design and operations issues and addressing high field and density issues. The Recovery Act funding for the Alcator C-Mod Upgrades enabled the improvements to the facility's auxiliary heating and diagnostic systems. In FY 2011, Alcator C-Mod will operate for 15 weeks.

	FY 2009	FY 2010	FY 2011
Achieved Operating Hours	291	N/A	N/A
Planned Operating Hours[a]	288	416	480
Optimal Hours	800	800	800
Percent of Optimal Hours	36.4%	52.0%	60.0%
Unscheduled Downtime	8	N/A	N/A
Number of Users	182	195	200

	FY 2009	FY 2010	FY 2011
NSTX	**22,536**	**22,150**	**22,024**

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 2009, NSTX operated for 16.8 weeks, which included 5.8 weeks using Recovery Act funding. In FY 2010, 15 weeks of operation are planned, including one week using Recovery Act funding. The Recovery Act funding for NSTX enabled the facility and diagnostic upgrades. In FY 2011, there is funding for 14 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

[a] Planned hours do not include Recovery Act supported operations in FY 2009 and FY2010.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

initiatives. In FY 2011, NSTX will fully exploit new capabilities added in FY 2009 such as the liquid lithium divertor and the upgraded high harmonic fast wave antenna.

	FY 2009	FY 2010	FY 2011
Achieved Operating Hours	440	N/A	N/A
Planned Operating Hours[a]	440	560	560
Optimal Hours	1,000	1,000	1,000
Percent of Optimal Hours	44.0%	56.0%	56.0%
Unscheduled Downtime	0	N/A	N/A
Number of Users	140	145	145

NSTX Upgrade (MIE)	**5,235**	**6,550**	**7,685**

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 line that will double the plasma heating power 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 whether to carry out both upgrades in parallel or in series will be made at CD-2.

Other, GPE, and GPP	**3,698**	**2,103**	**2,103**

Funding for general plant projects (GPP) and general purpose equipment (GPE) provides support for general infrastructure repairs and upgrades for the PPPL site based upon quantitative analysis of safety requirements, equipment reliability, and research needs. Recovery Act funding supports a major upgrade to PPPL’s electrical power distribution system, including 138 kilovolt switch gear, transformers, and associated circuit breakers.

U.S. Contributions to ITER Project (MIE)	**124,000**	**135,000**	**80,000**

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 the Geneva Summit in November 1985; the U.S. participated in the initial design activity and after a hiatus, the U.S. joined the ITER negotiations in early 2003.

[a] Planned hours do not include Recovery Act supported operations in FY 2009 and FY2010.

(dollars in thousands)

FY 2009	FY 2010	FY 2011

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 comprises 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 a 'green field' site in 2006, the ITER enterprise at Cadarache had staffed up to about two thirds of its full complement of 600 personnel by the end of 2009.

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. Although the JIA included a goal for construction completion and first plasma to be achieved in 2016, this has proven to be unrealistic. Together with other factors, these developments have increased the estimate for ITER's construction cost. The IO's most urgent tasks now are to complete work on the overall ITER design and systems engineering, and to establish realistic technical, schedule, and cost baselines. The ITER Council has asked the IO to prepare a baseline proposal for the Council to review and approve by mid-2010. The U.S. will continue to emphasize the importance of completing these efforts as soon as possible and provide support as needed.

U.S. ITER Project Status: The main cost risk to the U.S. ITER Project is the slow rate of progress by the IO and some Members' Domestic Agencies who are responsible for critical path hardware components, which has delayed the construction schedule. Next, there remains some ambiguity over the effect 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 2011.

Estimated ITER TPC Range: The TPC range approved at CD-1 accounts for the magnitude of cost risks that were identified at the time the range was developed in late 2007. The sources of potential cost growth can be categorized as follows: actions taken by the ITER Council and the IO, external factors outside of the ITER project, 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, and 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, some of which may increase the U.S. ITER TPC.

External factors include changes in Dollar/Euro exchange 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 less favorable Dollar-Euro exchange rates. Prices for raw materials used in manufacturing U.S.-supplied hardware have also been steadily increasing. This remains a significant long-term concern.

Finally, the reference design for ITER is not complete in certain areas such as the blanket first wall and shield system. 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 established 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 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. However, the approved TPC range presumed a much more aggressive schedule than has evolved thus far.

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	115,000	20,000	135,000
2011	75,000	5,000	80,000
Outyears	TBD	TBD	TBD

In FY 2010, funds are being used to perform a variety of design, R&D, and long-lead procurement activities for the U.S. hardware contributions to ITER construction. For the two largest elements of U.S. scope, the central solenoid magnet system and the tokamak cooling water system, these include industrial design and manufacturing R&D efforts as well as long-lead procurements of materials. Long-lead procurement of toroidal field magnet conductors from industrial vendors is also continuing. In other areas of U.S. responsibility, design and R&D is continuing for the blanket first wall and shield modules, fueling pellet injector, tokamak exhaust processing system, ion and electron cyclotron heating transmission lines, steady-state electric power system, vacuum pumping system, and diagnostics. The U.S. is continuing to provide conceptual design and cost estimating services to the IO for the ITER in-vessel coil system. The balance of funds will be used to support the USIPO, provide a small number of U.S. secondees to work on the IO staff, and furnish prescribed funding contributions to the IO.

[a]A complete baseline funding profile, including the outyears, will be established at CD-2, which is anticipated to be in FY 2011.

	FY 2009	FY 2010	FY 2011

(dollars in thousands)

The $80,000,000 requested for the U.S. ITER Project in FY 2011 is a reflection of the pace of ITER construction as of the end of 2009. The Administration is engaged in a range of initiatives to implement management reforms at the IO and accelerate ITER construction with the goal of minimizing the overall cost of the Construction Phase for the U.S. and the other ITER Members.

The FY 2011 funding request will be used to make progress on all of the design, R&D, and long-lead procurement activities described above for the U.S. hardware contribution, albeit at a reduced rate. Emphasis will continue to be given to industrial involvement in completing design work in preparation for subsequent large-scale fabrication activities. Toroidal field magnet conductor production will be largely completed. The U.S. effort on the in-vessel coils will be handed over to the IO, which will be responsible for completing preliminary design, prototyping, final design, as well as fabrication. The balance of funds will be used to support the USIPO, provide a small number of U.S. secondees to work on the IO staff, and furnish prescribed funding contributions to the IO.

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 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 2037 dollars.	25,000	25,000

	FY 2009	FY 2010	FY 2011
Total, Facility Operations	**207,649**	**220,717**	**170,020**

[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.

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
DIII-D	
The increase in funding for FY 2011 will allow for completion of the facility upgrades begun in FY 2010 as part of the long torus opening activity. It will also support 14 weeks of single-shift operations.	+2,271
Alcator C-Mod	
The increase in funding for FY 2011 will allow completing a new antenna for radio frequency heating experiments and installation of a second lower hybrid launcher. It will enable design of a tungsten divertor relevant to a future demonstration reactor and will support 15 weeks of operation.	+1,023
NSTX	
The decrease in funding for the NSTX Facility is applied to the increase for the NSTX Upgrade MIE project. This budget will support 14 run weeks of plasma operation.	-126
NSTX Upgrade (MIE)	
The increase will provide for continued work on two possible enhancements to the NSTX Facility. An upgrade to the magnet system, including the central solenoid, is designed to permit higher plasma currents and magnetic fields. The additional neutral beam heating power is designed to enable control of the plasma stability by modifying the plasma current. Completing both upgrades would enable higher plasma pressures to be obtained.	+1,135
U.S. Contributions to ITER Project (MIE)	
U.S. Contributions to ITER MIE funding is decreased by $55,000,000 to match the Administration's late 2009 estimation of the pace of the ITER project.	-55,000
Total Funding Change, Facility Operations	**-50,697**

Enabling R&D

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Enabling R&D			
Engineering Research	18,573	17,974	18,311
Materials Research	4,817	5,217	5,729
Total, Enabling R&D	23,390	23,191	24,040

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. Enabling R&D also 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.

Selected FY 2009 Accomplishments

- *New Disruption Mitigation Tool Successfully Tested on DIII-D:* Disruptions are the sudden, uncontrolled termination of the plasma that can potentially damage the plasma chamber from sudden thermal loads and high magnetic forces. A new technique has been developed to mitigate these effects by injecting a solid hydrogen pellet nearly the size of a wine cork into the disrupting plasma. The pellet is fired by a pneumatic gun and shattered by hitting a metal plate just before entering the plasma to produce a spray of hydrogen that quickly dissipates the plasma energy in approximately $1/1000^{th}$ of a second before any plasma chamber damage can take place. A new system using this technique has been installed on DIII-D and has been shown to control the rapid termination of high performance plasmas and reduce thermal loads and forces. This technique can potentially be employed on ITER to prevent any disruptions from reducing machine availability for physics experiments.
- *Understanding plasma material interactions for ITER:* A burning plasma creates a harsh environment that challenges the materials inside the plasma chamber. During ITER operation, we must understand the very complex mechanistic effects of a burning plasma on the materials so as to optimize the design as well as ensure safe operating scenarios for the device. As part of a U.S.-Japan collaboration, which is focused on plasma chamber issues, experiments are being conducted at the University of California at San Diego to simulate fusion-type plasmas to better understand these complicated phenomena. These experiments show that helium, a byproduct of the deuterium-tritium fusion reaction, has a beneficial effect of reducing surface blistering in tungsten, which will be used as a plasma facing material in ITER. This beneficial effect is caused by nano-sized high density helium bubbles created in the near-surface region of the tungsten acting as a diffusion barrier. The implication of this result is that tritium uptake in tungsten surfaces, an important safety concern, may be reduced by the presence of helium contained in the plasma interacting with the tungsten surfaces.
- *Developing materials for use in the fusion environment:* Significant progress has been made on a new class of structural materials known as nanocomposited ferritic alloys. These materials contain an ultrahigh density of nanometer-scale particles that impart excellent high-temperature strength,

radiation damage resistance, and the potential to tolerate the high-levels of helium produced in the fusion neutron environment. Recent modeling has revealed that the basic strengthening mechanism in these alloys is due to the unique crystal structure of the nanometer-scale particles. Novel experiments performed in the High Flux Isotope Reactor have also demonstrated the capability of these materials to manage fusion-relevant helium production through the formation of numerous, very fine-scale bubbles on the nanoparticles.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Engineering Research	**18,573**	**17,974**	**18,311**

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 heating, fueling, plasma chamber, safety research, and surface protection technologies. While much of the effort is focused on current devices, an increasing amount of the research is oriented toward the technology needs or issues that will be faced in future experiments, including ITER. An example is 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.

▪ **Plasma Technology**	**14,471**	**13,651**	**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 addition, the collaborative program on plasma facing and blanket materials for use in future facilities, Tritium Irradiation Thermofluid American-Japanese Network (TITAN), will be continued.

In FY 2011, 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 experimental 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.

Research will also be conducted on plasma facing components, heating and fueling technologies, and blanket concepts that could be tested in ITER. In addition, this category funds research in safety and plasma-surface interaction and modeling to address potential issues that could be encountered during operation of ITER or future devices.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
▪ **Advanced Design**	**4,102**	**4,323**	**4,660**

In FY 2011 this effort will continue to focus on system studies by a team from the fusion research community with 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, FES will initiate a series of strategic planning/scoping studies as follow-on to the 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.

Materials Research	**4,817**	**5,217**	**5,729**

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 make it more effective at using and leveraging the substantial work on nanosystems and computational materials science being funded by other programs. 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 lifetimes.

The FY 2011 request will maintain and modestly grow 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 and plasma facing 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.

Total, Enabling R&D	**23,390**	**23,191**	**24,040**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Engineering Research	
▪ **Advanced Design**	
The increase will support strategic planning/scoping studies on issues and topics identified during the Research Needs Workshops. The studies will help identify possible approaches for the next steps in the U.S. fusion research program.	+337

	FY 2011 vs. FY 2010 ($000)
Materials Research	
The increase will support scientific research on new nano-composited high strength materials.	+512
Total Funding Change, Enabling R&D	**+849**

Supporting Information

Operating Expenses, Capital Equipment and Construction Summary

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Operating Expenses	273,026	298,646	290,588
Capital Equipment	118,499	125,861	87,919
General Plant Projects	2,993	1,493	1,493
Total, Fusion Energy Sciences	394,518	426,000	380,000

Funding Summary

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Research	186,869	205,283	209,980
Scientific User Facilities Operations	74,716	77,064	80,232
Major Items of Equipment	129,235	141,550	87,685
Other (GPP, GPE and Infrastructure)	3,698	2,103	2,103
Total, Fusion Energy Sciences	394,518	426,000	380,000

Scientific User Facilities Operations and Research

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
DIII-D			
Operations	36,456	37,480	39,751
Facility Research	25,740	27,504	26,604
Total DIII-D	62,196	64,984	66,355
Alcator C-Mod			
Operations	15,724	17,434	18,457
Facility Research	9,002	9,045	9,045
Total Alcator C-Mod	24,726	26,479	27,502
NSTX			
Operations	22,536	22,150	22,024
Facility Research	17,104	17,549	17,549
Total NSTX	39,640	39,699	39,573

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Scientific User Facilities Operations and Research			
Operations	74,716	77,064	80,232
Facility Research	51,846	54,098	53,198
Total, Scientific User Facilities Operations and Research	126,562	131,162	133,430

Facility Users and Hours

	FY 2009	FY 2010	FY 2011
DIII-D National Fusion Facility			
Achieved Operating Hours	559	N/A	N/A
Planned Operating Hours[a]	520	560	560
Optimal Hours	1,000	1,000	1,000
Percent of Optimal Hours	55.9%	56%	56%
Unscheduled Downtime	85	N/A	N/A
Number of Users	220	235	235
Alcator C-Mod			
Achieved Operating Hours	291	N/A	N/A
Planned Operating Hours[a]	288	416	480
Optimal Hours	800	800	800
Percent of Optimal Hours	36.4%	52%	60%
Unscheduled Downtime	8	N/A	N/A
Number of Users	182	195	200
National Spherical Torus Experiment			
Achieved Operating Hours	440	N/A	N/A
Planned Operating Hours[a]	440	560	560
Optimal Hours	1,000	1,000	1,000
Percent of Optimal Hours	44.0%	56%	56%
Unscheduled Downtime	0	N/A	N/A
Number of Users	140	145	145

[a] Planned hours do not include Recovery Act supported operations in FY 2009 and FY2010.

	FY 2009	FY 2010	FY 2011
Total, Facilities Users and Hours			
Achieved Operating Hours	1,290	N/A	N/A
Planned Operating Hours[a]	1,248	1,536	1,600
Optimal Hours	2,800	2,800	2,800
Percent of Optimal Hours	46.1%	54.9%	57.1%
Unscheduled Downtime	93	N/A	N/A
Number of Users	542	575	580

Major Items of Equipment

(dollars in thousands)

	Prior Years	FY 2009	FY 2010	FY 2011	Outyears	Total
MIEs						
NSTX Upgrade						
TEC	0	0	5,550	7,685	TBD	TBD
OPC	0	5,235	1,000	0	TBD	TBD
TPC	0	5,235	6,550	7,685	TBD	TBD
ITER						
TEC	82,366	109,000	115,000	75,000	TBD	TBD
OPC	23,019	15,000	20,000	5,000	TBD	TBD
TPC	105,385	124,000	135,000	80,000	TBD	TBD
Total MIEs						
TEC		109,000	120,550	82,685	TBD	TBD
OPC		20,235	21,000	5,000	TBD	TBD
TPC		129,235	141,550	87,685	TBD	TBD

Facility Operations MIEs:

- ***National Spherical Torus Experiment Upgrade Major Item of Equipment Project***

  The NSTX Upgrade Project was initiated in FY 2009 to support major upgrades at NSTX to keep its world-leading status. As presently envisioned, this project 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 available to heat the plasma. CD-0 (Approve Mission Need) was completed on February 23, 2009. The CD-1 Independent Project Review was completed in December 2009. Upon completion of the Departmental review and approval of CD-1, anticipated in the second quarter FY 2010, more definition on the project's scope, schedule, and cost will become available. A decision on the baseline scope, schedule, and cost of this project 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. The U.S. ITER Project 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). 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.

The $80,000,000 requested for the U.S. ITER Project in FY 2011 is a reflection of the pace of ITER construction as of the end of 2009. The Administration is engaged in a range of initiatives to implement management reforms at the IO and accelerate ITER construction with the goal of minimizing the overall cost of the construction phase for the U.S. and the other ITER Members.

Scientific Employment

	FY 2009 actual	FY 2010 estimate	FY 2011 estimate
# University Grants	305	246	320
# Laboratory Projects	158	167	166
# Permanent Ph.D's (FTEs)	725	723	763
# Postdoctoral Associates (FTEs)	113	113	118
# Graduate Students (FTEs)	327	327	344
# Ph.D.'s awarded	37	42	44

High Energy Physics

Funding Profile by Subprogram

(dollars in thousands)

	FY 2009 Current Appropriation	FY 2009 Current Recovery Act Appropriation[a]	FY 2010 Current Appropriation	FY 2011 Request
High Energy Physics				
Proton Accelerator-Based Physics	401,368	+107,990	434,167	439,262
Electron Accelerator-Based Physics	32,030	+1,400	27,427	24,707
Non-Accelerator Physics	101,138	+4,445	99,625	88,539
Theoretical Physics	66,148	+5,975	66,962	69,524
Advanced Technology R&D	175,184	+112,580	182,302	189,968
Subtotal, High Energy Physics	775,868	+232,390	810,483	812,000
Construction	0	0	0	17,000
Total, High Energy Physics	775,868[b]	+232,390	810,483	829,000

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 the 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.

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. Data have revealed that only about 5% of the universe is made of the normal, visible 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:

[a] The Recovery Act Current Appropriation column reflects the allocation of funding as of September 30, 2009.
[b] Total is reduced by $19,858,000: $17,730,000 of which was transferred to the Small Business Innovation Research (SBIR) program and $2,128,000 of which was transferred to the Small Business Technology Transfer (STTR) program.

- *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, such as:

- *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 theoretically 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 the last six billion years, the universe has been expanding at an accelerating rate due to a mysterious dark energy that overcame gravitational attraction. This energy, which permeates empty space, 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 extra dimensions of space and generally supersymmetry. 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 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 pairings or "families" of quarks and leptons have been discovered—most of these 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 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 certainly 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 second with little or no interaction. Their detection requires intense neutrino sources and large detectors. HEP supports research into fundamental neutrino properties because they can reveal important clues to the unification of forces and the very early history of the universe. 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 present universe come to be?*

  The 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.

- *What happened to the antimatter?*

  The universe appears to contain very little antimatter. Antimatter 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 has, to date, been 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 present day matter-antimatter asymmetry arose.

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 instruments to detect particles from space and observe astrophysical phenomena that advance our understanding of fundamental particle properties.

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), the composite nature of the protons (which are like bean bags full of quarks and gluons), 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 Fermi National Accelerator Laboratory (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) they are well-suited to precision measurements of particle properties and exacting beam control. The next-generation Energy Frontier accelerator after the LHC is likely to be a high-energy lepton (electron or perhaps muon) 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. 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, gamma rays, and neutrinos from astrophysical sources, and neutrinos from commercial nuclear power reactors.
- 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 that high energy physicists seek to answer, 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. HEP, as steward of accelerator science and advanced accelerator technology R&D in the Office of Science, has developed the knowledge and technologies that are the basis for all of the Office of Science major accelerator user facilities. HEP's contributions to the underlying technologies now used in medicine, science, industry, homeland and national security, as well as for workforce training, are also 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 hazardous material 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 HEP's development of the science and technologies needed for next-generation particle accelerator and detector applications will be transferred and exploited.

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 two thirds of those completing doctoral degrees ultimately pursue careers in diverse sectors of the national economy such as industry, national defense, information technology, medical instrumentation, electronics, communications, and biophysics—where 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 DOE and 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, 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 provided important input for setting programmatic priorities for the HEP program. Many of the recommendations contained in the report have been implemented, and this budget request in particular emphasizes implementation of the P5 roadmap for the Intensity Frontier.

[a] The full HEPAP report is available at http://www.science.doe.gov/hep/files/pdfs/P5_Report%2006022008.pdf.

The Astronomy and Astrophysics Advisory Committee (AAAC) now reports on a continuing basis to DOE, as well as to NSF and the 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, astrophysics and astronomy, such as dark energy and dark matter, and the study of high energy cosmic and gamma rays.

The HEP program also instituted a 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] had 18 specific recommendations relating primarily to staffing, grants review and processing, and project management. HEP has completed seven of the recommendations, particularly in regard to staffing; six recommendations are in-process and five are on-going.

- *Review and Oversight*

  The HEP program office reviews and provides oversight for its research portfolio. All university research proposals are subject to a 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 2011, the Accelerator Science and Theoretical Physics subprograms will be reviewed. Laboratory proposals involving significant new research scope are also subject to peer-review by external experts on an *ad hoc* basis.

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 sponsored a workshop in October 2009 to identify the R&D needs of the various users of accelerators who would benefit from future technology R&D initiatives. The workshop focused on the role of accelerators in the nation's efforts in science, medicine, national security, and industry; the opportunities and research challenges for next generation accelerators; the most promising avenues for new or enhanced R&D efforts; and 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 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 available. Research facilities for high energy physics generally require significant investments over

[a] The 2007 COV report and HEP's response are available at http://www.science.doe.gov/SC-2/COV-HEP/HEP_Reviews.htm.

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 continuing shift of focus from the operation of the facilities built at the end of the 1990s to the design and construction of new research capabilities, while 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 Fermilab continues operations in FY 2011. Its record-breaking performance in delivering data over the last few years means that it will remain competitive with the LHC for significant discoveries during the first few years of LHC operations. 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. First beam collisions at the LHC occurred at the end of 2009 and the first physics run will begin in February 2010. 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 first phase of the anticipated LHC accelerator and detector upgrades to improve performance and reliability and provide 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 the first phase will guide the choice of the most promising physics to pursue in any future enhancement of LHC accelerator and detector capabilities. Physics results from the LHC will also help guide research and development for a potential next-generation lepton collider.

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. In FY 2011, project engineering and design (PED) funding is provided to initiate the Long Baseline Neutrino Experiment (LBNE) and the Muon to Electron Conversion Experiment (Mu2e) that will use the NuMI beam and other auxiliary beamlines before the end of the next decade. The HEP program is developing the LBNE project in coordination with NSF, which is proposing to construct a Deep Underground Science and Engineering Laboratory (DUSEL) in an old gold mine in South Dakota; DUSEL may be an attractive site for the large LBNE neutrino detector.

The Cosmic Frontier: DOE is partnering with NASA and 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 that detects gamma-rays emanating from astrophysical sources, and HEP continues support for commissioning and integration activities for the Alpha Magnetic Spectrometer experiment which is on NASA's Space Shuttle manifest for launch in 2010. HEP is collaborating with NSF on experiments using ground-based observatories, including the Baryon Oscillation Spectroscopic Survey, which is currently operating, and the Dark Energy Survey, currently in fabrication, and on R&D aimed at developing large, next-generation telescopes that can significantly advance our knowledge of dark energy. HEP and NASA continue to work together to develop a space-based Joint Dark Energy Mission that will complement and extend the ground-based measurements. HEP will also 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 funding to begin project engineering and design (PED) for the Long Baseline Neutrino Experiment (LBNE) and Muon to Electron Conversion Experiment (Mu2e) to enable future discoveries.

Annual Performance Results and Targets

Secretarial Priority: Innovation: Lead the world in science, technology, and engineering.

GPRA Unit Program Goal: High Energy Physics Program Goal: 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.

Annual Performance Measure: Deliver within 20% of baseline estimate a total integrated amount of data (in inverse picobarns [pb^{-1}]) to the CDF and D-Zero detectors at the Tevatron[a].

FY 2006	T: Baseline is 675, so within 20% of baseline is 540 pb^{-1}. A: Goal met
FY 2007	T: Baseline is 800 pb^{-1}, so within 20% of baseline is 640 pb^{-1}. A: Goal met
FY 2008	T: Baseline is 1,000 pb^{-1}, so within 20% of baseline is 800 pb^{-1}. A: Goal met
FY 2009	T: Baseline is 1,684 pb^{-1}, so within 20% of baseline is 1,347 pb^{-1}. A: Met
FY 2010	T: Total is 1,700 pb^{-1}, within 20% is 1360 pb^{-1} A: TBD
FY 2011	T: Total is 1,700 pb^{-1}, within 20% is 1,360 pb^{-1}. A: TBD
FY 2012	T: Completed/Discontinued

Annual Performance Measure: 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.

FY 2006	T: Less than 10% variance from established cost and schedule baselines A: Goal met

[a] FY 2011 is the last planned year of operations of the CDF and D-Zero detectors.

FY 2007	T: Less than 10% variance from established cost and schedule baselines A: Goal met
FY 2008	T: Less than 10% variance from established cost and schedule baselines A: Goal met
FY 2009	T: Less than 10% variance from established cost and schedule baselines A: Goal met
FY 2010 - 2015	T: Less than 10% variance from established cost and schedule baselines A: TBD

Annual Performance Measure: Achieve greater than 80% average operation time of the scientific user facilities (the Fermilab Tevatron) as a percentage of the total scheduled annual operating time.

FY 2006	T: 80% of scheduled operating time A: Goal not met
FY 2007	T: 80% of scheduled operating time A: Goal met
FY 2008	T: 80% of scheduled operating time A: Goal met
FY 2009	T: 80% of scheduled operating time A: Goal met
FY 2010	T: 80% of scheduled operating time A: TBD
FY 2011	T: 80% of scheduled operating time A: TBD
FY 2012	T: None[a] A: TBD
FY 2013 - 2015	T: 80% of scheduled operating time A: TBD

[a] The Tevatron complex is shut down in FY 2012 for the installation of the upgrades to the proton accelerator complex for the NOνA project.

Annual Performance Measure: Measure within 20% of the total integrated amount of data (in protons on-target) delivered to the MINOS (or NOvA) detector using the NuMI facility.[a]

FY 2006	T: N/A[b] A:
FY 2007	T: Baseline is 1.5 x 10^{20} protons-on-target to MINOS, so within 20% of baseline is 1.2 x 10^{20} protons-on-target. A: Goal met
FY 2008	T: Baseline is 2.0 x 10^{20} protons-on-target to MINOS, so within 20% of baseline is 1.6 x 10^{20} protons-on-target. A: Goal met
FY 2009	T: Baseline is 2.2 x 10^{20} protons-on-target to MINOS; goal will be met if total integrated amount of data measured is greater than or equal to 1.8 x 10^{20} protons-on-target. A: Goal met
FY 2010	T: 2.7 x10^{20} protons on target to the MINOS. (80% is 2.2 x 10^{20}) A: TBD
FY 2011	T: 2.7 x10^{20} protons on target to the MINOS. (80% is 2.2 x 10^{20}) A: TBD
FY 2012	T: None. A: TBD
FY 2013	T: 1.0 x10^{20} protons on target for NOvA. (80% is 0.8 x 10^{20}) A: TBD
FY 2014	T: 2.5 x10^{20} protons on target for NOvA. (80% is 2.0 x 10^{20}) A: TBD
FY 2015	T: 3.5 x10^{20} protons on target for NOvA. (80% is 2.8 x 10^{20}) A: TBD

[a] FY 2011 is the last planned year of operations of the MINOS detector, operations of the NOvA detector are planned to start in FY 2013.
[b] NuMI performance measure established in 2007.

Proton Accelerator-Based Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Proton Accelerator-Based Physics			
Research	126,405	125,436	130,299
Facilities	274,963	308,731	308,963
Total, Proton Accelerator-Based Physics	401,368	434,167	439,262

Description

The Proton Accelerator-Based Physics subprogram exploits the application of proton accelerators at two of the scientific frontiers. At the Energy Frontier, experiments at the Tevatron and LHC it will be used to 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. At the Intensity Frontier, experiments using the beams from NuMI will make precise, controlled measurements of basic neutrino properties and will provide important clues and constraints on the new world of matter and energy beyond the Standard Model, which is a primary goal of HEP-supported neutrino research.

Selected FY 2009 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 170 and 181 times the mass of the proton. 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 also support future discoveries.

- A groundbreaking ceremony was held in May 2009 at the site of the NOνA neutrino detector in northern Minnesota. The NOνA project will fabricate the NuMI Off-Axis Electron Neutrino Appearance (NOνA) detector near the Ash River, about 40 miles southeast of International Falls. This 14,000-ton particle detector is optimized to identify electron-type neutrinos and, using the NuMI beam from Fermilab, will observe for the first time the transformation of muon-type neutrinos into electron-type neutrinos. Fabrication of the NOνA detector was initiated in 2007, and is planned to be complete in FY 2014. Operations are planned to begin with a partially completed detector in 2013.

- Operations of the Large Hadron Collider (LHC) began in late 2009 after a year-long shutdown to repair electrical problems discovered in its initial start-up. The energy of the machine was ramped up to a center-of-mass energy of 2.36 TeV, surpassing the Tevatron Collider as the world's highest energy accelerator, although initial luminosity is very low as the machine is being carefully commissioned. Both the ATLAS and CMS large detectors have observed events and are taking data with fully functional detectors. The LHC is expected to increase its energy and accumulate much more data in 2010 with its first physics run.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Research	**126,405**	**125,436**	**130,299**

The major research 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 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 2011 is 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 boson with a mass in the range expected (based on other indirect experimental data) will require the entire Tevatron data set. The Tevatron Collider will continue operations in FY 2011 to provide the two detectors access to the entire 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, 16 U.S. universities, and institutions in five foreign countries. The major effort in FY 2011 will be data collection and analysis, along with optimizing accelerator performance to improve beam intensity for higher statistics measurements. The experiment is planned to complete its data taking in 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 2011, 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.

- **Grants Research**	**59,550**	**59,546**	**61,253**

The grant-based HEP experimental research program consists of groups at more than 60 universities performing experiments at proton accelerator facilities. Grant-supported 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 2011, the grant research effort is increased above the FY 2010 level, in order to fully support LHC research activities while maintaining participation in the Tevatron Collider and growing strong neutrino physics programs. Active participation of university physicists is needed to carry out both the collider and neutrino programs at the Tevatron during FY 2011. 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 full operation. Some migration of U.S. university researchers from the LHC back to the Tevatron Collider program has been observed in 2009 due to the delayed startup of the LHC. At the same time, university groups are expected to take important roles in developing the design, physics optimization, and analysis techniques for the planned neutrino initiatives, such as NOνA, Main Injector Experiment ν-A (MINERνA), and LBNE. U.S. university groups also have leadership roles in the Tokai-to-Kamioka (T2K) neutrino oscillation experiment that complements and extends the physics reach of NOνA. The detailed funding allocations will take into account the quality and scientific priority of the research proposed.

	FY 2009	FY 2010	FY 2011
▪ **National Laboratory Research**	**65,857**	**64,956**	**68,108**

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 conducted a comparative peer review of laboratory research groups in this subprogram in 2009, and findings from this review have been used to inform the funding decisions in the FY 2011 request.

In FY 2011, U.S. laboratory physicists will continue to play important roles in 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 the research program at the Tevatron during FY 2011. 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 NOνA, MINERνA, MicroBooNE, and LBNE 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 an enhanced effort related to future neutrino initiatives, in particular detector design for LBNE. The research group at ANL will be working primarily on the ATLAS research and computing program, analysis of the MINOS data, and research on NOνA. The relatively new research group from SLAC on the ATLAS experiment has taken on important roles in LHC research and data analysis.

	FY 2009	FY 2010	FY 2011
▪ **University Service Accounts**	**998**	**934**	**938**

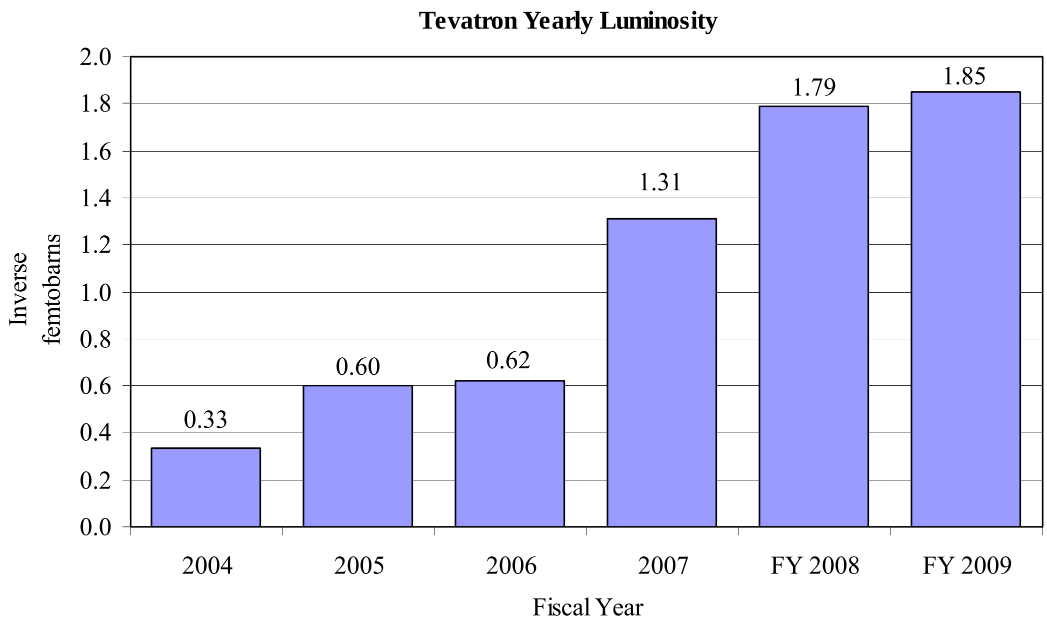
University Service Accounts facilitate the support of university groups working at accelerator facilities. This activity provides funding for these groups to purchase needed equipment and services from the laboratories with a minimum of time and cost overhead. Currently, 45 university groups

		(dollars in thousands)	
	FY 2009	FY 2010	FY 2011

maintain service accounts at Fermilab and at BNL. Funding for these university service accounts reflects the anticipated need.

Facilities	**274,963**	**308,731**	**308,963**
▪ **Proton Accelerator Complex Operations**	**129,585**	**123,985**	**123,215**

Fermilab operations include running the Tevatron accelerator complex for both collider and neutrino physics programs comprising two collider detectors and several neutrino experiments, 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 and reached a steady state of high performance in FY 2009. The plot below shows the annual integrated luminosity delivered to the experiments.



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 improved and the yearly total was slightly higher than FY 2008 with a normal length run. Performance in FY 2010 and FY 2011 should plateau around two inverse femtobarns per year, so the total delivered luminosity for Run II at the end of FY 2011 should be about twice as large as the total recorded by the end of FY 2009.

In FY 2011, the flat funding in this category reflects the fact that stable running has been achieved and that fewer personnel are needed to run the accelerator. Increased automation of data collection with the CDF and D-Zero detectors has also reduced personnel 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 and the MINERνA experiments that use neutrinos from the NuMI beamline. The small MINERνA experiment in the MINOS near detector hall at Fermilab is measuring the rates of neutrino interactions with ordinary matter. Its results are important for interpreting the data from MINOS and other neutrino experiments, including NOνA.

	FY 2009	FY 2010	FY 2011
Proton Accelerator Complex[a]			
Achieved Operating Hours	5,333	N/A	N/A
Planned Operating Hours	5,040	5,400	5,400
Optimal hours (estimated)	5,400	5,400	5,400
Percent of Optimal Hours	99%	100%	100%
Unscheduled Downtime	16%	N/A	N/A
Total Number of Users	2,160	2,000	1,800

▪ **Proton Accelerator Complex Support** **18,892** **14,161** **16,617**

This category includes funding for accelerator improvements, experimental computing expansion, and other detector support, as well as funds for general plant projects (GPP) and other infrastructure improvements at Fermilab. A backlog of GPP projects was addressed with 2009 Recovery Act funding, reducing the need for GPP funds in FY 2010. GPP funding in FY 2011 is increased to the level needed to adequately maintain site infrastructure over the long term.

▪ **Proton Accelerator Facility Projects** **46,958** **80,173** **74,463**

- **Current Facility Projects** **32,666** **61,843** **59,220**

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 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 (e.g., 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 five stories high with a football-field size

[a] Tevatron and NuMI operations run in parallel.

footprint), 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, and detector fabrication made significant progress in 2009, using FY 2009 and Recovery Act funds. In FY 2011, TEC funding has decreased from the peak in FY 2010. Fabrication will be completed in FY 2014, but the experiment can start taking data with a partially completed detector in FY 2013.

Funding in FY 2011 includes $8,000,000 to begin fabrication of the MicroBooNE experiment. This is a new Major Item of Equipment (MIE) project that will fabricate a liquid argon neutrino detector to be used in the Booster neutrino beam at Fermilab for the measurement of low energy neutrino cross-sections. These cross sections will be measured at lower neutrino energy than the work planned for MINERνA and will be important for interpreting data from T2K and the proposed Long Baseline Neutrino Experiment (LBNE).

	FY 2009	FY 2010	FY 2011
• **Future Facility Projects R&D**	**14,292**	**18,330**	**15,243**

Pre-conceptual R&D for possible future projects that utilize the Fermilab facility is funded in this category. Specifically, pre-conceptual R&D directed toward detector concepts tied to future facilities, and for a superconducting GeV linac, is supported in FY 2011. 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 approximately 2–3 times beyond the upgrades planned for NOνA.

	FY 2009	FY 2010	FY 2011
▪ **Large Hadron Collider Support**	**71,897**	**80,161**	**84,033**

U.S. involvement in the LHC has been regularly endorsed by HEPAP and by a National Academies report (EPP 2010[a]). The overall 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.

	FY 2009	FY 2010	FY 2011
• **LHC Accelerator Research**	**13,000**	**12,390**	**12,409**

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. This R&D effort will provide important technical data to CERN for management decisions on possible future LHC accelerator upgrades to increase luminosity. In late 2009, full-size prototype upgraded high-field LHC interaction region magnets composed of niobium-tin (Nb_3Sn) superconductor material, were demonstrated by the U.S. groups developing this technology. The development of these magnets is in preparation for possible U.S. participation in a second phase of upgrades to LHC. Special instrumentation such as LHC beam collimation and monitoring systems is also being developed under the LARP

[a] "Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics" is available at http://www.nap.edu/catalog.php?record_id=11641.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

program. These instruments will play an important role in improving and achieving reliable LHC accelerator operations.

- **LHC Detector Support** **56,397** **58,771** **62,374**

  Funding is provided for operations and maintenance of the U.S.-built detector subsystems. These detectors were commissioned with cosmic ray data until the first LHC beam collisions occurred late in 2009. 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 is also 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 2011, 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 as the rate of physics data is expected to increase as accelerator operations become standardized.

  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-term replacements of major elements of the detectors are ongoing, with proposals expected by the end of 2010. The proposals are expected to cover the two planned phases for LHC upgrades (targeted towards installation in the middle and near the end of the decade, respectively) and will emphasize areas where U.S. groups have particular expertise and technical capability. In FY 2011, funding for LHC upgrade-related detector R&D increases in preparation for possible U.S. participation in these upgrades.

- **LHC Upgrades** **2,500** **9,000** **9,250**

  Fabrication of the Accelerator Project for the Upgrade of the LHC (APUL) will be 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 has been completed. The scope of the project includes the design and fabrication of magnets, replacing those near ATLAS and CMS whose apertures limit the luminosity, and their associated cold powering and feedboxes. The intent is to have these components built by BNL and Fermilab and delivered to CERN for installation in the LHC by FY 2013. The U.S. scope has been coordinated with CERN management and takes advantage of U.S. expertise in the particular technical areas.

▪ **Other Facilities** **7,631** **10,251** **10,635**

This category includes funding for long-term D&D of the Alternating Gradient Synchrotron (AGS) facility at BNL, where operations as a HEP user facility were terminated at the end of FY 2002. Funding for private institutions, government laboratories, and foundations that participate in high

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
energy physics research is also included, 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.			
Total, Proton Accelerator-Based Physics	**401,368**	**434,167**	**439,262**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Research	
▪ **Grants Research**	
Funding for the core grants research program will fully support LHC and Tevatron collider research while growing a strong neutrino physics program to exploit future facilities.	+1,707
▪ **National Laboratory Research**	
Funding will fully support LHC and Tevatron collider research programs and enhance efforts in the neutrino physics program.	+3,152
• **University Service Accounts**	
Funding maintains the support needed for university groups working primarily on research programs at Fermilab and BNL.	+4
Total, Research	**+4,863**
Facilities	
▪ **Proton Accelerator Complex Operations**	
Funding for Proton Accelerator Complex Operations is decreased in FY 2011 due to somewhat reduced personnel needs as Tevatron Collider operations continue. Standardized running procedures and increased automation allow efficient and high performance operation with fewer personnel.	-770
▪ **Proton Accelerator Complex Support**	
Proton Accelerator Complex Support funding increases overall, primarily due to enhancement of GPP funding to the level needed to maintain Fermilab site infrastructure over the long term.	+2,456

	FY 2011 vs. FY 2010 ($000)
▪ **Proton Accelerator Facility Projects**	
• **Current Facility Projects**	
Net funding for Current Facility Projects decreases according to the planned project profiles. Funding decreases for NOvA ($-12,780,000) and MINERvA ($-800,000), offset by increases in funding for MicroBooNE ($+5,957,000) and the other project costs for the new Mu2e project ($+5,000,000).	-2,623
• **Future Facility Projects R&D**	
Funding decreases ($-11,962,000) as the R&D support in FY 2010 for LBNE and Mu2e has shifted out of this category as these efforts become approved projects, offset by increases in funding for pre-conceptual R&D for a superconducting GeV linac, and for specific detector concepts that would make use of possible future Fermilab accelerator facilties ($+8,875,000).	-3,087
Total, Proton Accelerator Facility Projects	**-5,710**
▪ **Large Hadron Collider Support**	
LHC Support increases for pre-conceptual R&D on technologies relevant to the proposed LHC Detector upgrades. ATLAS and CMS operations and support are maintained at about FY 2010 effort levels. LARP and LHC upgrade project (APUL) are continued at FY 2010 levels.	+3,872
▪ **Other Facilities**	
Funding provides for continued service and support in FY 2011 at approximately the same level of effort as FY 2010.	+384
Total, Facilities	**+232**
Total Funding Change, Proton Accelerator-Based Physics	**+5,095**

Electron Accelerator-Based Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Electron Accelerator-Based Physics			
Research	16,699	15,353	14,927
Facilities	15,331	12,074	9,780
Total, Electron Accelerator-Based Physics	32,030	27,427	24,707

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 decade, the electron B-factory at SLAC led 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. There are currently proposals in Italy and Japan for next-generation Intensity Frontier electron-positron colliders, so-called "Super-B Factories" because they are successors to the B-factory at SLAC, whose goal is to fully understand CP violation in B-mesons and hopefully find evidence for unexpected new phenomena.

Selected FY 2009 Accomplishment

Over the past several years, the B-factories in the U.S. and Japan have discovered several unexpected new particles which contain a charm quark and a charm antiquark. However, the masses and decay patterns of these new states do not fit within the theoretical expectations from Quantum ChromoDynamics (QCD) for standard strongly bound quark-antiquark states, and the evidence for some of these new states is controversial and in need of independent confirmation. These recently discovered exotic particles may be hybrid quark-antiquark-gluon states, loosely bound "molecules" of conventional charmed mesons, or four quark states. The exploration of this unforeseen new spectroscopy is an essential step towards fully understanding QCD. Studies of these exotic hadrons with the full B-factory datasets are ongoing.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Research	**16,699**	**15,353**	**14,927**

The research program at the B-factory/BaBar Facility at SLAC will continue 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 300 over the course of the year as analysis is completed on portions of the data. Physicists from approximately 30 universities, three national laboratories (LLNL, LBNL, and SLAC), and seven foreign countries have been actively involved in the data analysis. The physics issues to be addressed include expanding our understanding

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

of CP violation in many particle decay modes and the investigation of the many heavy quark states predicted by QCD.

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 NSF, also completed running in FY 2008. There are also small R&D efforts aimed at designing detectors for a possible next-generation "Super-B factory" in Italy or Japan.

	FY 2009	FY 2010	FY 2011
▪ **Grants Research**	**6,872**	**6,511**	**6,337**

Grant-supported 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 2011, funding continues at a reduced level of effort to complete analysis of physics data from BaBar and the CLEO-c experiment at CESR. Smaller efforts devoted to operations of the Belle detector at KEK B, and the Beijing Spectrometer at BEPC and the analysis of data taken there are supported. Also supported is a small research program devoted to physics studies of a 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 and scientific priority of the research proposed.

	FY 2009	FY 2010	FY 2011
▪ **National Laboratory Research**	**9,817**	**8,816**	**8,565**

The national laboratory research program consists of groups at four 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 FY 2010.

In FY 2011, laboratory-based research in this subprogram continues at about the same 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 period of intense analysis of the entire B-factory data set and will be focused on final archival analyses. Research groups at LBNL and LLNL have mostly transitioned to other activities. A small research program at Fermilab and SLAC devoted to physics studies of the International Linear Collider is also supported.

	FY 2009	FY 2010	FY 2011
▪ **University Service Accounts**	**10**	**26**	**25**

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.

(dollars in thousands)	FY 2009	FY 2010	FY 2011
Facilities	**15,331**	**12,074**	**9,780**
▪ **Electron Accelerator Complex Operations**	**10,951**	**11,194**	**8,880**

B-factory operations ended in FY 2008. Funding in this category supports the transition of the B-factory accelerator complex to a safe and stable maintenance mode and decommissioning and decontamination (D&D) activities. The funding category also supports ongoing BaBar computing operations and data analysis.

▪ **Electron Accelerator Complex Support**	**4,380**	**880**	**900**

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	**32,030**	**27,427**	**24,707**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($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. Analysis of the final archival results from BaBar and CLEO-c data is planned to be completed in 2011.	-426
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 the accelerator into a minimum maintenance configuration.	-2,314
▪ **Electron Accelerator Complex Support**	
Funding is increased slightly to maintain the computing capabilities needed to finish BaBar data analysis.	+20
Total, Facilities	**-2,294**
Total Funding Change, Electron Accelerator-Based Physics	**-2,720**

Non-Accelerator Physics
Funding Schedule by Activity

(dollars in thousands)

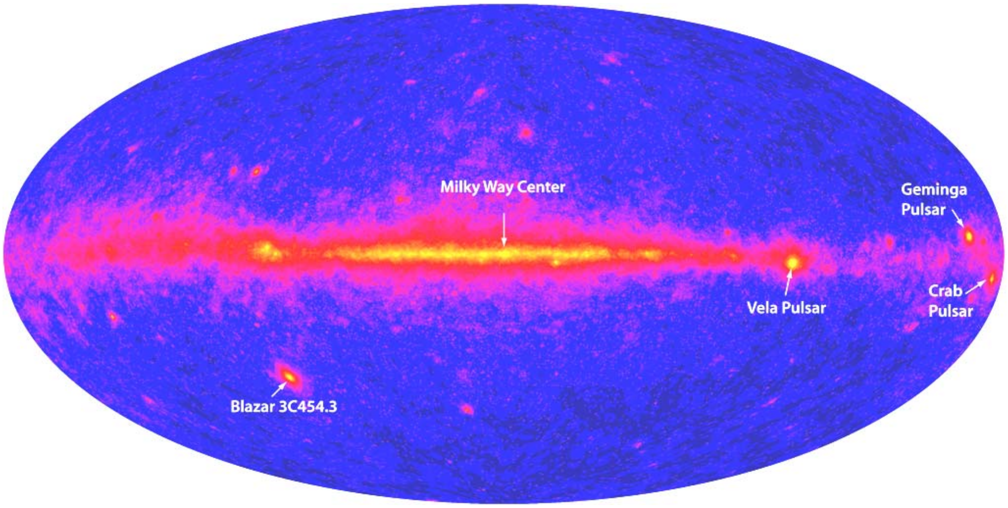
	FY 2009	FY 2010	FY 2011
Non-Accelerator Physics			
Grants Research	22,215	21,753	22,556
National Laboratory Research	40,181	40,813	43,923
Projects	35,542	37,059	22,060
Other	3,200	0	0
Total, Non-Accelerator Physics	101,138	99,625	88,539

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. For example, some of the earliest discoveries in particle physics were due to the production of previously unobserved particles in high-energy cosmic rays. Non-Accelerator Physics studies play an important role in the HEP program, using ever more sophisticated techniques to probe fundamental physics questions with naturally occurring particles and phenomena. Scientists in this subprogram investigate topics central to both the Intensity and Cosmic Frontiers, such as understanding the nature of dark matter and dark energy; precision measurements of neutrino properties that will illuminate their role in the history of the universe; and searches for new phenomena such as proton decay 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.

Selected FY 2009 Accomplishments

- In FY 2009, the Large Area Telescope (LAT), the primary instrument on NASA's Fermi Gamma-ray Space Telescope (FGST) mission, performed outstandingly delivering data that has resulted in over 35 peer reviewed publications and motivated a week-long workshop to present and discuss what these results mean for astronomy, astrophysics, and particle physics. The initial results from FGST were selected by the editors of *Science* magazine as the runner-up "Breakthrough of the Year" for 2009, noting, "The Fermi Telescope has … revealed, with unprecedented detail, a very restless high-energy universe, and it is solving old mysteries while making new, unexpected discoveries." The international LAT collaboration released an all-sky survey which shows the universe as seen in high-energy gamma rays (see the figure below). The LAT was a joint DOE and NASA project. 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 Cryogenic Dark Matter Search (CDMS) experiment announced in late 2009 the final results of the first phase of their experiment, based on several years of data taking with a few kilograms of ultra-sensitive silicon and germanium detectors that can detect extremely rare dark matter interactions. They found two events in their signal region, but this could be a statistical fluctuation of the expected background due to naturally-occuring radioactivity. An upgraded 15 kg detector with improved background rejection is in fabrication (SuperCDMS) and will be installed and operated in 2010 to confirm or deny the tantalizing initial results. Other experiments using different techniques are also actively exploring this region.

Detailed Justification

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Grants Research	**22,215**	**21,753**	**22,556**

The 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. This subprogram is carried out in collaboration with physicists supported by other government agencies and institutes; among them NSF, NASA, and the Smithsonian Astrophysical Observatory. 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 2011, the Non-Accelerator Physics grants program will support research on experiments that are now engaged in data collection, as well as preparations for future experiments. The operating experiments include the Very Energetic Radiation Imaging Telescope Array System, a ground-based gamma ray experiment at the Whipple Observatory in Arizona; the Pierre Auger Observatory in Argentina; and the LAT gamma-ray survey on NASA's FGST space-based mission. Other active research efforts include searches for dark matter using the upgraded "Super" Cryogenic Dark Matter Search (SuperCDMS) at the Soudan Mine in Minnesota and the Axion Dark Matter eXperiment (ADMX) at LLNL, as well as other dark matter searches using different techniques. Studies of dark

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

energy use data from the Baryon Oscillation Spectroscopic Survey (BOSS) experiment on the Sloan Digital Sky Survey telescope in New Mexico. Research also continues with Super-Kamiokande, a proton decay and neutrino detector located in the Kamioka Underground Laboratory in Japan and the Enriched Xenon Observatory (EXO), which is searching for neutrino-less double beta decay at the DOE Waste Isolation Pilot Plant facility in New Mexico.

These groups also participate in the research and planning for the Reactor Neutrino Detector at Daya Bay in China, the Dark Energy Survey (DES) experiment in Chile, 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. 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 and will begin taking data in FY 2011.

HEP also supports research groups participating in the design and R&D efforts for next-generation dark matter experiments and a next-generation neutrino-less double beta decay experiment.

National Laboratory Research	**40,181**	**40,813**	**43,923**

Groups at several national laboratories (ANL, BNL, Fermilab, LBNL, LLNL, LANL, and SLAC) currently 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 2011, the laboratory research program in non-accelerator physics will continue to support research and operations for ongoing experiments such as the Pierre Auger Observatory, SuperCDMS, the Chicagoland Observatory for Underground Particle Physics 60 kg (COUPP-60) experiment, ADMX, BOSS, EXO, 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 completing their fabrication phase such as DES. The laboratory groups also focus on the R&D and design efforts for other future projects such as the COUPP-500kg, other next generation dark matter experiments, and the proposed JDEM and LSST experiments to study dark energy.

Projects	**35,542**	**37,059**	**22,060**
▪ **Current Projects**	**24,700**	**21,110**	**6,060**

Funding for the fabrication of the Reactor Neutrino Detector MIE continues in FY 2011. 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 about 10 km away. From this data, a crucial neutrino oscillation parameter can be extracted. The U.S. collaboration is led by groups from BNL and LBNL. The project is expected to be completed in FY 2013.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

Final funding for the DES MIE is provided in FY 2011, with final project completion to occur one year later. 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.

▪ **Future Projects R&D**	**10,842**	**15,949**	**16,000**

This category provides support for R&D and pre-conceptual design activities for promising proposed future experiments. In FY 2011, this includes R&D on technical issues related to DOE's proposed contribution for the JDEM and LSST projects. DOE, NASA, and NSF await input from the community on the scientific priority given to these projects in the National Academies' Decadal Survey for Astronomy and Astrophysics. This report is due in summer 2010.

Other	**3,200**	**0**	**0**

FY 2009 funding provided for completion of EXO-200 experiment at the Waste Isolation Pilot Plant.

Total, Non-Accelerator Physics	**101,138**	**99,625**	**88,539**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Grants Research	
Funding for grant-based research continues at a constant level of effort in order to support experiments that are currently active in commissioning, operations, and/or data analysis and to respond to new research proposals.	+803
National Laboratory Research	
Funding for laboratory-based research is enhanced to provide support for pre-operations, operations, and commissioning for projects that have reached or will soon reach completion (SuperCDMS, DES).	+3,110
Projects	
▪ **Current Projects**	
Following the planned project profiles, funding decreases for Reactor Neutrino Detector ($-8,940,000), DES ($-4,610,000), and SuperCDMS ($-1,500,000).	-15,050

	FY 2011 vs. FY 2010 ($000)
▪ **Future Projects R&D**	
R&D funding is provided for proposed ground-based and satellite-based dark energy, dark matter, and other particle astrophysics experiments. This funding is maintained at approximately the FY 2010 level. Allocated funding will utilize guidance from the community on the priority given to these projects in the National Academies' Decadal Survey.	+51
Total, Projects	**-14,999**
Total Funding Change, Non-Accelerator Physics	**-11,086**

Theoretical Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Theoretical Physics			
Grants Research	26,801	26,801	27,555
National Laboratory Research	24,549	25,105	26,290
Computational HEP	11,280	10,000	10,400
Other	3,518	5,056	5,279
Total, Theoretical Physics	66,148	66,962	69,524

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 level of understanding 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 has provided many fundamental breakthroughs in the development of the Standard Model. This subprogram supports and advances research at all three high energy physics Frontiers.

Selected FY 2009 Accomplishments

- The 2008 Nobel Prize in Physics, announced in October 2008, was shared by Yoichiro Nambu for his theoretical work discovering how symmetry breaking can manifest itself in nature. His work was supported by HEP.
- High precision numerical simulations of the strong interactions of quarks and gluons, Quantum Chromodynamics (QCD), are producing accurate and reliable predictions of strong interaction decay constants and mass differences. These results, which use supercomputer simulations of QCD, include the important but difficult to calculate "virtual quark" effects in the underlying field theory. In some important cases, the agreement between the theoretical and experimental values has reached the level of the experimental uncertainty itself. This is a major success of the theory of strong interactions and is an improvement by nearly an order of magnitude over previous calculations. These breakthroughs have been accomplished by the application of new, highly efficient algorithms combined with the use of today's supercomputers and dedicated clusters of personal computers. The support for these research breakthroughs has come from ongoing efforts in the core HEP theory research program, as well as the SciDAC program for high-performance software, and investments in dedicated computing hardware to enable fast and reliable calculations.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Grants Research	**26,801**	**26,801**	**27,555**

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. 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 play leading roles in addressing these research areas.

In FY 2011, the Theoretical Physics Grants program supports enhanced efforts focused on 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 all three particle physics Frontiers.

National Laboratory Research	**24,549**	**25,105**	**26,290**

The national laboratory theoretical research program currently consists of groups at seven DOE laboratories (Fermilab, SLAC, BNL, ANL, LBNL, LLNL, 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 whose findings have been used to inform the funding decisions in this budget request; in particular there are targeted increases to support laboratory research programs which reviewed well. HEP will review these programs again in 2011.

In FY 2011, 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 data from the LHC becomes available, an increased effort will be made to identify the most promising and sensitive methods for finding signs of new phenomena in these data.

Computational HEP	**11,280**	**10,000**	**10,400**

This budget category provides for specific high energy physics research activities that require extensive or customized computational resources including R&D, design, fabrication, procurement, maintenance, and operation of computational software and hardware that is not associated with specific high energy physics experiments or research facilities. Current activities in this category include the Scientific

	FY 2009	FY 2010	FY 2011

(dollars in thousands)

Discovery through Advanced Computing (SciDAC) program, the Lattice QCD (LQCD) computing initiative, support for dedicated transatlantic networking, and U.S. contributions to experiment-independent computer codes required for HEP's program.

▪ **SciDAC**	**6,100**	**6,000**	**5,600**

All HEP-supported SciDAC projects had mid-term continuation reviews in FY 2009 and are planned to be re-competed in FY 2011. 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 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**	**5,180**	**4,000**	**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-teraflop computer capability for dedicated LQCD simulations. During FY 2009, the first phase of this joint effort was completed and provides 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.

This category also includes funding for the HEP-related transatlantic 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 2009, the U.S. LHC Net provided 40 gigabits per second of connectivity between CERN and points of presence in Chicago and New York and is being upgraded to 60 gigabits per second. U.S. LHC Net is closely integrated with the DOE Energy Science Network, which connects the U.S. LHC Net transatlantic bridge to the main U.S. research network backbone.

Other	**3,518**	**5,056**	**5,279**

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 funding for the QuarkNet education project. This project takes place in QuarkNet centers which are set up at universities and laboratories

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

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.

Total, Theoretical Physics	**66,148**	**66,962**	**69,524**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Grants Research	
The Theoretical Physics Grants program is supported at a constant level of effort that will support the analysis of current and previous experiments, and in the design and optimization of new experiments.	+754
National Laboratory Research	
The National Laboratory Research program is increased above a constant level of effort to provide additional support for the laboratory research groups which performed well in the HEP comparative review in 2008.	+1,185
Computational HEP	
The final allocation of funding among the activities in this category (SciDAC, LQCD, and Network Support) will depend upon peer-review of proposed activities, identified scientific priorities, and program needs and will provide for a constant level of support compared to FY 2010 funding levels.	+400
Other	
The increase maintains approximately a constant effort in education and outreach activities, and the data compilations and summaries provided by the Particle Data Group at LBNL.	+223
Total Funding Change, Theoretical Physics	**+2,562**

Advanced Technology R&D

Funding Schedule by Activity

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Advanced Technology R&D			
Accelerator Science	51,999	47,324	52,135
Accelerator Development	98,520	90,501	91,611
Other Technology R&D	24,665	24,819	26,195
SBIR/STTR	0	19,658	20,027
Total, Advanced Technology R&D	175,184	182,302	189,968

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.

Selected FY 2009 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.
- An example of a novel detector technology that was recently developed with DOE support is a large-area single photon sensor with extremely low radioactivity. These new photodetectors will enable cost-effective scale-up of highly sensitive photon detectors (such as dark matter detectors) that require large active volumes along with extremely low backgrounds from naturally-occurring radioactivity. This technology has a patent application pending and is being commercialized.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Accelerator Science	**51,999**	**47,324**	**52,135**

This activity focuses on understanding the science underlying the technologies used in particle accelerators and storage rings, as well as the fundamental physics of charged particle beams. Funding in this category includes costs for operating university and laboratory-based accelerator R&D test facilities.

▪ **Grants Research**	**9,060**	**9,060**	**9,725**

The FY 2011 budget will continue support for a broad research program in advanced accelerator physics and related technologies. Funding is increased above a constant level of effort to support increased university participation in experiments at new accelerator R&D facilities (BELLA and FACET, see below). Funding is included for private institutions, universities, industry, and federal research centers that participate in fundamental accelerator physics. As part of their research efforts, these groups train graduate students and postdoctoral researchers. Physicists in this research area often work in collaboration with other university and laboratory groups. For example, university groups are leading the development and execution of the proposals for the experimental program at FACET. Research efforts are selected based on a peer review process.

The grant-based 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**	**34,939**	**38,264**	**42,410**

This activity supports accelerator R&D efforts and operations of test facilities at ANL, BNL, Fermilab, LBNL and SLAC, and theoretical studies of space-charge dominated beams at the Princeton Plasma Physics Laboratory. HEP conducted a comparative peer-review of the laboratory research efforts in this subfield in 2008, whose findings have been used to inform the funding decisions in this budget request; in particular there are targeted increases to support laboratory research programs which reviewed well. HEP will review these programs again in 2011.

The national laboratory accelerator science program explores advanced methods to accelerate charged particles with the goal of more efficient, compact, and inexpensive particle accelerators. Efforts in FY 2011 will focus on the development of new accelerating structures and techniques needed to achieve accelerating gradients in excess of 100 MeV/m. This work currently occurs primarily at the Argonne Wakefield Accelerator, the Laser Optical Accelerator Systems Integrated Studies (LOASIS) test facility at LBNL, and the new Facility for Accelerator Science and Experimental Test Beams (FACET) at SLAC. The new BErkeley Lab Laser Accelerator project (BELLA, see Projects below) will be in full fabrication in FY 2011 with completion planned for FY 2012. In FY 2011, the first round of experiments will begin at the new FACET facility where an electron bunch (the beam is not a continuous stream of electrons but structured in discrete bunches) is accelerated by plasma wakefields. The goal of this effort will be a demonstration of efficient,

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

full-length accelerating structures with gradients well above 1 GeV per meter. Funding for FACET operations is included in this category.

The national laboratory groups are also involved in a significant long-range R&D effort to demonstrate the advanced technologies needed to realize muon-based accelerators; this is a global R&D program with major U.S. participation at Fermilab and BNL. A five-year R&D plan for muon-based accelerators, with milestones and deliverables, has been submitted by U.S. research institutions and will be reviewed by HEP in 2010.

BNL is also 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, based on proposal-driven, peer-reviewed research in accelerator concepts and beam physics. In FY 2011, 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.

▪ **Projects**	**8,000**	**0**	**0**

Funding was provided in the FY 2009 Appropriation and in the FY 2009 Recovery Act for the BELLA Project. 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 3 centimeter long structure. BELLA will initially improve this by a factor of ten, to 10 GeV in a one meter long structure. BELLA is planned to be complete in FY 2012.

Accelerator Development	**98,520**	**90,501**	**91,611**

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. Carrying out development of advanced high-technology components at this level often requires significant investments in research infrastructure. 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.

▪ **General Accelerator Development**	**39,520**	**33,501**	**34,171**

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 latter effort is coordinated with the SciDAC accelerator simulation project.

The R&D program on high-power RF systems is led by SLAC, including simulation codes for modeling RF system components and high-powered microwave tubes. This program also builds custom high-power RF sources for HEP and other scientific applications.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

Fermilab leads the R&D for a future high-intensity neutrino beam facility, in particular developing very high intensity proton sources for neutrino physics research.

The R&D program on superconducting magnets and materials includes efforts at BNL, Fermilab, and LBNL, focusing on demonstrating very high field superconducting magnets using advanced superconducting materials, and an industrially-based program to develop these materials, particularly niobium-tin.

	FY 2009	FY 2010	FY 2011
▪ **Superconducting RF R&D**	**24,000**	**22,000**	**22,440**

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. Completion of this essential technology infrastructure was accelerated in FY 2009 using Recovery Act funding.

In FY 2011, 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 2011 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.

Funding in FY 2011 includes $3,200,000 of capital equipment to procure an electron beam welder as an MIE project. The electron beam welder will be located at Fermilab and will be used to assemble and repair niobium superconducting cavities.

	FY 2009	FY 2010	FY 2011
▪ **International Linear Collider R&D**	**35,000**	**35,000**	**35,000**

A TeV-scale linear electron-positron collider iswidely considered by the international high energy physics community to be a likely successor to the LHC, though the data from the LHC may indicate that an even higher energy accelerator (such as a muon collider) is needed to understand the new physics that emerges at this energy scale. 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 results from the LHC (necessary to finalize operating parameters for a TeV-scale linear collider).

In FY 2011, 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

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

will also be provided for development and prototyping of high level RF equipment and components 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	**24,665**	**24,819**	**26,195**

This category includes R&D on new particle detector technologies, addressing fundamental scientific problems to foster new technologies in particle detection, measurement, and data processing; and providing support for prototyping and detector systems development to bring the technologies to the maturity where they can be incorporated into future particle physics experiments.

▪ **Detector Development, Grants Research**	**3,492**	**3,568**	**3,688**

The grants-based R&D program provides 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. This support includes maintaining university infrastructure to enable state-of-the-art R&D into new detector technologies. Technologies targeted for development are selected based on anticipated applications that require further technological improvements before deployment, and specific proposals are selected based on peer-review. Final funding levels depend on the number and quality of proposals received. Current areas of investigation include liquid noble gas detectors, silicon photomultipliers, large area photodetectors, and picosecond timing techniques. This activity was called Advanced Detector Research in past budget submissions.

▪ **Detector Development, National Laboratory Research**	**21,173**	**21,251**	**22,507**

This activity supports detector R&D efforts and operations of test facilities at ANL, BNL, Fermilab, LBNL and SLAC. HEP conducted a comparative peer-review of the laboratory research efforts in this subfield in 2009, whose findings have been used to inform the funding decisions in this budget request.

The FY 2011 request will maintain R&D efforts directed toward developing new detectors, including prototyping and in-beam studies. A diverse program will continue, including efforts on particle flow calorimeters, very low-mass trackers, advanced charged-coupled devices, and radiation resistant, fast readout electronics. Prototype detector systems will be operated in the Fermilab test beam, providing a major test of particle flow algorithms and detector construction techniques. Since the Fermilab test beam is over-subscribed, a reconfiguration of an old experimental beam line at SLAC into a dedicated test beam for detectors to meet this demand is being supported.

This activity was called Detector Development in past budget submissions.

SBIR/STTR	**0**	**19,658**	**20,027**

In FY 2009 $17,730,000 and $2,128,000 was transferred to the congressionally mandated Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, respectively. The FY 2010 and FY 2011 amounts are estimated requirements for the continuation of these programs.

Total, Advanced Technology R&D	**175,184**	**182,302**	**189,968**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Accelerator Science	
▪ **Grants Research**	
Funding for grant-based research increases relative to the FY 2010 level-of-effort to support university participation in experiments at new accelerator R&D facilities.	+665
▪ **National Laboratory Research**	
Funding for the core research program at the laboratories is increased to support enhanced research at newly completed accelerator facilities including FACET.	+4,146
Total, Accelerator Science	**+4,811**
Accelerator Development	
▪ **General Accelerator Development**	
Funding for General Accelerator Development activities maintains about a constant level of effort.	+670
▪ **Superconducting RF R&D**	
Funding for Superconducting RF development supports the planned implementation of capabilities at Fermilab and about a constant level of effort for supporting R&D efforts.	+440
Total, Accelerator Development	**+1,110**
Other Technology R&D	
Funding for Other Technology R&D maintains about a constant level of effort after the funding for the test beam is taken into account.	+1,376
SBIR/STTR	
SBIR/STTR programs are funded at the mandated level.	+369
Total Funding Change, Advanced Technology R&D	**+7,666**

Construction

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Construction			
11-SC-40, Long Baseline Neutrino Experiment, PED	0	0	12,000
11-SC-41, Muon to Electron Conversion Experiment, PED	0	0	5,000
Total, Construction	0	0	17,000

Description

This subprogram provides for the Construction and Project Engineering and Design that is needed to meet overall objectives of the High Energy Physics program.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
11-SC-40, Long Baseline Neutrino Experiment, PED	**0**	**0**	**12,000**

The Long Baseline Neutrino Experiment will be composed of a neutrino beamline, small (near) detector located near to the neutrino beamline, and a large (far) neutrino detector located a long distance from the neutrino source. In order to build a neutrino beam that passes through the earth, a beam of protons must be transported through a tunnel that points into the ground. At the end of the tunnel the protons hit a target producing neutrinos that then travel through the earth. An existing neutrino beam of this type is the Neutrino at the Main Injector (NuMI) beam at Fermilab. The new LBNE beamline would provide low-energy neutrinos, a more intense beam, and point in a different direction from NuMI in order to provide the needed longer distance to the detector to extend the study of neutrino oscillations.

It is expected that the far detector will also need to be located underground to reduce the background from cosmic rays to a manageable level. The scope of work currently being developed includes a neutrino beamline, a small near detector, one or more large far neutrino detectors, the large underground cavern(s) needed to house the far detector(s), and the infrastructure needed to support the construction and operation of the large detector if housed underground.

11-SC-41, Muon to Electron Conversion Experiment, PED	**0**	**0**	**5,000**

The conversion of a muon to an electron in the field of a nucleus provides a unique window on the structure of potential new physics discoveries and allows access to new physics at very high mass scales. The Particle Physics Project Prioritization Panel (P5) identified this opportunity as a top priority for the Intensity Frontier of particle physics.

	FY 2009	FY 2010	FY 2011
	(dollars in thousands)		
This project will construct a new beamline to take protons from the existing 8 GeV Booster synchrotron at Fermilab to a muon production target, a beamline to transport those muons to the detector, a low-mass magnetic spectrometer, which can measure the electron momentum with a resolution of order 0.15%, and a new experimental hall to house the muon production target, muon beamline, and the detector.			
Total, Construction	**0**	**0**	**17,000**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
11-SC-40, Long Baseline Neutrino Experiment, PED	
Funding is provided to initiate PED activities.	+12,000
11-SC-41, Muon to Electron Conversion Experiment, PED	
Funding is provided to initiate PED activities.	+5,000
Total, Construction	**+17,000**

Supporting Information

Operating Expenses, Capital Equipment and Construction Summary

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Operating Expenses	679,244	702,203	714,333
Capital Equipment	87,167	103,908	90,131
General Plant Projects	4,417	2,952	7,536
Accelerator Improvement Projects	5,040	1,420	0
Construction	0	0	17,000
Total, High Energy Physics	775,868	810,483	829,000

Funding Summary

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Research	451,674	448,910	463,970
Scientific User Facilities Operations	247,497	239,711	239,638
Projects			
Major Items of Equipment	69,066	91,953	72,730
Construction	0	0	22,000
Total, Projects	69,066	91,953	94,730
Other	7,631	29,909	30,662
Total, High Energy Physics	775,868	810,483	829,000

Scientific User Facilities Operations

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Tevatron	162,769	156,476	155,075
B-factory	15,331	12,074	9,780
LHC Detector Support and Operations	69,397	71,161	74,783
Total, Scientific User Facilities Operations	247,497	239,711	239,638

Total Facility Hours and Users

	FY 2009	FY 2010	FY 2011
Proton Accelerator Complex[a]			
Achieved Operating Hours	5,333	N/A	N/A
Planned Operating Hours	5,040	5,400	5,400
Optimal hours (estimated)	5,400	5,400	5,400
Percent of Optimal Hours	99%	100%	100%
Unscheduled Downtime	16%	N/A	N/A
Total Number of Users	2,160	2,000	1,800
SLAC B-factory			
Total Number of Users	800	600	300
Total Facilities			
Achieved Operating Hours	5,333	N/A	N/A
Planned Operating hours	5,040	5,400	5,400
Optimal hours (estimated)	5,400	5,400	5,400
Percent of Optimal Hours	99%	100%	100%
Unscheduled Downtime	16%	N/A	N/A
Total Number of Users	2,960	2,600	2,100

Major Items of Equipment (MIE)

(dollars in thousands)

	Prior Years	FY 2009	FY 2009 Recovery Act	FY 2010	FY 2011	Outyears	Total
Proton Accelerator-Based Physics							
MINERνA							
Total Estimated Costs (TEC)	5,000	4,900	0	800	0	0	10,700
Other Project Costs (OPC)	6,100	0	0	0	0	0	6,100
Total Project Costs (TPC)	11,100	4,900	0	800	0	0	16,800

[a] Tevatron and NuMI operations run in parallel.

(dollars in thousands)

	Prior Years	FY 2009	FY 2009 Recovery Act	FY 2010	FY 2011	Outyears	Total
NOνA							
TEC	550	15,542	14,936	59,000	46,220	60,720	196,968
OPC	28,744	12,224	40,064	0	0	0	81,032
TPC	29,294	27,766	55,000	59,000	46,220	60,720	278,000
T2K							
TEC	1,848	1,000	0	0	0	0	2,848
OPC	1,860	0	0	0	0	0	1,860
TPC	3,708	1,000	0	0	0	0	4,708
Accelerator Project for the Upgrade of the LHC							
TEC	0	0	0	TBD[a]	9,250	8,250	17,500
OPC	0	2,500	0	9,000[a]	0	0	11,500
TPC	0	2,500	0	9,000	9,250	8,250	29,000
MicroBooNE[b]							
TEC	0	0	0	0	8,000	8,957	16,957
OPC	0	0	0	2,043	0	0	2,043
TPC	0	0	0	2,043	8,000	8,957	19,000
Non-Accelerator Physics							
Reactor Neutrino Detector							
TEC	5,460	14,000	0	11,000	1,960	500	32,920
OPC	2,480	0	0	0	100	0	2,580
TPC[c]	7,940	14,000	0	11,000	2,060	500	35,500

[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. FY 2010 funding 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.

[b] This MIE is not yet baselined, and therefore the TEC and OPC have not yet been determined. The Mission Need (CD-0) was approved September 2009. The estimated cost range is $17,000,000–$19,000,000.

[c] A baseline change increasing the TPC from $34,000,000 to $35,500,000 with a planned completion date of April 2013 was approved by the Secretarial Acquisition Executive on January 11, 2010. This baseline change was needed to accommodate delays in the civil construction being performed by our Chinese partners.

(dollars in thousands)

	Prior Years	FY 2009	FY 2009 Recovery Act	FY 2010	FY 2011	Outyears	Total
Dark Energy Survey							
TEC	1,650	8,990	0	8,610	4,000	0	23,250
OPC	10,990	910	0	0	0	0	11,900
TPC	12,640	9,900	0	8,610	4,000	0	35,150
SuperCDMS at Soudan							
TEC/TPC	0	1,000	0	1,500	0	0	2,500
Advanced Technology R&D							
Advanced Accelerator R&D Test Facility[a]							
BELLA							
TEC	0	8,000	18,718	0	0	0	26,718
OPC	0	0	2,000	0	0	0	2,000
TPC	0	8,000	20,718	0	0	0	28,718
FACET							
TEC	0	0	11,000	0	0	0	11,000
OPC	0	0	2,000	0	0	0	2,000
TPC	0	0	13,000	0	0	0	13,000
Electron Beam Welder							
TEC/TPC	0	0	0	0	3,200	0	3,200

[a] Two proposals, Berkeley Lab Laser Accelerator (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, both are proceeding. FACET received only Recovery Act funds and BELLA received 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.

(dollars in thousands)

	Prior Years	FY 2009	FY 2009 Recovery Act	FY 2010	FY 2011	Outyears	Total
Total MIEs							
TEC		53,432	44,654	80,910	72,630		
OPC		15,634	44,064	11,043	100		
TPC		69,066	88,718	91,953	72,730		

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. A total of $55,000,000 was provided under the Recovery Act to advance the project. Funding planned for the outyears was reduced to maintain the same TPC. Work is ongoing to update the schedule to reflect the advanced funding profile. As of now, the planned completion for this project is still in 2014, but it is expected to be advanced.

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. This project was completed 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.

MicroBooNE is a new MIE planned to begin fabrication in FY 2011. The scope of the project is build a liquid argon neutrino detector to be used in the Booster neutrino beam at Fermilab for the measurement of low energy neutrino cross-sections. These cross sections will be measured at lower neutrino energy than the work planned for MINERνA and will be important for future neutrino oscillation experiments such as T2K and the proposed long baseline neutrino experiment for which PED funds are requested in FY 2011. This experiment will also be an important demonstration of efficacy of liquid argon time projection chambers as neutrino detectors.

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. A baseline change increasing the TPC from $34,000,000 to $35,500,000 with a planned completion date of April 2013 was approved January 2010. This baseline change was needed to accommodate delays in the civil construction being performed by our Chinese partners.

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 Accelerator (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, both projects are proceeding. FACET received only Recovery Act funds and BELLA is funded with 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. Both projects received CD-1 in September 2009. BELLA also received CD-2A/3A to approve procurement of the 1 petawatt laser.

Electron Beam Welder is a new MIE in FY 2011. This is a single procurement for a large piece of equipment needed in the processing of niobium superconducting RF cavities. Electron beam welding is the preferred method of welding niobium due to its very high melting point, approximately 4500° F, and the minimal size of the heat affected zone. The electron beam welder for Fermilab will be used to assemble and repair niobium superconducting cavities.

Construction Projects

(dollars in thousands)

	Prior Years	FY 2009	FY 2009 Recovery Act	FY 2010	FY 2011	Outyears	Total
Long Baseline Neutrino Experiment (PED)							
TEC	0	0	0	0	12,000	90,000	102,000
OPC	0	0	13,000	9,180	0	0	22,180
TPC	0	0	13,000	9,180	12,000	90,000	124,180
Muon to Electron Conversion Experiment (PED)							
TEC	0	0	0	0	5,000	30,000	35,000
OPC	0	0	0	5,000	5,000	0	10,000
TPC	0	0	0	5,000	10,000	30,000	45,000
Total Construction							
TEC		0	0	0	17,000		
OPC		0	13,000	14,180[a]	5,000		
TPC		0	13,000	14,180	22,000		

Scientific Employment

	FY 2009 estimate	FY 2010 estimate	FY 2011 estimate
# University Grants	200	200	200
# Laboratory Groups	45	45	45
# Permanent Ph.D.'s (FTEs)	1,150	1,140	1,140
# Postdoctoral Associates (FTEs)	600	550	550
# Graduate Students (FTEs)	605	595	595
# Ph.D.'s awarded	110	110	110

[a] Other Project Costs for planned Construction activities in FY 2010 reflects the budget plan in the Mission Need statements for these projects. Critical Decision documentation was recently approved and the funding will be provided in the 2nd Quarter of FY 2010.

11-SC-40, Long Baseline Neutrino Experiment (LBNE), Fermi National Accelerator Laboratory, Batavia, Illinois
Project Data Sheet is for PED

1. Significant Changes

The most recent DOE O 413.3A approved Critical Decision (CD) is CD-0 that was approved January 8, 2010.

A Federal Project Director (FPD) has not been assigned to this project, but an FPD will be assigned by CD-1.

This PDS is new for PED. The FY 2011 request is for PED only.

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 2011	1/8/2010	1Q FY 2011	4Q FY 2013	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[b]

(dollars in thousands)

	TEC, PED	TEC, Construction	TEC, Total	OPC Except D&D	OPC, D&D	OPC, Total	TPC
FY 2011	102,000[c]	TBD	TBD	22,180[d]	TBD	TBD	TBD

4. Project Description, Justification, and Scope

The Long Baseline Neutrino Experiment (LBNE) will be composed of a neutrino beamline, a small near detector, and a large neutrino detector located a long distance from the neutrino beam. A neutrino beam designed to pass through earth is built in a downward sloping tunnel, like the Neutrinos at the Main Injector (NuMI) beam, and therefore requires the construction of an underground tunnel. This new beamline would provide low-energy neutrinos, a more intense beam, and point in a different direction from NuMI in order to provide the longer distance to the detector needed for the study of neutrino oscillations.

[a] This project does not have CD-2 approval and is not requesting construction funds.
[b] This project is not yet baselined.
[c] This is a preliminary estimate for the planned PED over FY 2011–FY 2013.
[d] This is a preliminary estimate for Other Project Costs (OPC) including R&D, conceptual design, but not commissioning, and pre-operations.

Depending on the technology used, the detector may also need to be located underground to reduce the background from cosmic rays to a manageable level. The scope of work currently being developed includes: a neutrino beamline, one or more large neutrino detectors, the large underground cavern(s) needed to house the detector(s), and the infrastructure needed to support the construction and operation of the large detector underground.

The Particle Physics Project Prioritization Panel saw the Deep Underground Science and Engineering Laboratory (DUSEL), proposed by the National Science Foundation (NSF) to be a good match to the needs of a long baseline neutrino experiment. The Office of High Energy Physics (HEP) has been in discussions with the NSF Physics Division on cooperating during the development of these two initiatives, but will not commit to the DUSEL location for the long baseline neutrino experiment until the DOE alternatives analysis is completed, which is estimated to be early in FY 2011. Among the technical issues that need to be addressed in the alternatives analysis is the preferred detector technology. Two technologies are presently being considered: water Cerenkov and liquid argon time projection chamber. Water Cerenkov is a well established technology with more than 20 years of use, while liquid argon is a highly promising technology that could prove to be less expensive. Funding will be provided for R&D to answer a number of questions about liquid argon that will allow for a better comparison of the technologies.

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 2011	12,000	12,000	0	10,000
FY 2012	35,000	35,000	0	34,000
FY 2013	55,000	55,000	0	50,000
FY 2014	0	0	0	8,000
Total, PED	102,000	102,000	0	102,000
Other Project Cost (OPC)				
OPC except D&D				
FY 2009 Recovery Act	13,000	13,000	0	0
FY 2010	9,180	9,180	13,000	7,000
FY 2011	0	0	0	2,180
Total, OPC except D&D	22,180	22,180	13,000	9,180
Total Project Cost (TPC)				
FY 2009 Recovery Act	13,000	13,000	0	0
FY 2010	9,180	9,180	13,000	7,000

(dollars in thousands)

	Appropriations	Obligations	Recovery Act Costs	Costs
FY 2011	12,000	12,000	0	12,180
FY 2012	35,000	35,000	0	34,000
FY 2013	55,000	55,000	0	50,000
FY 2014	0	0	0	8,000
Total, TPC	124,180	124,180	13,000	111,180

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	75,000	N/A	N/A
Contingency	27,000	N/A	N/A
Total, PED	102,000	N/A	N/A
Total, TEC	102,000	N/A	N/A
Contingency, TEC	27,000	N/A	N/A
Other Project Cost (OPC)			
OPC except D&D			
R&D	2,000	N/A	N/A
Conceptual Planning	7,000	N/A	N/A
Conceptual Design	9,000	N/A	N/A
Contingency	4,180	N/A	N/A
Total, OPC except D&D	22,180	N/A	N/A
Contingency, OPC	4,180	N/A	N/A
Total, TPC	124,180	N/A	N/A
Total, Contingency	31,180	N/A	N/A

7. Funding Profile History

(dollars in thousands)

Request Year		Prior Years	FY 2009	FY 2009 Recovery Act	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	Total
FY 2011[a]	TEC	0	0	0	0	12,000	35,000	55,000	0	0	102,000
	OPC	0	0	13,000	9,180	0	0	0	0	0	22,180
	TPC	0	0	13,000	9,180	12,000	35,000	55,000	0	0	124,180

8. Related Operations and Maintenance Funding Requirements

Not applicable for PED.

9. Required D&D Information

Not applicable for PED.

10. Acquisition Approach

The conceptual design and study of alternatives is being led by Fermi National Accelerator Laboratory with the assistance of Brookhaven National Laboratory. This work will be used to develop an Acquistion Strategy that will be approved as part of CD-1. At this time it is expected that a new neutrino beamline and neutrino detector will be needed. The technical expertise needed to design and build these components is very specialzed and will limit the acquisition approaches.

[a] This project has not yet received CD-2 approval and this is the first request for PED funds. Only PED and OPC excluding D&D are shown.

11-SC-41, Muon to Electron Conversion Experiment (Mu2e), Fermi National Accelerator Laboratory, Batavia, Illinois
Project Data Sheet is for PED

1. Significant Changes

The most recent DOE O 413.3A approved Critical Decision (CD) is CD-0 was approved November 24, 2009.

A Federal Project Director has not yet been assigned to this project, but will be by CD-1.

This PDS is new for PED. The FY 2011 request is for PED only.

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 2011	11/24/2009	4Q FY 2010	4Q FY 2012	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[b]

(dollars in thousands)

	TEC, PED	TEC, Construction	TEC, Total	OPC Except D&D	OPC, D&D	OPC, Total	TPC
FY 2011	35,000[c]	TBD	TBD	10,000[d]	TBD	TBD	TBD

4. Project Description, Justification, and Scope

The conversion of a muon to an electron (Mu2e) in the field of a nucleus provides a unique window on the structure of potential new physics discoveries and allows access to new physics at very high mass scales. The Particle Physics Project Prioritization Panel (P5) identified this opportunity as a top priority for the Intensity Frontier of particle physics.

This project will construct a new beamline to take protons from the existing 8 GeV Booster synchrotron at Fermilab to a muon production target, a beamline to transport those muons to the detector, a low-mass magnetic spectrometer, which can measure the electron momentum with a resolution of order 0.15%, and a new experimental hall to house the muon production target, muon beamline, and the detector.

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[a] This project does not have CD-2 approval and is not requesting construction funds.
[b] This project is not yet baselined.
[c] This is a preliminary estimate for the planned PED in FY 2011 and FY 2012.
[d] This is a preliminary estimate for the OPC including R&D, conceptual design, but not commissioning, and pre-operations.

This project is very close to being completely ready technically for construction. The only needed R&D that has been identified is work on heating of the muon production target with an estimated cost of $150,000.

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 2011	5,000	5,000	4,500
FY 2012	30,000	30,000	20,000
FY 2013	0	0	10,500
Total, PED	35,000	35,000	35,000
Other Project Cost (OPC)			
OPC except D&D			
FY 2010	5,000	5,000	4,500
FY 2011	5,000	5,000	5,500
Total, OPC except D&D	10,000	10,000	10,000
Total Project Cost (TPC)			
FY 2010	5,000	5,000	4,500
FY 2011	10,000	10,000	10,000
FY 2012	30,000	30,000	20,000
FY 2013	0	0	10,500
Total, TPC	45,000	45,000	45,000

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	28,000	N/A	N/A
Contingency	7,000	N/A	N/A
Total, PED	35,000	N/A	N/A
Total, TEC	35,000	N/A	N/A
Contingency, TEC	7,000	N/A	N/A
Other Project Cost (OPC)			
OPC except D&D			
R&D	150	N/A	N/A
Conceptual Planning	3,850	N/A	N/A
Conceptual Design	4,000	N/A	N/A
Contingency	2,000	N/A	N/A
Total, OPC except D&D	10,000	N/A	N/A
Contingency, OPC	2,000	N/A	N/A
Total, TPC	45,000	N/A	N/A
Total, Contingency	9,000	N/A	N/A

7. Funding Profile History

(dollars in thousands)

Request Year		Prior Years	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	Total
FY 2011[a]	TEC	0	0	0	5,000	30,000	0	0	0	35,000
	OPC	0	0	5,000	5,000	0	0	0	0	10,000
	TPC	0	0	5,000	10,000	30,000	0	0	0	TBD

8. Related Operations and Maintenance Funding Requirements

Not applicable for PED.

9. Required D&D Information

Not applicable for PED.

[a] This project has not yet received CD-2 approval and this is the first request for PED funds. Only PED and OPC excluding D&D are shown.

10. Acquisition Approach

The conceptual design is being peformed by Fermilab, and it will inform the acquisition approach that will be documented in the Acquistion Strategy required for CD-1. It is already known that beamlines, detectors, and an experimental hall will be needed, and that the specialized expertise in those areas will be limit the range of acquisition options.

Nuclear Physics

Funding Profile by Subprogram

(dollars in thousands)

	FY 2009 Current Appropriation	FY 2009 Current Recovery Act Appropriation[a]	FY 2010 Current Appropriation	FY 2011 Request
Nuclear Physics				
Medium Energy Nuclear Physics	116,873	+15,390	127,590	129,610
Heavy Ion Nuclear Physics	194,957	+12,669	212,000	218,435
Low Energy Nuclear Physics	94,880	+29,667	114,636	113,466
Nuclear Theory	37,776	+17,237	41,574	44,709
Isotope Development and Production for Research and Applications[b]	24,760	+14,837	19,200	19,780
Subtotal, Nuclear Physics	469,246	+89,800	515,000	526,000
Construction	31,061	+65,000	20,000	36,000
Total, Nuclear Physics	500,307[c]	+154,800	535,000	562,000

Public Law Authorizations:

Public Law 95–91, "Department of Energy Organization Act", 1977

Public Law 101–101, "1989 Energy and Water Development Appropriations Act," establishing the Isotope Production and Distribution Program Fund)

Public Law 103–316, "1995 Energy and Water Development Appropriations Act," amending 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.

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

[a] The Recovery Act Appropriation column reflects the allocation of funding as of September 30, 2009.

[b] The Isotope Development and Production for Research and Applications program was transferred to the Office of Science from the Office of Nuclear Energy in FY 2009.

[c] Total is reduced by $11,773,000: $10,512,000 of which was transferred to the Small Business Innovative Research (SBIR) program and $1,261,000 of which was transferred to the Small Business Technology Transfer (STTR) program.

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 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:

- **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

[a] http://www.sc.doe.gov/np/nsac/nsac.html

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 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 being 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 made 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 by 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 decade 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 world-wide. DOE applies its unique expertise and capabilities to address technology issues associated with the application, production, handling, and distribution 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.

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 TJNAF) 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 of six of the Nuclear Physics program's university Centers of Excellence that has 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 two nuclear science frontiers—Nuclear Structure and Astrophysics and Fundamental Symmetries 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) at Michigan State University (MSU) is a next-generation machine that will advance the understanding of rare nuclear isotopes and the evolution of the cosmos. The subprogram also supports four university Centers of Excellence, three with unique low energy accelerator facilities and one with infrastructure capabilities for developing advanced instrumentation. These university Centers of Excellence provide outstanding hands-on science, technology, and engineering educational opportunities for students at various stages in their career. In addition, the program 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.
- Finally, 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 sited underground to shield them from cosmic background radiation 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 nuclear science subprograms and to

advance new ideas and hypotheses that stimulate experimental investigations. This subprogram supports the one of the program's university Centers of Excellence, 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, national security, and 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 Linac 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, other 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 interfaces with the user community and manages the coordination of isotope production across the many facilities and the business operations of the sale and distribution of isotopes.

Benefits

NP supports a wide range of facilities, instruments, and research that create forefront scientific knowledge and state-of-the-art tools to serve the Nation. Nuclear science basic research and the advancement of knowledge of nuclear matter and its properties are inherently relevant to and intertwined with a broad range of applications including nuclear power, waste disposal, nuclear medicine, commerce, medical physics, space exploration, finance, geology, environmental sciences, and national security. The NP program develops advanced instrumentation, accelerator technologies, and analytical and computational techniques that are needed for nuclear science research and which have broad societal and economic benefits, and supports reliable, timely, and economical delivery of stable and radioactive isotopes for commercial application and research. The development and construction of facilities and advanced instrumentation and accelerator technology needed to reach performance goals of the program not only contribute technically to other research and applied sciences, but educate a next generation of scientists and help to create technical and engineering jobs.

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 isotope availability and nuclear radiation, which made possible the entire field of nuclear medicine used today in both the diagnosis and treatment of disease.

Enhancements in isotope production and processing techniques has fueled the development of new isotopes, 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 research. The various applications resulting from isotope availability have improved the ability of physicians to diagnose illnesses and improved the quality of life and longevity for innumerable patients and strengthened 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. Each year several national laboratory junior scientists within the NP program have been recognized with Presidential Early Career Awards for Scientists and Engineers for their outstanding contributions to nuclear and accelerator physics research and their promise as future leaders of the field. In FY 2009, three junior laboratory researchers at BNL, TJNAF, and LANL were recognized for their efforts by receiving this prestigious award. 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 effectively as possible, the NP program has developed a rigorous and comprehensive system of planning and priority setting that relies heavily on input from groups of outside experts. All activities within the subprograms are peer reviewed and performance is assessed on a regular basis. Priority is given to those research activities which support the most compelling scientific opportunities. 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. NSAC completed a report in April 2009 that identifies *Compelling Research Opportunities Using Isotopes,*[a] and a second report, issued in November 2009, lays out a strategic plan for the Isotope Development and Production for Research and Applications subprogram, *Isotopes for the Nation's Future—A Long Range Plan.*[a] NSAC's most recent charge is to conduct a Committee of Visitors (COV) review of NP management processes in FY 2010.

NP strategic plans are also influenced by National Academies reports, Office of Science and Technology Policy (OSTP) and National Security Council (NSC) Interagency Working Group (IWG) efforts, the

[a] http://www.sc.doe.gov/np/nsac/nsac.html

latter two under the auspices of the Executive Office of the President. 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) Biological and Environmental Research program, to better coordinate radioisotope production and to address other issues important to nuclear medicine. The National Academies embarked on a new decadal study of nuclear science in 2009. In order to optimize interagency activities, NP is involved in four OSTP or NSC IWG's: *Large Scale Science, Forensic Science, Molybdenum-99 Production,* and *The Physics of the Universe*.

NP 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 NP's assessment of laboratory performance as documented in annual SC laboratory appraisals. The peer reviews result in recommendations and the institutions are held accountable for responding to them. Annual reviews of instrumentation projects, conducted by experts, focus on scientific merit, technical status and feasibility, cost and schedule, and effectiveness of management approach. The NP program conducted 22 such reviews with panels of national and international experts in FY 2009. 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 to determine the allocation of this scarce scientific resource. The Program Advisory Committees 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.

University grants are proposal driven. The NP 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 2009 for the Nuclear Theory 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 nuclear power, waste disposal, nuclear medicine, commerce, medical physics, space exploration, finance, geology, environmental sciences, national security, and others. In FY 2009, NP initiated support for targeted initiatives in Applications of Nuclear Science and Technology, the primary goal of which is to pursue forefront nuclear science research and development important to the NP mission, but inherently relevant to applications. One of the goals of this initiative was to help bridge the gap between basic research and applied science. The response to the first solicitation to this initiative in FY 2009 was extremely successful, with over 200 proposals submitted. A total of 22 awards were made with a combination of appropriated base funding and Recovery Act funds. The proposals supported include nuclear physics research that is relevant to the development of advanced fuel cycles for next generation nuclear power reactors; advanced and cost-effective accelerator technology and

[a] http://dels.nas.edu/dels/rpt_briefs/advancing_nuclear_medicine.pdf

particle detection techniques for medical diagnostics and treatment; and research in developing neutron, gamma and particle beam sources with applications in cargo screening and nuclear forensics. These initiatives are peer reviewed with participation from the applied sciences community. The integration of the underpinning nuclear science advances, resulting from innovative basic research with the applied sciences will optimize 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 research isotopes that are important for basic research and applications. 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. To ascertain current and future demands of the research community, NP continues to develop working groups with other federal agencies, foster interactions between researchers and Isotope Program staff, obtain data from site visits, attend society exhibitions, and develop strategic plans and priorities with community input. Recent examples include: forming a DOE and National Institutes of Health (NIH) federal working group to address the recommendations of the recent National Academies report, *Advancing Nuclear Medicine through Innovation*, which identified several areas in isotope production warranting attention; attending the Society of Nuclear Medicine annual meeting in Toronto in June 2009 and sponsoring a workshop dedicated to the use and production of alpha-emitters in medicine; and working with industry to define a path forward for ensuring the long-term availability of californium-252, an isotope of strategic and economic importance to the Nation. NP is also establishing cooperative isotope supply contracts with universities to increase the Department's ability to meet researchers' requests by improving product availability and reliability.

The Isotope Development and Production for Research and Applications subprogram also supports research for the development of alternative production and extraction techniques of stable and radioactive isotopes and the production of research isotopes identified by NSAC as needed for high priority research opportunities across a broad range of scientific disciplines.

Budget Overview

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 2011 budget appropriation 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, facility operations, and investments in advanced technology and capabilities. The increase of $27,000,000 over the FY 2010 appropriation includes a $16,000,000 increase in the baselined funding profile for the 12 GeV CEBAF Upgrade project, an increase in operations of the RHIC facility, and an increase to the rest of the NP program of about 2 percent relative to FY 2010 to maintain research efforts. The completion of the 12 GeV Upgrade is identified by NSAC as the highest priority for the field.

The heart of the program is the group of highly trained scientists who conceive, plan, execute, and interpret the numerous experiments carried out at various nuclear physics facilities. NP supports scientists at both universities and national laboratories and is involved in a variety of international collaborations. The program 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. With the FY 2011 request, research activities are conducted at approximately 90 academic institutions located in 35 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 excellent hands-on training opportunities for junior scientists. The Outstanding Junior Investigator (OJI) program, initiated in FY 2000, made approximately three new awards each year to early career tenure-track faculty through FY 2009 and has been very successful in identifying, recognizing, and supporting promising junior university faculty and future leaders of the field.

Research at nine national laboratories 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 detector and accelerator R&D 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 employing 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 facilities and equipment are large, complex, and expensive to build and operate, and thus they account for a significant portion of the program's budget—approximately 65 percent of the FY 2011 request. It is the planned project profiles that typically drive the funding increases within the NP federal budget requests. 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 scientific facilities provide research beams for a user community of approximately 3,300 scientists from all over the world, with more than 2,500 of the users utilizing RHIC and CEBAF. Approximately 40 percent of the users are from institutions outside of the U.S., and they 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 research programs.

The FY 2011 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 18,910 hours of beam time for research, a decrease of about 650 hours compared with the anticipated beam hours in FY 2010 due to a planned shutdown period at CEBAF associated with the construction of the 12 GeV CEBAF Upgrade project at TJNAF. The major scientific user facilities will be maintained and operated so that the unscheduled operational downtime will be kept to less than 20 percent, on average, of total scheduled operating time. Investments will be made in programmatic infrastructure, facility equipment, and accelerator improvement projects that will increase productivity, reliability, and cost-effectiveness, and provide new capabilities to pursue high discovery science.

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[a] http://www.sc.doe.gov/np/nsac/nsac.html

Construction of the 12 GeV CEBAF Upgrade project continues in FY 2011. The FY 2011 request reflects the final adjustment to the original planned funding profile to account for the advanced funding provided in FY 2009 under the Recovery Act. This project is the highest priority in the NSAC Long Range Plan for Nuclear Science. The 12 GeV CEBAF Upgrade project is expected to create over 500 jobs that are related to the construction of the project. Because the project is of high priority, over $50,000,000 is redirected from the base CEBAF program towards the construction over the lifetime of the project.

Approximately 2 percent of the total NP budget in FY 2011 is invested in a handful of ongoing small-scale Major Items of Equipment (MIE) projects, each 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. In FY 2010, conceptual design, NEPA activities, and R&D are supported for the proposed Facility for Rare Isotope Beams (FRIB), a next-generation nuclear structure and astrophysics machine that will map out the nuclear landscape. This project is supported with operating funds through a Cooperative Agreement with MSU. Although the FRIB property will not be a capital asset to the federal government and will be owned by the university, FRIB will be operated as a DOE national user facility upon completion. In FY 2011, funds are requested for engineering and design activities for FRIB. The FRIB project is expected to create approximately 800 jobs in the state of Michigan during the course of construction.

All of the NP subprograms benefited from Recovery Act funding. In Medium Energy support was provided for: advance funding of the 12 GeV CEBAF Upgrade project to accelerate procurements and reduce cost and schedule risk ($65,000,000); an accelerator improvement project at CEBAF to enhance facility capability ($2,760,000); and infrastructure improvements at TJNAF to accomplish backlogged projects ($10,000,000). In Heavy Ion support was provided for: completion of the PHENIX Silicon Vertex and Forward Vertex Major Items of Equipment (MIEs) ($2,250,000); and accelerator improvement projects to increase the luminosity of the RHIC collider beams ($8,000,000). In Low Energy support was provided for: completion of the Fundamental Neutron Physics Beamline MIE ($600,000); accelerator improvement projects at HRIBF, ATLAS and the 88-Inch Cyclotron to enhance facility capabilities ($14,240,000); and research under the Applications of Nuclear Science and Technology solicitation ($11,420,000). In Nuclear Theory support was provided for: workforce succession planning for the National Nuclear Data Program ($1,944,000); augmentation of the LQCD computing capabilities at TJNAF ($4,965,000); and research under the Applications of Nuclear Science and Technology solicitation ($8,020,000). In Isotope Development and Production for Research and Applications support 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 ($4,617,000); and 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 ($10,000,000).

Significant Program Shifts

There are no significant shifts in the Nuclear Physics program in FY 2011.

Annual Performance Targets and Results

Secretarial Priority: Innovation: Lead the world in science, technology, and engineering.

GPRA Unit Program Goal: Nuclear Physics Program Goal: *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.*

NP contributes to this Secretarial Priority and GPRA goal through strategic investments in science for discovery, science for national need, and national scientific user facilities—the 21st century tools for science, technology, and engineering. NP supports scientific research to discover, explore and understand all forms of nuclear matter focused on three strategic themes:

- Developing a complete understanding of how quarks and gluons assemble themselves into the various forms of nuclear matter, and searching for as yet undiscovered forms of matter.
- Understanding how protons and neutrons combine to form atomic nuclei, and how these nuclei have arisen since the birth of the cosmos.
- Developing a better understanding of the fundamental properties of the neutron and the neutrino, and exploring the implications of their properties for the Standard Model of fundamental particle and interactions.

The following indicators establish specific long-term goals in Scientific Discovery that NP is committed to, and progress can be measured against:

- Make 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;
- Create brief, tiny samples of hot, dense nuclear matter to search for the quark-gluon plasma and characterize its properties;
- Investigate new regions of nuclear structure, study interactions in nuclear matter like those occurring in neutron stars, and determine the reactions that created the nuclei of atomic elements inside stars and supernovae; and
- Measure fundamental properties of neutrinos and fundamental symmetries by using neutrinos from the sun and nuclear reactors and by using radioactive decay measurements.

Annual Performance Measure: Achieve at least 80% of the integrated delivered beam used effectively for all experiments run at each of the Argonne Tandem Linac Accelerator System (ATLAS) and the Holifield Radioactive Ion Beam (HRIBF) facilities measured as a percentage of the scheduled delivered beam considered effective for each facility.[a]

FY 2009	T: ≥ 80% A: Goal not met. ATLAS met the goal by achieving 92.4% of the integrated delivered beam used effectively for all experiments run at the facility. HRIBF achieved 77%, 3% short of the goal, as a result of an operational emergency that occurred near the end of FY 2008.

[a] Measure established in FY 2009

FY 2010–2015	T: ≥ 80% A: TBD

Annual Performance Measure: 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 (CEBAF) measured as a percentage of the scheduled delivered beam considered effective for each Hall. The values from each Hall will be averaged for the end of year result starting in FY 2010.[a]

FY 2009	T: ≥ 80% A: Goal not met. Halls A and B met their goals for the year by achieving 95.9% and 86.6% effective use of their planned integrated delivered beam, respectively. However, because Hall C only achieved 67.4%, thus failing to meet its goal of 80%, the overall goal was "not met." Hall C performance was impacted by the failure of a target provided by outside collaborators that required significant time to repair and a second commissioning period.
FY 2010–2015	T: ≥ 80% A: TBD

Annual Performance Measure: Achieve at least 80% of the projected integrated heavy-ion 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.[a]

FY 2009	T: N/A, Heavy-Ion collision experiments were not planned for FY 2009. A:
FY 2010–2015	T: ≥ 80% A: TBD

Annual Performance Measure: Achieve at least 80% of the projected integrated proton-proton collision luminosity for 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.[a]

FY 2009	T: ≥ 80% A: Goal not met. PHENIX met the goal by achieving 90.5% of sampled integrated proton-proton collision luminosity, while STAR achieved only 65.4%. The STAR detector's low number is due to the fact that RHIC did not achieve its projected integrated luminosity for 200 GeV running. Both detectors were impacted, but only STAR failed to make the 80% goal. The facility was not able to achieve projected increases in the luminosity at 200 GeV that it had achieved in previous years. Beam studies indicated that the 200 GeV luminosity is at a maximum for the present machine configuration.

[a] Measure established in FY 2009

FY 2010–2015	T: Proton-proton collision experiments are not planned for FY 2010. A: N/A

Annual Performance Measure: Achieve at least 80% average operation time of the scientific user facilities as a percentage of the total scheduled annual operating time.

FY 2006	T: 80% of scheduled operating time A: Goal met
FY 2007	T: 80% of scheduled operating time A: Goal met
FY 2008	T: 80% of scheduled operating time A: Goal met
FY 2009	T: 80% of scheduled operating time A: Goal met
FY 2010–2015	T: 80% of scheduled operating time A: TBD

Annual Performance Measure: 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.

FY 2006	T: N/A, no major construction project/MIE tracked this fiscal year. A:
FY 2007	T: N/A, no major construction project/MIE tracked this fiscal year. A:
FY 2008	T: Cost and schedule variance are both less than 10% A: Goal met
FY 2009	T: Cost and schedule variance are both less than 10% A: Goal met
FY 2010–2015	T: Cost and schedule variance are both less than 10% A: TBD

Medium Energy Nuclear Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Medium Energy Nuclear Physics			
Research			
University Research	18,678	19,674	20,796
National Laboratory Research	16,864	18,085	18,590
Other Research[a]	937	7,309	6,979
Total, Research	36,479	45,068	46,365
Operations			
TJNAF Operations	80,394	82,522	83,245
Total, Medium Energy Nuclear Physics	116,873	127,590	129,610

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 also 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? Finally, this subprogram 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?

Funding for this subprogram 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

[a] In FY 2009, $3,665,000 was transferred to the SBIR program and $1,246,000 was transferred to the STTR program. This activity includes $4,034,000 for SBIR and $1,334,000 for STTR in FY 2010 and $4,082,000 for SBIR and $1,354,000 for STTR in FY 2011.

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.

Construction of the 12 GeV CEBAF Upgrade project is a priority. CEBAF operations are reduced from 5,110 to 4,090 hours, the maximum level of operations possible in FY 2011 due to a planned shutdown to accommodate installation of components for the 12 GeV CEBAF Upgrade project.

Selected FY 2009 Accomplishments

- A recent series of measurements from TJNAF show evidence for a possible new excited state of the proton, that if confirmed, would help resolve a major debate concerning whether the three quarks that make up the proton bind together symmetrically or not. Asymmetrical binding was postulated to explain the lack of a large number of excited states predicted by symmetrical binding. If the asymmetrical binding is correct, then this new state should not exist.
- TJNAF researchers are on track to complete one of their major scientific performance milestones to determine the charge and magnetic distributions in the proton and neutron. The data set is of sufficient precision and quantity to allow scientists to separate the contributions of the different flavors of quarks (up, down, and strange) that determine the properties of the proton and neutron. New data on the charge distribution of the neutron have been collected that probe the smallest distances inside the neutron to date.
- TJNAF achieved a top beam energy of 6.0 GeV during their FY 2009 run period. This was a goal of the accelerator cavity refurbishment program that began in FY 2006 to increase the beam energy from the nominal maximum of 5 GeV.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Research	**36,479**	**45,068**	**46,365**
▪ **University Research**	**18,678**	**19,674**	**20,796**

This activity supports about 160 scientists and 125 graduate students at 33 universities in 21 states and the District of Columbia studying QCD and the behavior of quarks inside protons and neutrons. The university scientists conduct experiments at CEBAF and RHIC and participate in the development and fabrication of advanced instrumentation for utilization at these facilities. These state-of-the-art detectors often have relevance to applications in medicine and homeland security. Included in this activity is support for the Massachusetts Institute of Technology's Research and Engineering (R&E) Center that has specialized infrastructure for fabrication of scientific instrumentation. The Center has unique expertise in the study of high current, polarized electron sources. The FY 2011 request starts to build a user community for the new experimental hall scientific program being constructed as part of the 12 GeV CEBAF Upgrade Project.

▪ **National Laboratory Research**	**16,864**	**18,085**	**18,590**

This funding supports research groups at TJNAF, BNL, ANL, LBNL, and LANL that carry out research at CEBAF and RHIC. It also supports two experiments at Fermilab and nuclear research

		(dollars in thousands)	
	FY 2009	FY 2010	FY 2011

using laser trapping technology at ANL. Funding decisions are influenced by the results of periodic peer reviews of the national laboratory research groups and their subsequent ranking in terms of performance level.

• **TJNAF Research**	**6,150**	**6,200**	**6,695**

TJNAF staff research efforts include developing experiments, acquiring data, and performing data analysis in the three existing CEBAF experimental Halls. Funding is provided to develop a scientific group for the new experimental Hall D that is being constructed as part of the 12 GeV CEBAF Upgrade project. Scientists also are identifying the scientific opportunities and developing the scientific goals for next generation facilities. The remaining approximately 70 percent of support for experiments at CEBAF is under Experimental Support discussed below. Funding also supports an active visiting scientist program at the laboratory and bridge positions with regional universities, which is a cost-effective approach to augmenting scientific expertise at the laboratory and boosts educational opportunities in the southeast region of the Nation. Detectors developed for nuclear physics research supported at TJNAF have found applications in medical imaging instrumentation.

• **Other National Laboratory Research**	**10,714**	**11,885**	**11,895**

Argonne National Laboratory scientists continue their primary research program at TJNAF and one experiment at Fermilab. Argonne scientists are leading an experiment at Fermilab to distinguish the different quark contributions to the structure of the proton. These measurements are also important to interpreting the RHIC proton spin measurements. 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. This technology at ANL has found practical applications in geology and environmental fields, for example, in tracking ground water flows in Egypt.

Support is provided to the RHIC spin physics research groups at BNL, LBNL, and LANL, which have important roles and responsibilities in the RHIC program. These groups play lead roles in determining the spin structure of the proton by development and fabrication of advanced instrumentation, as well as data acquisition and analysis efforts.

At LANL, support is provided to allow scientists and collaborators to complete the Fermilab MiniBooNE anti-neutrino running and analysis. A present discrepancy between the anti-neutrino and neutrino data needs to be resolved with additional anti-neutrino running. If these results are confirmed, they could unveil new physics beyond the Standard Model. The results of these efforts will drive future research directions of this group.

Modest funding for capital equipment investments at these laboratories is provided in support of the above efforts.

▪ **Other Research**	**937**	**7,309**	**6,979**
• **SBIR/STTR and Other**	**572**	**6,544**	**6,279**

In FY 2009, $3,665,000 was transferred to the Small Business Innovation Research (SBIR) program and $1,246,000 was transferred to the Small Business Technology Transfer (STTR) program. This activity includes $4,034,000 for SBIR and $1,334,000 for STTR in FY 2010 and

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

$4,082,000 for SBIR and $1,354,000 for STTR in FY 2011 as well as other established obligations that the Medium Energy Nuclear Physics subprogram must meet.

	FY 2009	FY 2010	FY 2011
• **Accelerator R&D Research**	**365**	**765**	**700**

The Medium Energy Accelerator R&D research at universities and laboratories will develop the knowledge, technologies, and trained scientists to design and build the next-generation NP accelerator facilities. These programmatic activities are of relevance to machines being developed by other domestic and international programs and can lead to technological advances that are relevant to a variety of applications. Allocation of these funds will be determined by peer review and competed amongst university and laboratory proposals.

	FY 2009	FY 2010	FY 2011
Operations	**80,394**	**82,522**	**83,245**
▪ **TJNAF Operations**	**80,394**	**82,522**	**83,245**

Funding supports CEBAF operations and experimental support for 4,090 hours and a 3-Hall operations schedule, a 20 percent decrease from estimated running in FY 2010. The run time is the maximum possible due to a planned several-month shutdown in FY 2011 as part of the 12 GeV CEBAF Upgrade project schedule. The savings realized from reduced operational costs, such as power, are offset by cost of living increases for accelerator staff and materials and supplies needed to operate and maintain the facility. CEBAF is a unique facility with unparalleled capabilities using polarized electron beams to study quark structure; there is no other facility in the world like it and its user community has a strong international component.

	FY 2009	FY 2010	FY 2011
• **TJNAF Accelerator Operations**	**51,335**	**51,755**	**52,675**

Support is provided for the accelerator physicists that operate the facility, operations, power costs, capital infrastructure investments, and accelerator improvements of the CEBAF accelerator complex, and to maintain efforts in developing advances in superconducting radiofrequency (SRF) technology. The core competency in SRF technology that is nurtured at this laboratory plays a crucial role in many DOE projects and facilities outside of nuclear physics and has broad applications in medicine and homeland security. For example, SRF research and development at TJNAF has led to techniques for detection of buried land mines using terahertz radiation and carbon nanotube and nano-structure manufacturing techniques for the manufacture of super-lightweight composites such as aircraft fuselages.

TJNAF also has a core competency in cryogenics and has developed award-winning techniques which have led to more cost-effective operations at TJNAF and several other Office of Science facilities. TJNAF has recently been approached by the national Canadian nuclear physics facility, known as TRIUMF, and CERN for implementation of its cryogenic techniques.

TJNAF accelerator physicists are also strongly engaged in educating the next generation of accelerator physicists, with seventeen graduate students integrated into research programs and eleven staff members with university affiliations. TJNAF has started a Center for Accelerator Science at Old Dominion University (ODU) where staff members teach courses at the Center and the laboratory jointly supports the ODU Director position.

	FY 2009	FY 2010	FY 2011
(dollars in thousands)			

Investments in accelerator improvement projects are aimed at increasing the productivity, cost-effectiveness, and reliability of the facility. Capital equipment investment is targeted towards instrumentation needed to support the laboratory's core competencies in SRF and cryogenics.

	FY 2009	FY 2010	FY 2011
CEBAF Hours of Operation with Beam			
Achieved Operating Hours	5,117	N/A	N/A
Planned Operating Hours	4,965	5,110	4,090
Optimal Hours	5,980	5,980	5,980[a]
Percent of Optimal Hours	86%	85%	68%
Unscheduled Downtime	8.	N/A	N/A
Number of Users	1,350	1,390	1,430

- **TJNAF Experimental Support** **29,059** **30,767** **30,570**

Experimental Support is provided for the scientific and technical staff, materials, and services for CEBAF experiments 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. Capital equipment investments for experimental support at TJNAF is maintained relative to FY 2010 to provide scientific instrumentation for the major experiments, including data acquisition computing and supporting infrastructure (e.g., targets, mechanical structures, power supplies, gas systems, and cooling equipment). In FY 2011, TJNAF expects to run experiments distributed among all three halls that address compelling physics including a precision measurement of the weak charge of the proton to help constrain new physics beyond the Standard Model, an important experiment for the laboratory's search for missing excited states of the neutron, and experiments that will help develop the laboratory's research program using the 12 GeV CEBAF Upgrade.

The FY 2011 funding supports efforts to implement high priority experiments before the completion of the current 6 GeV experimental program and prior to the 12 GeV CEBAF Upgrade project installation.

Total, Medium Energy Nuclear Physics **116,873** **127,590** **129,610**

[a] While the optimal operations for CEBAF remains at 5,980 hours, the maximum number of hours the facility can operate in FY 2011 is 4,090 hours due to a planned shutdown for installation of 12 GeV components. The facility therefore operates at 100% of maximal hours.

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Research	
▪ **University Research**	
The increase in FY 2011 funding maintains the FY 2010 level of research effort at universities and starts to build a user community for the new experimental Hall D being constructed as part of the 12 GeV CEBAF Upgrade Project.	+1,122
▪ **National Laboratory Research**	
The increase maintains National Laboratory Research at roughly the FY 2010 level of effort and develops a scientific group for the new experimental Hall D that is being constructed as part of the 12 GeV CEBAF Upgrade project.	+505
▪ **Other Research**	
• SBIR/STTR and Other decreases at levels required proportionate to research and development activities.	-265
• Accelerator R&D research funding is provided at approximately the FY 2010 level to allow the university and national laboratory community to continue to develop the technologies needed for next generation NP facilities.	-65
Total, Other Research	**-330**
Total, Research	**+1,297**
Operations	
▪ **TJNAF Operations**	
• **TJNAF Accelerator Operations**	
FY 2011 funding operates CEBAF at the maximum allowable schedule, in consideration of planned shutdowns for 12 GeV CEBAF Upgrade project component installation. The requested funding will support completion of the highest priority experiments within the current 6 GeV program and maintain the staff and infrastructure at approximate constant effort.	+920
• **TJNAF Experimental Support**	
Funding is provided to maintain effort in FY 2011 at a level that supports implementation of the highest priority 6 GeV experiments.	-197
Total, Operations	**+723**
Total Funding Change, Medium Energy Nuclear Physics	**+2,020**

Heavy Ion Nuclear Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Heavy Ion Nuclear Physics			
Research			
University Research	14,009	14,474	15,511
National Laboratory Research	26,640	27,308	26,530
Other Research[a]	0	6,998	7,042
Total, Research	40,649	48,780	49,083
Operations			
RHIC Operations	148,684	157,470	163,301
Other Operations	5,624	5,750	6,051
Total, Operations	154,308	163,220	169,352
Total, Heavy Ion Nuclear Physics	194,957	212,000	218,435

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 plasma 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 plasma.

The RHIC facility places 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. U.S. 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

[a] In FY 2009, $5,296,000 was transferred to the SBIR program. This activity includes $5,662,000 for SBIR in FY 2010 and $5,673,000 for SBIR in FY 2011.

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?

The funding for this subprogram is increased in FY 2011 to operate RHIC near optimal levels and to maintain research efforts.

Selected FY 2009 Accomplishments

- Scientists continued work to determine the physical characteristics of the perfect liquid produced in the highly energetic nucleus-nucleus collisions at RHIC. The temperature is one of the most important of these characteristics because 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 and are one indicator of temperature. Further, data analysis now suggests that the initial fluid temperature may correspond to an energy greater than 300 MeV which exceeds the critical temperature thought necessary for the formation of the quark-gluon plasma.
- The formation of the anti-hypertriton (a hypertriton is a hypernucleus which is a nucleus that contains at least one hyperon—an unstable particle with a mass greater than a neutron—in addition to nucleons) is a major new discovery at RHIC. This observation could provide important information about the interior structure of neutron stars and the development of the cosmos.
- In FY 2009, RHIC delivered high intensity beams of polarized protons. Polarized protons were successfully accelerated to 250 GeV and first collisions for physics measurements at this energy occurred for several weeks.
- Plans for luminosity improvements for heavy ion collisions by implementing bunched-beam stochastic cooling systems are in progress. Tests have validated modeling codes which predict luminosity enhancement is feasible. Recovery Act funding has accelerated plans for stochastic cooling systems which are expected to be available in each RHIC collider ring by 2012. Accelerator scientists expect the planned implementation of longitudinal and transverse stochastic cooling to both accelerator rings, together with a new 56 MHz storage radio frequency system, will provide a 10-fold increase in gold beam luminosity by 2012. With these technological advances, the previously envisioned RHIC II upgrade is no longer needed and has been canceled by the NP program, saving the federal government approximately $100,000,000.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Research	**40,649**	**48,780**	**49,083**
▪ **University Research**	**14,009**	**14,474**	**15,511**

Research support is provided for about 120 scientists and 100 graduate students at 30 universities in 19 states. Funding supports research efforts at RHIC and the continuation of a modest program at the

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

LHC with heavy ions. The university groups provide scientific personnel and graduate students needed for running 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. For example, university personnel led the effort in the fabrication of the STAR Time-of-Flight detector, an MIE which was completed on cost and schedule in FY 2009.

The FY 2011 request maintains research effort and supports increases targeted towards operations of recently completed scientific instrumentation.

	FY 2009	FY 2010	FY 2011
▪ **National Laboratory Research**	**26,640**	**27,308**	**26,530**

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 that supports the high priority scientific goals for the field of heavy ion physics. 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. Some of the new research topics that will be investigated at RHIC in the next several years include determining the speed of sound in the quark-gluon plasma and trying to discover the critical point in the QCD phase diagram. RHIC could revolutionize the quantitative understanding of the QCD phase diagram by discovering the QCD critical point. Funding decisions are influenced by the results of periodic peer reviews of the national laboratory research groups and their subsequent ranking in terms of performance level.

	FY 2009	FY 2010	FY 2011
• **BNL RHIC Research**	**9,602**	**9,032**	**10,797**

The FY 2011 budget request allows BNL scientists to continue to develop and implement new instrumentation, to provide maintenance and infrastructure support of the RHIC experiments, to effectively utilize the beam time for research, to train junior scientists, and to develop the computing infrastructure used by the scientific community. The PHENIX Silicon Vertex Tracker (VTX) MIE, a joint project with Japan, received its final funding increment under the Recovery Act and is on track for completion in FY 2010 on cost and schedule. 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 is on track for completion in FY 2011 on cost and schedule. 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), a new MIE initiated in FY 2010, is an ultra-thin, high-precision tracking detector that will provide direct reconstruction of short-lived particles containing heavy quarks. Support for this initiative ramps up in FY 2011 in accordance with project plans and dominates the increase in this funding category relative to FY 2010. Funding supports the efforts of BNL scientists to identify the most compelling scientific opportunities for a possible future electron ion collider. Capital equipment funds are provided to meet the computing obligations of U.S. researchers involved in the LHC program.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
• **Other National Laboratory Research**	**17,038**	**18,276**	**15,733**

Researchers at LANL, LBNL, LLNL, and ORNL provide support for the RHIC and LHC experiments and develop new instrumentation. They also 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 LHC data analysis. LBNL staff are leading 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 heavy ion experiment to provide the capability to study energy loss in the quark-gluon plasma. Support for the EMCal ramps down in FY 2011 according to the planned profile, and is the cause for the decrease in funding in this category relative to FY 2010.

▪ **Other Research**	**0**	**6,998**	**7,042**
• **SBIR and Other**	**0**	**5,728**	**5,742**

In FY 2009, $5,296,000 was transferred to the Small Business Innovative Research (SBIR) program. This activity includes $5,662,000 for SBIR in FY 2010 and $5,673,000 for SBIR in FY 2011 as well as other established obligations that the Heavy Ion Nuclear Physics subprogram must meet.

• **Accelerator R&D Research**	**0**	**1,270**	**1,300**

The Heavy Ion Accelerator R&D research at universities and laboratories will develop the knowledge, technologies, and trained scientists to design and build the next-generation NP accelerator facilities. These programmatic activities are of relevance to machines being developed by other domestic and international programs and can lead to technological advances that are relevant to a variety of applications. Allocation of these funds will be determined by peer review and competed among university and laboratory proposals.

Operations	**154,308**	**163,220**	**169,352**
▪ **RHIC Operations**	**148,684**	**157,470**	**163,301**

RHIC operations are supported for an estimated 3,720 hour operating schedule (91 percent utilization) in FY 2011, an increase of 370 hours over FY 2010 which effectively addresses high priority scientific opportunities and goals. In FY 2011, it is currently planned to conduct the first search at RHIC for discovering the critical point in the QCD phase diagram. This would be the first such measurement of its kind and is important because it would identify when certain phase transitions occur in a medium, such as a region in the interior of a neutron star, or inside the hot and dense fireball created by a heavy ion collision.

The Electron Beam Ion Source (EBIS) construction project will be 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. EBIS will also lead to more cost-effective operations of the

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

facility as it replaces the aging Tandems as part of the RHIC injector. DOE and NASA partnered on the construction of EBIS, and this project will also provide new capabilities to the NASA Space Radiation Program.

	FY 2009	FY 2010	FY 2011
• **RHIC Accelerator Operations**	**115,560**	**121,935**	**126,337**

Support is provided for the operations, power costs, capital infrastructure investments, and accelerator improvement projects of the RHIC accelerator complex. This includes EBIS, the Booster, and AGS accelerators that together serve as the injector for RHIC. Measurements of rare particles will require higher integrated beam luminosity and modest support is provided for R&D of electron beam cooling and other luminosity enhancement technologies. Funding is also provided to reduce the backlog of infrastructure items which most impede the cost-effective and efficient operations of the facility. Operations of RHIC also support parallel (and cost-effective) operations of the NASA Space Radiation Program, for the study of space radiation effects applicable to human space flight, and the Brookhaven Linac Isotope Production Facility (BLIP), for the production of research and commercial isotopes needed by the Nation. Funding is increased to operate RHIC close to optimal levels. A slight decrease in accelerator improvement funding in FY 2011 is made possible by the advance of funding under the Recovery Act in FY 2009.

BNL has nurtured core competencies in accelerator physics techniques, which have had applications in industry, medicine, homeland security, and other scientific projects outside of NP. The RHIC accelerator physicists have been leading the effort to address technical feasibility issues which are of relevance to a possible future collider, including beam cooling techniques and energy recovery linacs. RHIC accelerator physicists also play an important role in the education of next generation accelerator physicists, with support of graduate and post-doctoral students. The laboratory supports the Center for Accelerator Science and Education (CASE) in partnership with Stony Brook University. CASE takes advantage of the collaboration with BNL, providing opportunities for students to learn on the state-of-the-art accelerators at BNL and by having BNL staff teach courses and advise students.

	FY 2009	FY 2010	FY 2011
RHIC Hours of Operation with Beam			
Achieved Operating Hours	3,153	N/A	N/A
Planned Operating Hours	2,915	3,350	3,720
Optimal Hours	4,100	4,100	4,100
Percent of Optimal Hours	77%	82%	91%
Unscheduled Downtime	19.7%	N/A	N/A
Number of Users	1,200	1,200	1,200

	FY 2009	FY 2010	FY 2011
• **RHIC Experimental Support**	**33,124**	**35,535**	**36,964**

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.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

Instrumentation advances by this community have led to practical applications. For example, technical developments from the RHIC detectors, especially PHENIX, have recently led to the development of a positron emission tomography scanner to image the brain of an awake animal. Capital equipment funding is provided to maintain computing capabilities at the RHIC Computing Facility.

	FY 2009	FY 2010	FY 2011
▪ **Other Operations**	**5,624**	**5,750**	**6,051**

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 2009	FY 2010	FY 2011
Total, Heavy Ion Nuclear Physics	**194,957**	**212,000**	**218,435**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Research	
▪ **University Research**	
The increase for University Research grants in FY 2011 maintainseffort for data collection with STAR and PHENIX, supports research at the LHC heavy ion program, and provides for operations of recently completed scientific instrumentation.	+1,037
▪ **National Laboratory Research**	
• BNL RHIC Research is increased relative to FY 2010 largely due to an increase for the fabrication of the STAR HFT MIE according to the planned funding profile, as well as supporting research with the STAR and PHENIX detectors.	+1,765
• Other National Laboratory Research decreases in FY 2011 as funding ramps down for the final year of funding to complete the fabrication of the LHC Heavy Ion MIE according to the planned profile.	-2,543
Total, National Laboratory Research	**-778**
▪ **Other Research**	
• SBIR and Other increases at levels required proportionate to R&D activities.	+14

	FY 2011 vs. FY 2010 ($000)
• Accelerator R&D research is increased in FY 2011 to enable the university and national laboratory community to continue to develop the technologies needed for next-generation NP facilities.	+30
Total, Other Research	**+44**
Total, Research	**+303**
Operations	
▪ **RHIC Operations**	
• RHIC Accelerator Operations increases in FY 2011 to maintain operations 370 hours above FY 2010 levels.	+4,402
• RHIC Experimental Support increases in FY 2011 to maintain efforts associated with the implementation of experimental and computing capabilities and infrastructure.	+1,429
Total, RHIC Operations	**+5,831**
▪ **Other Operations**	
Funding increases to maintain laboratory general purpose equipment.	+301
Total, Operations	**+6,132**
Total Funding Change, Heavy Ion Nuclear Physics	**+6,435**

Low Energy Nuclear Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Low Energy Nuclear Physics			
Research			
University Research	20,601	22,186	22,582
National Laboratory Research	31,447	41,448	41,139
Other Research[a]	960	2,011	1,952
Total, Research	53,008	65,645	65,673
Operations	34,872	36,991	37,793
Facility for Rare Isotope Beams	7,000	12,000	10,000
Total, Low Energy Nuclear Physics	94,880	114,636	113,466

Description

The research effort supported by the Low Energy Nuclear Physics subprogram aims primarily at answering the overarching questions associated with the second and third frontiers identified by NSAC. Questions associated with the second frontier, Nuclei and Nuclear Astrophysics, 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? Major goals of this subprogram are to develop a comprehensive description of nuclei across the entire nuclear chart, to utilize rare isotope beams to reveal new nuclear phenomena and structures unlike those gleaned from studies using stable nuclei, and to 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, Fundamental Symmetries and Interactions, using neutrinos and neutrons as primary probes. 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 non-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 (a Majorana particle). These neutrino properties are believed to play a role in the evolution of the cosmos. Beams of cold and ultracold neutrons will be used for precision measurements of neutron lifetime and beta-decay parameters and to investigate the dominance of matter over antimatter in the universe in order to answer fundamental questions in nuclear and particle physics, astrophysics, and cosmology. Funding supports both research and operations of the subprogram's two national user facilities, HRIBF and ATLAS, which serve an international community of approximately 700 users. These two facilities

[a] In FY 2009, $1,426,000 was transferred to the SBIR program. This activity includes $1,426,000 for SBIR in FY 2010 and $1,528,000 for SBIR in FY 2011.

provide beams for nuclear structure and astrophysics studies and a strong training ground for the next generation Facility for Rare Isotope Beams (FRIB), which will be constructed at MSU. Both HRIBF and ATLAS possess unique capabilities in an international context and have cutting edge instrumentation. Research at these facilities are coordinated and optimized to achieve the high priority scientific goals for this field. Fabrication of the Gamma Ray Energy Tracking In-Beam Nuclear Array (GRETINA) MIE is on track for completion in FY 2011. GRETINA, a segmented germanium detector array with unparalleled position and energy resolution for nuclear structure studies with fast nuclear beams, will rotate amongst the domestic low-energy facilities thereby increasing scientific productivity. Support continues in FY 2011 for efforts in implementing the Rare Isotope Beam Science Initiatives, enabling U.S. researchers to participate in forefront rare isotope beam facilities with unique capabilities around the world. A peer review process, started in August 2009, recently identified eleven initiatives that will be pursued, varying in cost and complexity. These are now undergoing individual peer review; NP will break out and separately describe the selected Major Items of Equipment in future budget narratives. These efforts encourage cooperation and communication on a global level in this quickly evolving field of science. 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 (USAF) provide support towards improvements in radiation hardness of electronic circuit components against damage caused by cosmic rays. In addition, the subprogram 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. At the University of Washington, the subprogram supports infrastructure to develop scientific instrumentation projects and to provide technical and engineering educational opportunities. These university Centers of Excellence each support 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 ATLAS and HRIBF have 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. nuclear physics program, and the NSAC Long Range Plan recommended its construction. In FY 2008, NP announced an open solicitation to universities and laboratories, inviting proposals for FRIB. Following peer review of the submitted proposals, the DOE selected Michigan State University (MSU) as the host institution to establish FRIB. This project is supported with operating funding through a Cooperative Agreement with MSU and will follow the management principles of DOE O 413.3A. Supporting information on the project is provided at the end of this budget narrative. While not a DOE capital asset (the facility will be owned by the university) it will be operated as a DOE national user facility upon completion. In FY 2011, engineering and design activities begin on FRIB.

In the area of neutrino physics, U.S. researchers are involved in several important efforts focused primarily on neutrino mass and whether the neutrino is its own anti-particle. The U.S. continues to participate in the fabrication of 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 and measure or set a limit on the effective mass of the neutrino using the neutrinoless double beta decay (DBD) mechanism. Efforts also continue in FY 2011 on the Majorana Demonstrator R&D effort to determine technical feasibility of using high purity, enriched germanium to explore the nature of the neutrino via DBD. Projects that study DBD with extreme sensitivity such as these will address two fundamental properties of the neutrino, its mass and its particle-antiparticle nature, that are important for understanding the matter-antimatter asymmetry in the universe and the evolution of the cosmos. U.S. university scientists are also participating in the fabrication of 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, U.S. researchers at the Kamioka Large Anti-Neutrino Detector (KamLAND) experiment in Japan are continuing a modest effort 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 a Japanese-funded upgrade of the detector.

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 is on track for completion in FY 2010 on cost and schedule at the SNS. These include the neutron Electric Dipole Moment Experiment MIE currently being fabricated at Oak Ridge National Laboratory, which could shed light on why the universe is composed mostly of matter when the Big Bang Theory of cosmology suggests that the universe should contain equal amounts of matter and anti-matter.

Finally, it is within the Low Energy subprogram, as well as the Theory subprogram, that the Applications for Nuclear Science and Technology initiative is supported. This effort was started in FY 2009 and was augmented with Recovery Act funds. Community response to this initiative was extremely positive with over 200 proposals that were peer reviewed to identify the most compelling opportunities; 14 projects were selected for funding under the Low Energy program. This initiative supports basic nuclear physics research that addresses high priority scientific goals and has practical applications to other fields, such as medicine, next-generation nuclear reactors, and homeland security.

The Low Energy subprogram is the broadest within the NP portfolio, supporting research activities aligned with diverse scientific thrusts. It also currently supports the most instrumentation projects, as well as the Majorana Demonstrator R&D effort and the Cooperative Agreement to construct FRIB; most of these initiatives are international in nature and project profiles are optimized to take advantage of international commitments.

Selected FY 2009 Accomplishments

- A new upper limit on the permanent electric dipole moment of atomic mercury has been reported by University of Washington scientists. The electric dipole moment is generated by interactions that violate time reversal symmetry (i.e., physical laws remain unchanged when time is reversed). The result obtained for mercury-199 is the most sensitive test of time reversal symmetry violation in ordinary matter achieved to date. Measuring time reversal symmetry is important because it constrains possible extensions of the Standard Model of particles and fundamental interactions.

- New precise mass measurements of 55 neutron-rich nuclei have been carried out at the ATLAS facility with the Canadian Penning Trap. The data indicate that nuclei with increasingly higher neutron excess are not as tightly bound as previously thought. This observation affects nucleosynthesis models of the astrophysical *r*-process, the process responsible for the creation of 50 percent of the elements in the Universe.

- The process of beta-delayed neutron emission (b_n) from fission products created in nuclear reactors contributes to the total number of neutrons inducing fission in nuclear fuels. The b_n also shapes the final distribution of nuclei remaining after a supernovae explosion. Scientists at HRIBF have developed unique methods for separating the rare neutron-rich fission products of interest and measuring their decays. Studies of these pure isotopic samples indicate beta-delayed neutron decay rates that are two to five times higher than previously reported. These findings have important implications for design of next-generation nuclear fuels and modeling of astrophysical nucleosynthesis processes.

- Successes in the synthesis of the heaviest elements with atomic numbers Z=114 to 118 have been reported by Russian scientists using "hot" fusion reactions. These important results, however, had not been confirmed independently. Recently, scientists using beams and experimental facilities at the 88-Inch Cyclotron at LBNL succeeded in reproducing the Russian results for the synthesis of Element 114. This confirmation allows the field of chemistry to claim the discovery of Element 114 and validates the utility of "hot" fusion as an important tool for synthesis of heavier elements.
- Large amounts of radioactive aluminum-26 (^{26}Al) have been detected in the galaxy by satellite observatories, but the source is still unknown. Researchers at ORNL have used intense beams of ^{26}Al at HRIBF to probe important energy levels that elucidate production and subsequent destruction of this nucleus in some massive and exploding stars. These results are being incorporated into models that aim at improved understanding of ^{26}Al production in the galaxy.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Research	**53,008**	**65,645**	**65,673**
▪ **University Research**	**20,601**	**22,186**	**22,582**

Research aimed at addressing high priority scientific goals is supported for about 126 scientists and 98 graduate students at 35 universities; university research is supported in FY 2011 at approximately a constant level of effort relative to FY 2010. About two-thirds of the supported university scientists conduct nuclear structure and astrophysics research using specialized instrumentation at the ATLAS and HRIBF national user facilities.

Accelerator operations are supported for primarily in-house research programs at the facilities at Duke University, TAMU, and Yale University. These Centers of Excellence 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; they also provide excellent training opportunities to junior scientists and engineers.

University scientists are supported to play key roles in the development of experiments using cold neutrons at the SNS FNPB—an experimental program which is being launched in FY 2011. The FY 2011 request also includes support for the international KATRIN project which is led by a university group.

	FY 2009	FY 2010	FY 2011
▪ **National Laboratory Research**	**31,447**	**41,448**	**41,139**

Support is provided for the research programs at six national laboratories (ANL, BNL, LBNL, LANL, LLNL, and ORNL). These scientists continue to develop and implement new instrumentation, to provide maintenance and infrastructure support of the ATLAS and HRIBF, to effectively utilize beam time for research, to train junior scientists, to develop and utilize non-accelerator experiments, and to support the development and fabrication of FRIB. Funding decisions are influenced by the results of periodic peer reviews of the national laboratory research groups and their subsequent ranking in terms of performance level.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
• **National Laboratory User Facility Research**	**11,326**	**8,768**	**9,840**

Questions fundamental to the understanding of stellar nucleosynthesis—how the elements are manufactured in stars—requires accelerators with low energy capabilities. In fact, because many nuclear reactions that take place in stars are at very low energies, an accelerator capable of producing stable low energy beams is a requirement. Funding is provided for ANL researchers for nuclear structure studies using stable and selected radioactive beams from ATLAS coupled to specialized instrumentation. Modest capital equipment investments support the fabrication and implementation of small-scale detectors at the facility. The most recent addition to the unique instrumentation at ATLAS is the HELical Orbit Spectrometer (HELIOS), a novel superconducting solenoidal spectrometer that probes the structure of exotic nuclei.

Because stars generate heavier elements from lighter ones in a process that takes place in the cores of stars or through stellar explosions, many of the intermediate nuclei that are produced are short-lived and very unstable. To study them requires accelerators capable of producing beams composed of radioactive ions. ORNL researchers use radioactive beams from the HRIBF and specialized spectrometers to study the nuclear structure of nuclei far from stability. Nuclei far from stability are thought to play a decisive role in those astrophysical processes that build up heavier elements from lighter nuclei, e.g., in supernovae, and thus knowledge about such exotic nuclei can help us understand our own origin. The fabrication and implementation of small-scale detectors at HRIBF are supported with modest capital equipment investments. For example, the recently completed Low-energy Radioactive Ion Beam Spectroscopy Station (LeRIBSS) enables exploitation of the most neutron rich beams at HRIBF to study fission products such as those in nuclear reactors. Increased funding in FY 2011 maintains efforts at ATLAS and HRIBF.

• **Other National Laboratory Research**	**20,121**	**32,680**	**31,299**

Scientists at BNL, LBNL, LLNL, LANL, and ORNL play lead roles in several high-priority accelerator- and non-accelerator-based projects (nEDM, CUORE, RIB Science Initiatives, GRETINA, FNPB, and KamLAND). Both nEDM and CUORE are joint DOE/NSF-supported projects, but managed by DOE-supported scientists. In addition, DOE-supported scientists have the lead role in the R&D to demonstrate a proof of principle for a neutrino-less double beta decay experiment with germanium, the Majorana Demonstrator. The total cost of the Majorana R&D effort over four years is approximately $20,000,000. Researchers are also supported to develop and implement neutron science experiments at the newly completed fundamental neutron physics beamline at the Spallation Neutron Source and to contribute to FRIB project engineering and design efforts.

Research efforts relevant to Applications of Nuclear Science and Technology are decreased by $980,000 in FY 2011 relative to FY 2010 as a result of funding a number of multi-year initiatives under the Recovery Act. This initiative is competed among university and laboratory researchers and supports nuclear science research that is inherently relevant to a broad range of applications. A number of instrumentation MIEs are supported within this activity; the project funding profiles tend to drive the overall funding requests of this subprogram. Capital equipment funding is increased in FY 2010 to support the ongoing instrumentation projects according to planned profiles and to initiate a new MIE. In FY 2011, funding for capital equipment decreases as the result of planned funding profiles.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

- ► The GRETINA MIE, which is scheduled for completion in FY 2011, 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. GRETINA will be shared amongst low-energy facilities in the United States (including an NSF facility) to cost-effectively boost scientific productivity.
- ► Support is provided to ORNL to continue to play a leadership role in the development of the scientific and experimental program with neutrons at the FNPB, a beamline at the SNS. The FNPB, which will be completed in FY 2010, will deliver cold and ultra-cold neutrons at the highest intensities in the world for studying the fundamental properties of the neutron, leading to a refined characterization of the weak force.
- ► In FY 2011, funding continues for the fabrication of the Electric Dipole Moment of the neutron (nEDM) MIE, a high-risk, high-potential discovery experiment at the FNPB. The nEDM experiment is a joint DOE/NSF experiment to measure a non-zero electric dipole moment of the neutron, which will significantly constrain extensions of the Standard Model. Fabrication, scheduled to start in FY 2010, will be initiated once the project completes high-priority R&D, and is baselined and has CD-2 approval.
- ► In FY 2011, funding ramps down to continue fabrication of the international CUORE experiment to search for neutrino-less double beta decay (DBD) of tellurium-130 isotope. This is a joint DOE/NSF project.
- ► In FY 2011, funding increases to continue Rare Isotope Beam Science Initiatives to support forefront scientific instrumentation opportunities at rare isotope beam facilities around the world. A merit peer review was held in August 2009 to identify the most compelling initiatives to fabricate and to guide the optimum balance of funding between R&D activities and fabrication activities in FY 2010 and FY 2011. The selected initiatives are undergoing project-specific peer review, and selected Major Items of Equipment will be broken out and separately described in future budget narratives. No fabrication activities on the MIEs will be supported prior to project baseline or CD-2 approval.

▪ **Other Research**	**960**	**2,011**	**1,952**

In FY 2009, $1,426,000 was transferred to the SBIR program. This activity includes $1,426,000 for SBIR in FY 2010, and $1,528,000 for SBIR in FY 2011. 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.

Operations	**34,872**	**36,991**	**37,793**
▪ **ATLAS Operations**	**15,180**	**16,093**	**16,196**

The ATLAS Facility is the premiere stable beam facility in the world. ATLAS accelerator operations and experimental support provide for 5,900 beam hours of operation and continued cost-effective 7 day-a-week operations in FY 2011, the same as FY 2010. The slight increase in funding in FY 2011 maintains level of effort support for scientific and technical personnel. The Californium Rare Ion Breeder Upgrade (CARIBU) accelerator improvement project is completed in FY 2010, and will enhance the radioactive beam capabilities and productivity of ATLAS. Accelerator

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

improvement projects in FY 2011 are focused on increasing the reliability and efficiency of operations. Modest capital equipment funding is provided for helium compressors and cryogenics upgrades to improve operations. The ATLAS facility nurtures a core competency in accelerator expertise with superconducting radio frequency cavities for heavy ions that is relevant to the next generation of high-performance proton and heavy-ion linacs, and is important to the Office of Science mission and international stable and radioactive ion beam facilities. ANL accelerator physicists and scientists are working closely with MSU researchers in the development and fabrication of components for FRIB.

	FY 2009	FY 2010	FY 2011
ATLAS Hours of Operation with Beam			
Achieved Operating Hours	5,448	N/A	N/A
Planned Operating Hours	5,200	5,900	5,900
Optimal Hours	6,600	6,600	6,600
Percent of Optimal Hours	83%	89%	89%
Unscheduled Downtime	4.1%	N/A	N/A
Number of Users	360	410	410

- **HRIBF Operations** **15,860** **16,645** **17,174**

HRIBF is the only facility in the U.S. dedicated solely to the production of radioactive beams by the Isotope Separator On-Line (ISOL) technique, which can produce extremely intense beams of rare isotopes, and is the only one that reaccelerates medium mass nuclei to the Coulomb barrier. Accelerator physicists and scientists at this facility have developed core competencies in high power target design and ISOL ion beam production techniques that are recognized in an international context. HRIBF accelerator operations and experimental support provide for 5,200 beam hours of operation and the transition from 5 day to the more cost effective 7 day-a-week operations. The facility begins to commission a second source and transport beamline (IRIS2) for radioactive ions in FY 2010, which will increase operations efficiency and reliability. Accelerator improvement projects target the elimination of single-point failures and increased operations reliability. Capital equipment funding is provided for items such as accelerator power supplies and remote handling systems to enhance performance and increase scientific productivity.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

	FY 2009	FY 2010	FY 2011
HRIBF Hours of Operation with Beam			
Achieved Operating Hours	4,653	N/A	N/A
Planned Operating Hours	3,600	5,200	5,200
Optimal Hours	6,100	6,100	6,100
Percent of Optimal Hours	76%	85%	85%
Unscheduled Downtime	14.7%	N/A	N/A
Number of Users	260	260	260

▪ **Other Operations**	**3,832**	**4,253**	**4,423**

The NRO and USAF will continue to jointly provide support for the 88-Inch Cyclotron for approximately 2,000 hours for their electronics testing program, and NP continues support in FY 2011 for approximately 3,000 hours for the in-house nuclear physics research program at LBNL. Funding is also provided for maintenance of the Oak Ridge Electron Accelerator (ORELA) which is used for criticality measurements supported by DOE/NNSA.

Facility for Rare Isotope Beams	**7,000**	**12,000**	**10,000**

Funds are requested in FY 2011 to begin engineering and design efforts aimed at developing FRIB. MSU is undertaking a comprehensive R&D plan for FRIB, utilizing core competencies developed at the NP-supported national laboratory groups. 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 (for additional details, see the Supporting Information section). The FY 2011 funding supports the project profile as agreed upon between MSU and DOE in the Cooperative Agreement.

Total, Low Energy Nuclear Physics	**94,880**	**114,636**	**113,466**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Research	
▪ **University Research**	
FY 2011 funding increases to maintain support for university researchers.	+396
▪ **National Laboratory Research**	

- National Laboratory User Facility Research funding maintains personnel at levels needed to support the highest priority research efforts and implementation of

	FY 2011 vs. FY 2010 ($000)
scientific instrumentation at the ATLAS national user facility and increases staff at HRIBF.	+1,072
• Other National Laboratory Research funding supports a number of MIEs according to their planned project profile, maintaining cost and schedule baselines and meeting international commitments. In FY 2011, funding in total for all of the Low Energy Nuclear Physics MIEs decreases by $3,504,000. Funding for research relevant to Applications of Nuclear Science and Technology decreases by $980,000 relative to FY 2010 as a result of funding a number of multi-year proposals with FY 2009 funding and Recovery Act funding. Offsetting these decreases are increases for the proof of principle Majorana Demonstrator R&D project which begins to ramp up in FY 2011 (+$1,700,000), the development of experiments for the new neutron science program at the FNPB (+$1,000,000), and a modest increase to maintain laboratory research groups (+$403,000).	-1,381
Total, National Laboratory Research	**-309**
▪ **Other Research**	
SBIR and other funded at levels required proportionate to R&D activities.	-59
Total, Research	**+28**
Operations	
▪ ATLAS Operations reflects an increase to maintain staff and effectively operate this national user facility, which is partially offset by a decrease in accelerator improvement project funding as a result of completion of the CARIBU accelerator project in FY 2010.	+103
▪ The increase in HRIBF Operations addresses staffing requirements to effectively operate and maintain this national user facility.	+529
▪ Other Operations increases to provide needed funding for maintenance of operations at the 88-Inch Cyclotron and ORELA at approximately a constant level of effort.	+170
Total, Operations	**+802**
Facility for Rare Isotope Beams	
▪ Funding for the Facility for Rare Isotope Beams is requested to begin engineering and design work; the decrease is consistent with the planned profile in the Cooperative Agreement signed with MSU in June 2009.	-2,000
Total Funding Change, Low Energy Nuclear Physics	**-1,170**

Nuclear Theory

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Nuclear Theory			
Theory Research			
University Research	14,551	15,060	15,753
National Laboratory Research	13,482	16,089	17,587
Scientific Discovery through Advanced Computing (SciDAC)	2,679	2,773	2,870
Total, Theory Research	30,712	33,922	36,210
Nuclear Data Activities	7,064	7,652	8,499
Total, Nuclear Theory	37,776	41,574	44,709

Description

The Nuclear Theory subprogram supports theoretical research at universities and DOE national laboratories with the goal of improving 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). LQCD 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, the joint HEP/NP initiative was operating facilities with an aggregate capacity of 18 sustained teraflops. This LQCD initiative is being replaced by a joint 5-year HEP/NP follow-on project, LQCD-ext, beginning in FY 2010. The NP LQCD computer capability at TJNAF is also being augmented with Recovery Act funding; when fully operational at the end of FY 2010, this computing equipment will have increased the U.S. computing capability for LQCD to a minimum of 45 sustained teraflops.

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; its organizational structure promotes cost effective collaboration and educational opportunities. 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 Nuclear Theory subprogram also supports targeted investments in short-term topical theory collaborations within the university and national laboratory communities to facilitate cooperation and communication on specialized nuclear theory challenges that require concerted effort in order to advance the field.

Another component of the Nuclear Theory subprogram is the National Nuclear Data program which compiles, evaluates, and disseminates nuclear data for basic research and applications in an online database 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.

The FY 2011 increases address staff shortages at the national laboratories, the ramp-up of the second-generation LQCD project in partnership with the DOE Office of High Energy Physics, and additional topical theory collaboration support. Within the Nuclear Data subprogram, support for the recently initiated Applications of Nuclear Science and Technology program is reduced due to opportunities enabled by Recovery Act funding.

Selected FY 2009 Accomplishments

- The quark-gluon plasma (QGP), studied experimentally in relativistic heavy-ion collisions at the RHIC facility at BNL, has continued to be of great interest to nuclear theorists. Advances this past year include a more realistic description of the QGP using viscous fluid dynamics. Lattice Quantum Chromodynamics (LQCD) calculations have provided the value of the viscosity coefficients in a gluon plasma, yielding clear confirmation that the QGP is not a nearly free gas of quarks and gluons but instead behaves as a nearly perfect fluid.
- Meson-baryon interactions play an important role in nuclear physics and potentially also in astrophysics. During the last year, the first fully dynamical LQCD calculation of meson-baryon scattering was performed by the Nuclear Physics LQCD collaboration, demonstrating that the longstanding building blocks of nuclear structure calculations are accountable to the underlying quark-gluon degrees of freedom. This is only the beginning of the LQCD effort in this area, but it is an important step towards determining meson-baryon interaction strengths and quantifying the associated systematic uncertainties.
- In Low Energy Nuclear Physics, the question of "How far does the periodic table go?" and the accompanying technical challenge of how best to form new elements experimentally have been the focus of great attention. Recent calculations using microscopic density functional theory suggest possibly very favorable experimental approaches for creating new heavy elements and may also provide a wider context for understanding fission reactions such as those exploited in energy-producing nuclear reactors. These studies have also led to a better theoretical understanding of aspects of nuclear structure that were already known experimentally, including the mass differences

between nuclei with even and odd numbers of neutrons and protons and properties of the excited states of even nuclei. This work includes many predictions that can be tested at the planned FRIB facility.

- In recent observations of the Sun, improved analyses of absorption lines in the solar spectrum have lowered estimates of the Sun's surface metal content (metallicity). These new results lead to a puzzling discrepancy with predictions of the speed of sound in the solar interior using the standard solar model. This demonstrates the importance of developing improved three-dimensional solar models using the next generation of supercomputers. It was also recently shown that new solar neutrino flux experiments could resolve this solar metallicity puzzle by directly determining the metal content of the gas cloud from which our solar system formed.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Theory Research	**30,712**	**33,922**	**36,210**
▪ **University Research**	**14,551**	**15,060**	**15,753**

The University Research activity supports the research of approximately 160 academic scientists and 120 graduate students through 65 research grants at 45 universities in 29 states and the District of Columbia, and will allow the start of several new research grants in specific growth areas of nuclear theory in FY 2011. Funding will support the necessary level of theoretical effort needed for interpretation of experimental results obtained at the NP facilities and the training of next-generation nuclear theorists. The overall nuclear theory effort is aligned with the experimental program through the program performance milestones established by NSAC.

▪ **National Laboratory Research**	**13,482**	**16,089**	**17,587**

Research programs in nuclear theory are supported at seven national laboratories (ANL, BNL, LANL, LBNL, LLNL, ORNL, and TJNAF) to achieve high priority scientific goals and interpret experimental results. The theoretical research at a given laboratory is primarily aligned to the experimental program at that laboratory, or in some cases to take advantage of the unique facilities or programs at that laboratory. In FY 2011, funding is provided for staffing at several of the national laboratories, and investments in LQCD computer capabilities are increased slightly in a joint effort with High Energy Physics, LQCD-ext. Additional topical theory collaboration support is also provided. Funds for topical theory collaborations are reflected in National Laboratory Research, but are awarded after open competition between university and laboratory groups; awards are determined by peer review. In FY 2009, the seven laboratory groups were evaluated on the significance of their accomplishments and planned future program; scientific leadership, creativity and productivity of the personnel; and the overall cost-effectiveness of the group. The results of this review will influence final budget allocations in FY 2010 and FY 2011.

▪ **Scientific Discovery through Advanced Computing (SciDAC)**	**2,679**	**2,773**	**2,870**

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. The NP SciDAC program currently supports research projects in nuclear astrophysics, grid

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

computing, lattice quantum chromodynamics, low energy nuclear structure and nuclear reaction theory, and advanced accelerator design, which are jointly funded with ASCR, HEP, and NNSA. The portfolio of NP-supported SciDAC projects will be re-competed in FY 2010 and FY 2011, and a new set of these computationally intensive projects of nuclear theory will be under investigation in FY 2011.

Nuclear Data Activities	**7,064**	**7,652**	**8,499**

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 addresses long-standing staffing issues. The NNDC relies on the U.S. Nuclear Data Network, 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 cycles. This initiative is funded from both the Low Energy Program and the Nuclear Data Program; while funding increases in this subprogram, overall the support for this initiative decreases in FY 2011 as compared to FY 2010.

Total, Nuclear Theory	**37,776**	**41,574**	**44,709**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Theory Research	
▪ **University Research**	
In FY 2011, increased support is provided to university nuclear theory groups to continue research on the topics in theoretical nuclear physics that were identified in the previous NSAC report on performance measures and milestones and to implement recommendations from the NSAC Subcommittee on Nuclear Theory.	+693
▪ **National Laboratory Research**	
FY 2011 funding provides an increase above cost of living for the theoretical efforts at the seven NP-supported national laboratory theory groups to allow these groups to achieve the scientific goals of the Nuclear Physics program. These activities include increasing staff, additional topical collaboration support, and the increased support of the LQCD initiative, LQCD-ext, which is jointly funded with HEP.	+1,498
▪ **Scientific Discovery through Advanced Computing (SciDAC)**	
The portfolio of NP-supported SciDAC projects will be re-competed in FY 2010 and FY 2011. Funding in FY 2011 will allow support for the newly defined set of	

	FY 2011 vs. FY 2010 ($000)
computationally intensive SciDAC projects in nuclear theory that require terascale and petascale computing capabilities.	+97
Total, Theory Research	**+2,288**
Nuclear Data Activities	
FY 2011 funding will continue to support the activities of the National Nuclear Data Center and institutions that collaborate on the Nuclear Data project at a near constant level of effort (+$325,000), and support for the Applications of Nuclear Science and Technology initiative increases in this subprogram (+$522,000).	+847
Total Funding Change, Nuclear Theory	**+3,135**

Isotope Development and Production for Research and Applications

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Isotope Development and Production for Research and Applications			
Research			
National Laboratory Research	1,500	1,500	1,560
University Research	3,360	1,500	1,560
Other Research[a]	0	84	90
Total, Research	4,860	3,084	3,210
Operations			
University Operations	200	250	262
Isotope Production Facility Operations	2,790	1,068	1,111
Brookhaven Linear Isotope Producer Operations	770	500	520
National Isotope Data Center (NIDC)	1,024	1,915	1,992
Other National Laboratory Operations	15,116	12,383	12,685
Total, Operations	19,900	16,116	16,570
Total, Isotope Development and Production for Research and Applications	24,760	19,200	19,780

Description

The primary goal of this subprogram is to support research, development, and production of research and commercial isotopes that are of critical importance to the Nation and in short supply. 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 isotope production component of the Isotope Development and Production for Research and Applications subprogram include the availability of research and commercial isotopes that would have otherwise not be possible, reduced dependence on foreign supplies, new scientific applications for isotopes not currently supplied, the development of more effective isotope production and processing techniques, and the ability to meet both present and future research needs for isotopes. The subprogram places an emphasis on the R&D efforts associated with developing new and more cost-effective and efficient production and processing techniques, and the production of isotopes needed for research purposes.

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 produced by the program are utilized by Federal agencies, including the National Institutes of Health and their grantees, National

[a] In FY 2009, $125,000 was transferred to the SBIR program and $15,000 was transferred for the STTR program. This activity includes $75,000 for SBIR and $9,000 for STTR in FY 2010 and $80,000 for SBIR and $10,000 for STTR in FY 2011.

Institute of Standards and Technology, Environmental Protection Agency, Department of Agriculture, National Nuclear Security Administration, Department of Homeland Security, other DOE Office of Science programs, and other Federal agencies.

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 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 to detect terrorist threats.

Isotopes are made available by using the Department's unique facilities, the Brookhaven Linac Isotope Producer (BLIP) at BNL and the Isotope Production Facility (IPF) at LANL, for which the subprogram has stewardship responsibilities. In FY 2009, the subprogram also explored production capabilities at university and other laboratory facilities in order to make high priority isotopes more available and cost-effective. 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 the production of isotopes at the reactors at Oak Ridge and Idaho National Laboratories and 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 Program was transferred to the Office of Nuclear Physics with the FY 2009 Appropriation, and much effort has been expended on establishing long-term strategies, priorities, peer review mechanisms, and effective lines of communication with isotope stakeholders. The Nuclear Science Advisory Committee (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. The first NSAC report, released in April 2009, includes federal, commercial, and community input and establishes priorities for the production of research isotopes. Following release of the report, NP issued a broad call to university, laboratory, and commercial facilities, inviting them to submit proposals describing their capabilities for producing these high priority research isotopes. These proposals were reviewed and selections were made based on cost and products in short supply; the result is that the Isotope Program will establish new production capabilities at other laboratory sites and university facilities to optimize its ability to supply reliable sources of research isotopes at more affordable prices. A data call is now planned to the broad research community announcing the isotopes that can be produced at the increased suite of facilities and soliciting interest in the demand for these isotopes so that production schedules can be developed and coordinated. The second NSAC report on a long-range strategic plan was released in November 2009.[a]

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[a] http://www.sc.doe.gov/np/dev/nsac/nsac.html

NP continues to work in close collaboration with other federal agencies in the development of strategic plans regarding isotope production. A goal of the program is to establish effective communication with federal agencies to better forecast isotope needs and leverage resources. For example, NP continues to work with the National Institutes of Health (NIH) on a federal working group NP assembled to address the recommendations of the recent National Academies report, *Advancing Nuclear Medicine through Innovation*, which identified several areas in isotope production warranting attention. A five-year production strategy has been generated which identifies the isotopes and projected quantities needed by the medical community in the context of the Isotope Program capabilities. While the Isotope Program is not responsible for the production of molybedenum-99 (Mo-99), it recognizes the importance of this isotope for the Nation and is working closely with DOE/NNSA, the lead entity responsible for domestic Mo-99 production, by offering technical and management support. NP has also facilitated the formation of a federal working group on the He-3 supply issue involving staff from NP, NNSA, the Department of Homeland Security, and the Department of Defense. The Isotope Program's role in helium-3 (He-3) is limited to packaging and distribution of the isotope. However, the objective of this working group is to ensure that the limited supply of He-3 will be distributed to the highest priority applications and basic research.

In addition, NP held many discussions during FY 2009 with the Californium-252 (Cf-252) source manufacturers and users, conducted a full bottom-up evaluation of the costs associated with Cf-252 production, and considered more effective approaches to produce this isotope to meet projected demands. The result is that a four-year contract was signed with the source manufacturers in May 2009 to continue Cf-252 production and ensure its availability in the outyears.

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 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 at more affordable rates, with research isotopes sold at a unit price. 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.

In FY 2011,emphasis is placed on supporting and organizing a stable and efficient workforce for the production of isotopes and R&D efforts. The suite of isotope production facilities is increased to include university facilities and other capabilities at national laboratories. Starting in FY 2010, the Isotope Program will increase productivity by broadening its suite of facilities to include university accelerator and reactor facilities, as well as other agency facilities, which can provide cost-effective and unique capabilities; these include cyclotron facilities at the National Institutes of Health, the Washington University cyclotron, the University of California at Davis cyclotron and the Missouri University Research Reactor. Partnerships with industrial counterparts are pursued to leverage resources. Under the research category, FY 2009 funding reflects the outcome of decisions based upon peer review regarding production of isotopes at university and national laboratory facilities, and their corresponding balance. It is expected that in FY 2010 and FY 2011 that balance will be optimized based on merit peer review.

Selected FY 2009 Accomplishments

- Copper-67 is an attractive radioisotope for application in therapy of various cancers when attached to the appropriate carrier molecule, such as a monoclonal antibody. In an ongoing effort to improve the specific activity of copper-67, BNL has investigated the use of a highly enriched zinc-68 target in place of natural zinc. A test irradiation with zinc-68 improved the specific activity three-fold over the best previous result. In order to improve the economics of this process, a method to recover and reuse the enriched material from the process waste was successfully developed.

- A Drug Master File for the tungsten-188/rhenium-188 generator system, used in cancer research, is now on file with the Food and Drug Administration. Coupled with the hot cells at ORNL now being approved for current Good Manufacturing Practices, the tungsten-188/rhenium-188 generator will be suitable for human clinical trials.
- Recent major equipment purchases of stable isotope processing equipment at ORNL will greatly enhance stable isotope supply. A new high vacuum/induction heating system replaced one that was over 40 years old and contained legacy thorium contamination, and a new scanning electron microscope with an x-ray energy dispersive analyzer will allow for enhanced chemistry and materials product and process evaluation.
- Yttrium-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. Currently this isotope is in short supply. A number of activities have been undertaken to increase the reliable supply of yttrium for use in research: investigations to improve product purity using very low energy protons; development of a method to recover irradiated strontium-86 for reuse; design of a new target capsule that can be sealed and opened in a hotcell; and development of a new accelerator tune to reduce the BLIP facility beam energy from the maximum of 200 MeV to 66 MeV in order to more effectively produce the isotope.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Research	**4,860**	**3,084**	**3,210**

Research is supported to identify, design, and optimize production targets and separation methods. Examples for planned research include 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 and treat diseases spread through acts of bioterrorism, the development of production methods for alpha-emitting radionuclides that exhibit great potential in 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 is being used to support R&D in alternative isotope production techniques, which complements these research efforts in FY 2010.

▪ **National Laboratory Research**	**1,500**	**1,500**	**1,560**

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 more affordable rates. R&D activities also utilize the reactors at INL and ORNL and the accelerators at LANL and BNL. Researchers provide unique expertise and facilities for data analysis. Funding in FY 2009 reflects the selection of national laboratory proposals following peer review. Amounts

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

reflected in FY 2010 and FY 2011 are estimates; the actual split of funding between National Laboratory Research and University Research will be determined based on merit peer review. Additional funding was provided in FY 2009 under the Recovery Act for R&D on alternative isotope production and processing techniques.

	FY 2009	FY 2010	FY 2011
▪ **University Research**	**3,360**	**1,500**	**1,560**

Support is provided for scientists at universities and with industry 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 more affordable rates. Funding in FY 2009 reflects the selection of university and industry proposals. Amounts reflected in FY 2010 and FY 2011 are estimates; the actual split of funding between University Research and National Laboratory Research will be determined based on merit peer review.

	FY 2009	FY 2010	FY 2011
▪ **Other Research**	**0**	**84**	**90**

In FY 2009, $125,000 was transferred to the Small Business Innovation Research (SBIR) program and $15,000 was transferred to the Small Business Technology Transfer (STTR) program. This activity includes $75,000 for SBIR and $9,000 for STTR in FY 2010 and $80,000 for SBIR and $10,000 for STTR in FY 2011.

	FY 2009	FY 2010	FY 2011
Operations	**19,900**	**16,116**	**16,570**

Operations funding is provided to support the core facility scientists and engineers needed to effectively operate the Isotope Development and Production for Research and Applications facilities, and includes facility maintenance and investments in new facility capabilities. In addition, Recovery Act funding is supporting enhanced utilization of isotope facilities, including additional isotope production and one-time investments in infrastructure and new capabilities.

	FY 2009	FY 2010	FY 2011
▪ **University Operations**	**200**	**250**	**262**

Funding is provided to academic institutions with reactors and cyclotrons for providing capabilities in the production and processing of isotopes to complement or increase the subprogram's isotope portfolio. Research isotope production at universities and national laboratories is supported under the research category above.

	FY 2009	FY 2010	FY 2011
▪ **Isotope Production Facility (IPF) Operations**	**2,790**	**1,068**	**1,111**

The IPF operates in a parallel-mode in accordance with the Los Alamos Neutron Science Center (LANSCE) for about 22 weeks in FY 2011; the IPF is completely dependent upon the operations of LANSCE. The IPF produces isotopes such as germanium-68, strontium-82, and arsenic-73. Support is provided in FY 2011 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 and with Recovery Act funding.

	FY 2009	FY 2010	FY 2011
▪ **Brookhaven Linac Isotope Producer (BLIP) Operations**	**770**	**500**	**520**

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,

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
and strontium-82. Support is provided in FY 2011 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 and with Recovery Act funding.			
▪ **National Isotope Data Center (NIDC)**	**1,024**	**1,915**	**1,992**
The National Isotope Data Center (NIDC) is a newly created 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 in FY 2010 and FY 2011 to support the staff that are needed to oversee these activities.			
▪ **Other National Laboratory Operations**	**15,116**	**12,383**	**12,685**
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 2011 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. In addition, several upgrade projects were supported with Recovery Act funding. FY 2011 funding maintains efforts at approximately constant effort, relative to FY 2010.			
Total, Isotope Development and Production for Research and Applications	**24,760**	**19,200**	**19,780**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Research	
Funding for research and development, which is guided by priorities in research isotope production developed by NSAC, is maintained at constant effort in FY 2011. R&D efforts benefited significantly from Recovery Act funding for R&D on alternative isotope production techniques.	+126
Operations	
▪ **University Operations**	
Funding maintains constant effort.	+12

	FY 2011 vs. FY 2010 ($000)
▪ **Isotope Production Facility (IPF) Operations**	
Funding maintains constant effort.	+43
▪ **Brookhaven Linac Isotope Producer (BLIP) Operations**	
Funding maintains constant effort.	+20
▪ **National Isotope Data Center (NIDC)**	
An increase is provided to maintain constant effort for the NIDC to meet its mission to coordinate isotope activities and customer data.	+77
▪ **Other National Laboratory Operations**	
Funding maintains constant effort at the hot cell facilities.	+302
Total, Operations	**+454**
Total Funding Change, Isotope Development and Production for Research and Applications	**+580**

Construction

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Construction			
07-SC-02, Electron Beam Ion Source, BNL	2,438	0	0
06-SC-01, 12 GeV CEBAF Upgrade (PED/Construction), TJNAF	28,623	20,000	36,000
Total, Construction	31,061	20,000	36,000

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 2009	FY 2010	FY 2011
07-SC-02, Electron Beam Ion Source, BNL	**2,438**	**0**	**0**

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 was jointly supported by NP and NASA.

06-SC-01, 12 GeV CEBAF Upgrade (PED/Construction), TJNAF	**28,623**	**20,000**	**36,000**

In FY 2011, 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 addition to the funding reflected above, the project also received Recovery Act funding of $65,000,000 in FY 2009 which advanced a portion of the original FY 2010 and FY 2011 planned funding. The FY 2010 and FY 2011 requests reflect a total of $65,000,000 in reductions to the originally planned funding profile to account for the advanced Recovery Act funding.

Total, Construction	**31,061**	**20,000**	**36,000**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($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 after taking into account advanced funding provided under the Recovery Act, and the FY 2010 Appropriation.	+16,000

Supporting Information

Operating Expenses, Capital Equipment and Construction Summary

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Operating Expenses	421,951	463,951	481,208
Capital Equipment	38,810	42,571	37,497
General Plant Projects	2,330	2,000	2,000
Accelerator Improvement Projects	6,155	6,478	5,295
Construction	31,061	20,000	36,000
Total, Nuclear Physics	500,307	535,000	562,000

Funding Summary

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Research	157,709	185,233	196,235
Scientific User Facilities Operations	260,118	272,730	279,916
Other Facility Operations	23,732	20,369	20,993
Projects			
Major Items of Equipment	15,063	18,918	12,805
Facility for Rare Isotope Beams[a]	7,000	12,000	10,000
Construction Projects	31,061	20,000	36,000
Total Projects	53,124	50,918	58,805
Other	5,624	5,750	6,051
Total Nuclear Physics	500,307	535,000	562,000

Scientific User Facilities Operations and Research

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
RHIC (BNL)			
Operations	148,684	157,470	163,301
Facility Research/MIEs	10,427	9,032	10,797
Total RHIC	159,111	166,502	174,098

[a] FRIB is being funded with operating expense dollars through a Cooperative Agreement with Michigan State University (MSU).

	FY 2009	FY 2010	FY 2011
	(dollars in thousands)		
CEBAF (TJNAF)			
Operations	80,394	82,522	83,245
Facility Research/MIEs	10,301	9,799	10,648
Total CEBAF	90,695	92,321	93,893
HRIBF (ORNL)			
Operations	15,860	16,645	17,174
Facility Research/MIEs	6,103	4,068	4,805
Total HRIBF	21,963	20,713	21,979
ATLAS (ANL)			
Operations	15,180	16,093	16,196
Facility Research/MIEs	5,223	4,700	5,035
Total ATLAS	20,403	20,793	21,231
Scientific User Facilities			
Operations	260,118	272,730	279,916
Facility Research/MIEs	32,054	27,599	31,285
Total Scientific User Facilities	292,172	300,329	311,201

Total Facility Hours and Users

	FY 2009	FY 2010	FY 2011
Hours of Operation with Beam			
RHIC (BNL)			
Achieved Operating Hours	3,153	N/A	N/A
Planned Operating Hours	2,915	3,350	3,720
Optimal Hours	4,100	4,100	4,100
Percent of Optimal Hours	77%	82%	91%
Unscheduled Downtime	19.7%	N/A	N/A
Number of Users	1,200	1,200	1,200

	FY 2009	FY 2010	FY 2011
CEBAF (TJNAF)			
Achieved Operating Hours	5,117	N/A	N/A
Planned Operating Hours	4,965	5,110	4,090
Optimal Hours	5,980	5,980	5,980[a]
Percent of Optimal Hours	86%	86%	68%
Unscheduled Downtime	8.5%	N/A	N/A
Number of Users	1,350	1,390	1,430
HRIBF (ORNL)			
Achieved Operating Hours	4,653	N/A	N/A
Planned Operating Hours	3,600	5,200	5,200
Optimal Hours	6,100	6,100	6,100
Percent of Optimal Hours	76%	85%	85%
Unscheduled Downtime	14.7%	N/A	N/A
Number of Users	260	260	260
ATLAS (ANL)			
Achieved Operating Hours	5,488	N/A	N/A
Planned Operating Hours	5,200	5,900	5,900
Optimal Hours	6,600	6,600	6,600
Percent of Optimal Hours	83%	89%	89%
Unscheduled Downtime	4.1%	N/A	N/A
Number of Users	360	410	410
Total Facilities			
Achieved Operating Hours	18,411	N/A	N/A
Planned Operating Hours	16,680	19,560	18,910
Optimal Hours	22,780	22,780	22,780
Percent of Optimal Hours	81%	86%	83%
Unscheduled Downtime	11%	<20%	<20%
Total Number of Users	3,170	3,260	3,300

[a] While the optimal operations for CEBAF remains at 5,980 hours, the maximum number of hours the facility can operate in FY 2011 is 4,090 hours due to a planned shutdown for installation of 12 GeV components. The facility therefore operates at 100% of maximal hours.

Major Items of Equipment

	Prior Years	FY 2009	FY 2009 Recovery Act Appropriation	FY 2010	FY 2011	Outyears	Total
Heavy Ion Nuclear Physics							
Heavy Ion LHC Experiments, LBNL							
TEC	3,000	4,000	0	5,000	1,205	0	13,205
OPC	295	0	0	0	0	0	295
TPC	3,295	4,000	0	5,000	1,205	0	13,500
PHENIX Silicon Vertex Tracker, BNL							
TEC/TPC	3,599	851	250	0	0	0	4,700
PHENIX Forward Vertex Detector, BNL							
TEC/TPC	700	2,200	2,000	0	0	0	4,900
STAR Heavy Flavor Tracker, BNL							
TEC	0	0	0	1,400	2,900	TBD	TBD
OPC	0	0	0	0	0	TBD	TBD
TPC	0	0	0	1,400	2,900	TBD	11,000–17,000
Low Energy Nuclear Physics							
GRETINA, Gamma-Ray Detector, LBNL							
TEC	14,570	2,000	0	430	0	0	17,000
OPC	1,200	300	0	300	0	0	1,800
TPC	15,770	2,300	0	730	0	0	18,800
Fundamental Neutron Physics Beamline, ORNL							
TEC	7,100	1,500	600	0	0	0	9,200
OPC	88	0	0	0	0	0	88
TPC	7,188	1,500	600	0	0	0	9,288
Neutron Electric Dipole Moment (nEDM), LANL							
TEC	2,947	1,100	0	4,500	2,900	TBD	TBD
OPC	933	0	0	0	0	TBD	TBD
TPC	3,880	1,100	0	4,500	2,900	TBD	17,600–19,000

	Prior Years	FY 2009	FY 2009 Recovery Act Appropriation	FY 2010	FY 2011	Outyears	Total
Cryogenic Underground Observatory for Rare Events (CUORE), LBNL							
TEC	400	3,112	0	3,088	800	186	7,586
OPC	764	0	0	0	0	350	1,114
TPC	1,164	3,112	0	3,088	800	536	8,700
Rare Isotope Beam Science Initiatives							
TEC	0	0	0	4,200	5,000	TBD	TBD
OPC	0	0	0	0	0	TBD	TBD
TPC	0	0	0	4,200	5,000	TBD	2,000–20,000
Total MIEs							
TEC		14,763	2,850	18,618	12,805		
OPC		300	0	300	0		
TPC		15,063	2,850	18,918	12,805		

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 FY 2011. The project received its final funding of $2,000,000 under the Recovery Act.

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. The scope funded with Recovery Act funding was completed in November 2009.

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. Engineering design and R&D efforts continued in FY 2009 and FY 2010 for this high-risk project. Fabrication, scheduled to start in FY 2010, will be initiated once the project completes high priority R&D and is baselined and has CD-2 approval. This is a joint DOE/NSF project with NSF contributing additional funds.

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-2/3 approval in December 2009 and is scheduled to finish in FY 2013. This is a joint DOE/NSF project with NSF contributing additional funds.

Rare Isotope Beam Science Initiatives: These initiatives consist of multiple initiatives, each ranging in TPC between $2–20 million, 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 were selected following peer review of solicited proposals. Eleven initiatives were selected and are undergoing individual peer review in FY 2010; NP will break out and separately describe selected Major Items of Equipment in future budget narratives. No fabrication activities will be supported prior to project baseline or CD-2 approval.

Construction Projects

(dollars in thousands)

	Prior Years	FY 2009 Current Appropriation	FY 2009 Recovery Act Appropriation	FY 2010	FY 2011	Outyears	Total
12 GeV CEBAF Upgrade, TJNAF							
TEC	20,877	28,623	65,000	20,000	36,000	117,000	287,500
OPC	10,500	0	0	0	0	12,000	22,500
TPC	31,377	28,623	65,000	20,000	36,000	129,000	310,000
Electron Beam Ion Source, BNL							
TEC	11,262	2,438	0	0	0	0	13,700
OPC	800	300	0	0	0	0	1,100
TPC	12,062	2,738	0	0	0	0	14,800

(dollars in thousands)

	Prior Years	FY 2009 Current Appropriation	FY 2009 Recovery Act Appropriation	FY 2010	FY 2011	Outyears	Total
Total Construction							
TEC		31,061	65,000	20,000	36,000		
OPC		300	0	0	0		
TPC		31,361	65,000	20,000	36,000		

Scientific Employment

(estimated)

	FY 2009	FY 2010	FY 2011
# University Grants	190	200	200
Average Size per year	$340,000	$345,000	$345,000
# Laboratory Projects	33	33	34
# Permanent Ph.Ds	779	790	790
# Postdoctoral Associates	364	370	375
# Graduate Students	516	515	515
# Ph.D.s awarded	85	80	80

Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan

1. Introduction

In 2008, DOE issued a Funding Opportunity Announcement (FOA) for the establishment, operations, and management of a rare isotope beam facility for nuclear structure and astrophysics research with overall technical capabilities as described in a 2007 Nuclear Science Advisory Committee (NSAC) study.[a] Michigan State University (MSU) was selected to design and establish the Facility for Rare Isotope Beams (FRIB) based on the evaluation of their application. MSU was awarded a Cooperative Agreement in June 2009.

FRIB is not a DOE line item construction project or capital asset and is being funded with operating expense dollars through a cooperative agreement with MSU. Although cooperative agreements are excluded under DOE O 413.3A, the management principles of DOE O 413.3A will be followed, including the approval of Critical Decisions. When completed, FRIB will be operated as a DOE National User Facility. Consistent with 10 CFR 600, real property and equipment acquired with Federal funds shall be vested with MSU. However, such items will not be encumbered by MSU for as long as the Federal government retains an interest. When the property and equipment are no longer of interest to the government, MSU will be responsible for decontamination and decommissioning.

[a] http://www.sc.doe.gov/np/nsac/nsac.html

The most recent Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on February 9, 2004, with a preliminary cost estimate range of $900,000,000 to $1,100,000,000. However, as part of an alternatives analysis, the technical scope as originally conceived has changed and the new preliminary cost estimate range to the federal government is now $450,000,000 to $550,000,000 with a proposed completion date (CD-4) range of FY 2017 to FY 2019. The cooperative agreement between DOE and MSU identifies MSU providing $94.5 million in cost share. The final DOE federal investment will be determined when the project is more mature and ready to be baselined at CD-2.

While the requirements in DOE Order 413.3A are not applicable to cooperative agreements covered by 10 CFR 600, MSU is required to implement a project management system that is consistent with the widely accepted industry or DOE project management principles and standards/practices. Funds were appropriated in FY 2010 to continue work on R&D, conceptual design activities, and NEPA requirements. The FY 2011 request will initiate engineering and design activities.

2. Design and Construction Schedule[a]

	CD-0	CD-1	Design Complete	CD-2	CD-3	CD-4
FY 2011	02/09/2004	4Q 2010	TBD	TBD	TBD	FY 2017–FY 2019

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

3. Baseline and Validation Status[b]

(dollars in thousands)

	TEC, Engineering and Design	TEC, Construction	TEC, Total	OPC	TPC
FY 2011	58,000	TBD	TBD	19,000	TBD

4. Project Description, Justification, and Scope

FRIB is based on a heavy-ion linac with a minimum energy of 200 MeV/u for all ions at beam power of 400 kW. The proposed facility will have a production area, three-stage fragment separator, three ion stopping stations, and post accelerator to reach at least 12 MeV/u for all ions.

This proposed facility is to provide intense beams of rare isotopes for a wide variety of studies in nuclear structure, nuclear astrophysics, and fundamental symmetries. This facility will impact the study of the origin of the elements and the evolution of the cosmos, and offers a laboratory for exploring the limits of nuclear existence and identifying new phenomena, with the possibility that a more broadly applicable theory of nuclei will emerge. The facility will offer new glimpses into the origin of the elements by leading to a better understanding of key issues by creating exotic nuclei that, until now, have existed only in nature’s most spectacular explosion, the supernova. Experiments addressing questions of the

[a] This project does not have a performance baseline. The CD-4 schedule range is a preliminary estimate.
[b] This project does not have a performance baseline. The preliminary DOE total project cost (TPC) range is $450,000,000 to $550,000,000, not including the MSU cost share. The amounts shown reflect the requested DOE appropriations only and do not include the planned cost share from MSU.

fundamental symmetries of nature will similarly be conducted through the creation and study of certain exotic isotopes.

5. Financial Schedule (DOE only)

(dollars in thousands)

	Appropriations	Obligations	Costs
Total Estimated Cost (TEC)			
FY 2011	10,000	10,000	9,874
FY 2012	30,000	30,000	28,000
FY 2013	18,000[a]	18,000[b]	18,000[b]
FY 2014	TBD	TBD	2,126
Total, TEC[b]	58,000[b]	58,000[b]	58,000[b]
Other Project Cost (OPC)			
FY 2009	7,000	7,000	1,874
FY 2010	12,000	12,000	13,000
FY 2011	0	0	4,126
Total, OPC[c]	19,000	19,000	19,000
Total Project Cost			
FY 2009	7,000	7,000	1,874
FY 2010	12,000	12,000	13,000
FY 2011	10,000	10,000	14,000
FY 2012	30,000	30,000	28,000
FY 2013	18,000 [a]	18,000 [a]	18,000 [a]
FY 2014	TBD	TBD	2,126
Outyears	TBD	TBD	TBD
Total, TPC[d]	TBD	TBD	TBD

[a] In addition to the TEC funding of $18,000,000 reflected for engineering and design in FY 2013, funding will be requested for construction in FY 2013 and the outyears and will be included upon CD-2 approval.
[b] The funding reflected in the operating funded TEC profile is for DOE's share of engineering and design activities only. The total engineering and design cost is estimated to be $64,100,000; the DOE share shown is in anticipation that MSU will provide an additional $6,100,000 as their cost share. MSU's annual cost share may change as the project matures.
[c] The funding reflected in the OPC profile is for DOE's share of R&D, conceptual design, and NEPA activities only. The total OPC for these activities is estimated to be $25,500,000; the DOE share shown is in anticipation that MSU will provide an additional $6,500,000 as their cost share during this period. MSU's annual cost share may change as the project matures.
[d] The preliminary DOE total project cost (TPC) range is $450,000,000 to $550,000,000, not including the MSU cost share. The amounts shown reflect the requested DOE appropriations only and do not incude the planned cost share from MSU

6. Details of Cost Estimate (DOE only)

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Estimate
Total Estimated Cost (TEC)[a]			
Design and engineering	42,500	N/A	N/A
Construction	TBD	N/A	N/A
Contingency	15,500	N/A	N/A
Total, Total Estimated Cost	58,000	N/A	N/A
Other Project Cost (OPC)			
Conceptual Design / NEPA	6,500	N/A	N/A
R&D	12,500	N/A	N/A
Contingency	0	N/A	N/A
Total, OPC[b]	19,000	N/A	N/A
Total, TPC[c]	TBD	N/A	N/A
Total, Contingency	TBD	N/A	N/A

7. Funding Profile History

(dollars in thousands)

Request Year		FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	Outyears	Total
FY 2010	TEC[d]	0	0	10,000	33,000	18,000[e]	TBD	TBD
	OPC[f]	7,000	9,000	0	0	0	TBD	TBD
	TPC[g]	7,000	9,000	10,000	33,000	18,000	TBD	TBD
FY 2011	TEC[a]	0	0	10,000	30,000	18,000[b]	TBD	TBD
	OPC[c]	7,000	12,000	0	0	0	TBD	TBD
	TPC[d]	7,000	12,000	10,000	30,000	18,000	TBD	TBD

[a] The TEC funding is for DOE's share of engineering and design activities only at this time.
[b] The OPC funding is for DOE's share of R&D, conceptual design, and NEPA activities only at this time.
[c] The preliminary DOE total project cost (TPC) range is $450,000,000 to $550,000,000, not including the MSU cost share. The amounts shown reflect the requested DOE appropriations only and do not incude the planned cost share from MSU.
[d] The TEC funding is for DOE's share of engineering and design activities only at this time.
[e] In addition to the TEC funding of $18,000,000 reflected for engineering and design in FY 2013, funding will be requested for construction in FY 2013 and the outyears and will be included upon CD-2 approval.
[f] The OPC funding is for DOE's share of R&D, conceptual design, and NEPA activities only at this time.
[g] The preliminary DOE total project cost (TPC) range is $450,000,000 to $550,000,000, not including the MSU cost share. The amounts shown reflect the requested DOE appropriations only and do not include the planned cost share from MSU.

Workforce Development for Teachers and Scientists

Funding Profile by Subprogram

(dollars in thousands)

	FY 2009 Current Appropriation	FY 2009 Current Recovery Act Appropriation[a]	FY 2010 Current Appropriation	FY 2011 Request
Workforce Development for Teachers and Scientists				
Student Programs	5,628	+12,500	13,078	22,700
Educator Programs	6,342	0	5,750	6,400
Program Administration and Evaluation	1,613	0	1,850	6,500
Total, Workforce Development for Teachers and Scientists	13,583	+12,500	20,678	35,600

Public Law Authorizations:
Public Law 95–91, "Department of Energy Organization Act of 1977"
Public Law 101–510, "DOE Science Education Enhancement Act of 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 contribute to the national effort that will ensure that DOE and the Nation have a sustained pipeline of highly skilled and diverse science, technology, engineering, and mathematics (STEM) workers.

Background

DOE and its predecessor organizations have a 60-year history of training and educating scientists, mathematicians, and engineers in the U.S. These highly skilled workers are a key element of the Department's research enterprise and are supported through research grants and contracts at universities, the DOE national laboratories, and the private sector. This commitment to supporting the Nation's scientific and technical workforce has produced tens of thousands of leading scientists, engineers, and technicians who have dedicated their careers to solving national security, energy, and environmental challenges, while pursuing answers to many of the most important scientific questions in physics, chemistry, biology, and other areas of basic science.

DOE's 17 national laboratories provide tremendous opportunities and resources for STEM training and education. The national laboratory system offers a unique learning environment with access to world-class scientists who serve as research mentors to students and access to cutting-edge scientific instrumentation and facilities unavailable at universities or industry. On an annual basis, more than 250,000 K–12 students, 22,000 K–12 educators, 4,000 undergraduate interns, 3,000 graduate students, and 1,600 post-doctoral employees participate in education or training programs at the DOE national laboratories.

[a] The Recovery Act Appropriation column reflects the allocation of funding as of September 30, 2009.

WDTS leverages the unique capabilities at DOE's national laboratories to sponsor workforce training and education programs that motivate students and educators to pursue careers that will contribute to the Office of Science's mission in discovery science and science for national need. WDTS programs build a sustained pipeline for individuals to pursue STEM fields by rewarding and recognizing students from middle school through graduate school for their participation in science and technology in areas of importance to the Office of Science and to DOE. WDTS has launched the DOE Office of Science Graduate Fellowship Program to support U.S. graduate students pursuing degrees in areas of basic science and engineering important to the DOE mission and increased its support for undergraduate internships.

WDTS encourages the participation of under-represented populations at Minority Serving Institutions (MSIs) and other under-represented institutions through the WDTS Faculty and Student Teams (FaST) and Science Undergraduate Laboratory Internship (SULI) programs. Recruitment for minorities and women is strengthened through the building of partnerships with women and minority-serving scientific professional societies.

Subprograms

WDTS is organized into 3 subprograms: Student Programs, Educator Programs, and Program Administration and Evaluation.

- *Student Programs* focuses on encouraging middle school through graduate students to enter STEM careers and retaining them in the scientific and technical workforce.
- *Educator Programs* focuses on professional development experiences for middle school, high school, community college, and undergraduate educators.
- *Program Administration and Evaluation* develops and deploys evaluation methods for WDTS programs, provides the framework for developing outreach programs to public and private sector organizations, and supports the federal Science of Science Policy (SoSP) initiative.

Benefits

WDTS programs provide students and educators a pathway to STEM careers in scientific disciplines relevant to DOE's mission in energy, environment, national security, and scientific discovery, as well as careers at the Department and its national laboratories. These initiatives benefit society and promote the long-term health of our Nation by improving the STEM content knowledge of U.S. students, increasing the skills and capabilities of STEM educators, and creating a skilled and diverse scientific and technical workforce ready for high-wage job opportunities in emerging technical fields such as sustainable energy production.

WDTS programs provide students with the tools and knowledge needed to make an informed choice about STEM education and career options. Competitions, internships, fellowships, and other activities are designed to introduce students to world class scientific content and research environments. Students engage in science directly tied to societal challenges, such as energy and climate change.

Program Planning and Management

In FY 2010, the WDTS program planning and management activities were restructured to include:

- Rigorous evaluation of all WDTS programs, including a longitudinal workforce study and the development of six leading indicators that drive program improvement efforts: quality, scientific and technical content knowledge, leverage, competition with reward, retention, and diversity.

- Expansion of efforts to provide STEM professional development opportunities for undergraduate faculty as a way to increase the participation of under-represented minorities and women in DOE programs.
- Continued implementation of the DOE Office of Science Graduate Fellowship program in FY 2010–2011 through the addition of a second cohort of Fellows.

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), and other Federal agencies to develop interagency efforts in science education.

In FY 2010, the WDTS program will be reviewed by a Committee of Visitors (COV). The Basic Energy Sciences Advisory Committee (BESAC) has been charged to commission a COV subcommittee to examine WDTS business processes for their effectiveness and efficiency. The COV will also assess the quality of the WDTS portfolio, including its breadth and depth and national and international standing. The Office of Science conducts COV reviews of major programs every three years to ensure program quality.

Coordination of Education/Workforce Development Activities

WDTS coordinates with other DOE program offices to develop workforce and science education efforts. These efforts leverage existing WDTS capabilities and resources, particularly those developed within the DOE national laboratory system. WDTS has established several programs and supporting infrastructure dedicated to STEM education and workforce efforts (an online application system, outreach efforts, etc.) that have generated interest throughout the agency. As a result, other DOE programs often consult with WDTS as they launch new efforts or propose partnerships that leverage resources.

In FY 2009, WDTS worked with several programs as they developed workforce training and education initiatives. For example, the Office of Energy Efficiency and Renewable Energy (EERE) was encouraged to hire an Einstein Fellow to provide needed educational technical expertise for their efforts; the National Nuclear Security Administration (NNSA) consulted with WDTS as they developed a Faculty and Student Teams effort; and the Office of the Chief Human Capital Officer consulted with WDTS as they developed a STEM outreach effort in California.

In addition, WDTS provides support for K–12 educator professional development and undergraduate internship opportunities 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

In FY 2011, WDTS increases funding for the DOE Office of Science Graduate Fellowship program to support a second cohort of students who will pursue advanced science and engineering degrees in fields of basic research relevant to the DOE mission. Fellowships are awarded on a competitive basis and each award is for a period of three years contingent on the Fellow’s progress.

Funding in Evaluation Studies is increased in FY 2011 to support the federal Science of Science Policy initiative focused on developing improved data, tools, and methods to assess the effectiveness of investments in science.

WDTS increases funding for the Academies Creating Teacher Scientists (ACTS) as part of an overall strategy to expand research and training opportunities and efforts to provide scientific and technical content to diverse and under-represented populations. Support for the FaST, Community College Institutes (CCI), Outreach, and Workforce Studies programs is also maintained in FY 2011.

Student Programs

Funding Schedule by Activity

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Student Programs			
Science Undergraduate Laboratory Internship	3,009	4,000	4,150
Community College Institute of Science and Technology	266	800	600
Pre-Service Teachers	220	428	450
National Science Bowl®	2,033	2,350	2,100
High School Engineering	0	500	400
DOE Office of Science Graduate Fellowship	100	5,000	15,000
Total, Student Programs	5,628	13,078	22,700

Description

The Student subprogram encourages and enables students from middle school through graduate school to pursue education and training, and ultimately career interests, in science, mathematics, and engineering important to the Office of Science and DOE mission.

Through the National Science Bowl®, WDTS provides experiences to inspire middle and high school students to continue and focus on STEM education and careers. Undergraduate students are provided with mentor-intensive research opportunities at the DOE national laboratories to enhance content knowledge in science and mathematics, while also developing investigative expertise. The DOE Office of Science Graduate Fellowship (DOE SCGF) program sponsors fellowships for talented students pursuing advanced degrees in areas of basic research important to the DOE mission.

Selected FY 2009 Accomplishments

- FY 2009 program evaluation validated 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 confirmed the WDTS approach to STEM workforce development, which relies heavily upon mentored research experiences.
- WDTS sponsored the second annual Science and Energy Research Challenge (SERCh) in November 2009: a rigorous scientific poster competition for undergraduate students participating in DOE research projects at the national laboratories and universities. This competition highlighted the extraordinary quality of research and exposed the faculty at their home institutions to DOE and the research enterprise it supports. One hundred undergraduate students and 45 supporting faculty participated in this competition.
- In FY 2009, WDTS, partnering with the California State University (CSU) system, helped support 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

for K-12 educators. Forty pre-service educators supported by CSU participated in the second year of the implementation of the model which, through evaluation, has proven successful in its goals.

- Evaluations performed on 600 scientific abstracts produced by undergraduate students confirm that these WDTS-supported students are participating in highly technical research projects under the close supervision of a senior laboratory scientist. The evaluations also provide a leading indicator that WDTS undergraduate programs are succeeding in their goal of promoting effective mentor/protégé relationships.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Science Undergraduate Laboratory Internship	**3,009**	**4,000**	**4,150**

Science Undergraduate Laboratory Internship (SULI) supports a diverse group of students at DOE's National Laboratories in individually mentored research experiences. Students 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 on science careers and how to become part 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 published annually with 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. 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.

In FY 2009, a total of 341 SULI students were supported by WDTS. An additional 35 students were sponsored by NSF. WDTS will support an estimated 570 SULI students in FY 2010 and 590 students in FY 2011. In FY 2010, 100 of these undergraduates will be paired with college faculty as part of the WDTS Faculty and Student Teams (FaST) program. In FY 2011, 120 of these SULI undergraduates will participate in FaST.

Community College Institute of Science and Technology	**266**	**800**	**600**

The Community College Institute (CCI) of Science and Technology, which provides a 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 and scientific instrumentation. CCI students spend an intensive 10–16 weeks working under the individual mentorship of resident scientists, produce an abstract and formal research paper, and attend professional enrichment activities, workshops, and seminars on career options and how to become part 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 student abstracts.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

In FY 2009, 52 students directly participated in this internship. Eleven additional students were sponsored by NSF. WDTS will support an estimated 115 CCI students in FY 2010 and 85 students in FY 2011.

Pre-Service Teachers	**220**	**428**	**450**

The Pre-Service Teachers (PST) program, a partnership with NSF, 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 during the first five years). Students spend an intensive 10 weeks working under the mentorship of a master teacher and a DOE laboratory scientist to help maximize the building of content knowledge and skills through the research experience. They also produce an abstract and educational module related to their research; 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. Goals and outcomes are measured based on students' abstracts, education modules, pre- and post-surveys, and external evaluation.

In FY 2009, 6 DOE national laboratories hosted 29 participating students. In FY 2010, WDTS funding supports 60 students and 7 master teachers at 7 DOE national laboratories. In FY 2011, the increase in funding will support 63 students and 7 master teachers at 7 DOE national laboratories.

National Science Bowl®	**2,033**	**2,350**	**2,100**

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, and encourages the voluntary participation of more than 7,000 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.

In its 20-year history (1991–2010), more than 250,000 students from across the Nation have participated in regional and national competitions and have been encouraged to pursue careers in mathematics and science. 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 2011, 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 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 the national competition in recent years. About 22,000 middle and high school students participate at the regional and national competitions each year, along with more than 7,000 coaches and volunteers.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
High School Engineering	**0**	**500**	**400**

The High School Engineering activity (formerly the Real World Design Challenge [RWDC]) originated out of the National Science Bowl® high school engineering competition. The National Science Bowl® focuses on basic research knowledge, but for 5 years high school students also participated in an engineering challenge (typically a model fuel cell car event) as part of the competition. In FY 2010, WDTS is reviewing options to determine the most effective way to promote engineering education at the high school level, focusing on the sciences and technologies sponsored by DOE. Emphasis will be made on increasing under-represented population participation.

DOE Office of Science Graduate Fellowship	**100**	**5,000**	**15,000**

WDTS is implementing the DOE Office of Science Graduate Fellowship (DOE SCGF) program in FY 2010 with an initial cohort of approximately 160 graduate students. Approximately 80 graduate student fellowships are being supported through funding provided by the Recovery Act, and an additional 80 students are being supported by FY 2010 appropriated funds. The goal of the Fellowship is to encourage talented students to pursue research-focused graduate studies in physics, chemistry, biology, mathematics, computer science, engineering, and environmental science—areas of basic research important to the DOE mission. Applicants must be U.S. citizens pursing graduate studies at a U.S. accredited college or university. Awards are competitively selected on the basis of merit review of applications against established merit review criteria. The Fellowship provides up to three years of support for a graduate student, including a stipend for tuition and fees, an annual stipend for living expenses, and a research stipend that can be used for costs associated with the student's research and for travel to conferences and DOE scientific user facilities.

Program evaluation will include pre- and post-surveys of students, as well as longitudinal studies that determine whether students continue to pursue careers in scientific and technical fields. The FY 2011 funding will support a new cohort of 170 graduate fellows, creating a total of two cohorts (including fellows supported by Recovery Act funding) of 330 fellows.

Total, Student Programs	**5,628**	**13,078**	**22,700**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Science Undergraduate Laboratory Internship	
The number of students participating in this program increases by 20 in FY 2011, from 570 in FY 2010 to a total of 590 in FY 2011.	+150
Community College Institute of Science and Technology	
The number of students participating in this program decreases by 30 from 115 in FY 2010 to 85 in FY 2011.	-200

	FY 2011 vs. FY 2010 ($000)
Pre-Service Teachers	
The number of students participating in this program increases by 3 in FY 2011, from 60 in FY 2010 to 63 students.	+22
National Science Bowl®	
Support is decreased due to lower costs associated with kits needed for the middle school solar car competition.	-250
High School Engineering	
Support is decreased due to a restructuring of WDTS support for the former Real World Design Challenge activity.	-100
DOE Office of Science Graduate Fellowship	
A new cohort of 170 Fellows will be funded in FY 2011, joining the first cohort of 80 from FY 2010 and 80 supported by the Recovery Act.	+10,000
Total Funding Change, Student Programs	**+9,622**

Educator Programs

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Educator Programs			
Academies Creating Teacher Scientists	4,130	3,750	4,200
Faculty and Student Teams	1,212	1,000	1,200
Albert Einstein Distinguished Educator Fellowship	1,000	1,000	1,000
Total, Educator Programs	6,342	5,750	6,400

Description

Improving the ability of educators at all levels to serve as mentors and teach science content is one of the most effective ways to increase the size and quality of the STEM workforce. Mentored laboratory research experiences are an effective approach to meet this goal. WDTS has built programs at the K–12 and undergraduate levels that focus on increasing educator knowledge of DOE science and technology content, programs and missions, providing them with the resources that enable them to be successful in the classroom. The Academies Creating Teacher Scientists (ACTS) program is the platform from which WDTS launches its long-term relationships with K–12 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. The Albert Einstein Distinguished Educator Fellowship benefits Federal agencies and Congressional offices because these outstanding educators provide their real-world classroom expertise and advice to national policy makers.

Selected FY 2009 Accomplishments

- ACTS participants in FY 2009 reported in evaluation surveys that their content knowledge in physics, chemistry, and geophysics increased by more than 20%, on average: a key indicator that the program is succeeding in embedding key science content into K–12 classrooms.
- In FY 2009, WDTS significantly increased support for students and faculty through the FaST program, enabling an additional 30 faculty and 120 students from under-represented institutions to participate in mentored research projects at DOE national laboratories. Faculty and students reported in evaluation surveys that their scientific content knowledge, ability to conduct research, and understanding of how to pursue a research career increased as a result of the FaST experience.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Academies Creating Teacher Scientists	**4,130**	**3,750**	**4,200**

ACTS requires a 3-year commitment by educators to participate in this program. Each educator spends an intensive 4–8 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

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

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. Participants receive an $800 per week stipend plus travel and housing expenses while at DOE national laboratories.

The program includes self-identification of science content gaps by the educator participant, pre- and post-surveys that benchmark the progress of each participant, and a requirement for successful development of a professional development plan by each educator. Program impact is determined through review of the surveys and development plans, national laboratory self-appraisals, evaluation of impact on local STEM education and student achievement, and the ultimate retention of the educators in STEM K–12 education.

DOE ACTS funded 229 educators in FY 2009 and will fund 212 educators (140 continuing and 72 new) and 14 master teachers in FY 2010. The FY 2011 request funds a total of 238 educators (212 continuing and 26 new) and provides master teachers at each participating laboratory.

Faculty and Student Teams	**1,212**	**1,000**	**1,200**

Faculty and Student Teams (FaST) provides an opportunity for faculty and students from under-represented 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 research programs and student cohorts who accompany the faculty member and participate in a mentored research effort. FaST activities at DOE national laboratories are also being conducted in collaboration with the NSF.

Surveys and other evaluation studies have revealed that faculty support of students at the DOE 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 MSIs to build faculty research capabilities, encourages cohorts of diverse students to participate in DOE research, and improves the retention and recruitment of under-represented populations in the DOE system.

Beginning in FY 2010, all of the undergraduate students participating in FaST are supported on FaST teams will instead be supported through the SULI and CCI programs. The FaST budget request supports faculty participation. WDTS will support 50 faculty in FY 2010 and will support at least 60 faculty in FY 2011.

Albert Einstein Distinguished Educator Fellowship	**1,000**	**1,000**	**1,000**

The Albert Einstein Distinguished Educator Fellowship for K–12 STEM 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 also a valuable professional development opportunity for the educators because they return to the education field with knowledge of Federal programs and resources and an improved understanding of national education policies.

WDTS manages the Einstein Fellowship on behalf of the Federal government and encourages participation by other Federal agencies. In FY 2010, a total of 23 fellows participated in the program:

(dollars in thousands)

	FY 2009	FY 2010	FY 2011

3 fellows at DOE, 4 in Congress, and 16 at other Federal agencies, including NSF, NASA, NOAA, and NIH. Of these, 6 were directly supported by WDTS.

Evaluation of the Einstein Fellowship program is conducted through longitudinal surveys of past participants, surveys of current participants, and reviews by external experts.

The FY 2011, WDTS request will directly support 6 fellows. The funding will also augment stipends and health insurance for the participants.

Total, Educator Programs	**6,342**	**5,750**	**6,400**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Academies Creating Teacher Scientists	
The number of educators participating in DOE ACTS increases by 26 in FY 2011, from 212 in FY 2010 to 238.	+450
Faculty and Student Teams	
The number of faculty supported by DOE increases by 10 in FY 2011, from 50 in FY 2010 to 60 in FY 2011.	+200
Total Funding Change, Educator Programs	**+650**

Program Administration and Evaluation

Funding Schedule by Activity

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Program Administration and Evaluation			
Laboratory Equipment Donation Program	75	240	200
Evaluation Studies	220	200	5,200
Technology Development and On-Line Application	441	400	300
Outreach	302	610	400
Workforce Studies	575	300	300
Mentor Program	0	100	100
Total, Program Administration and Evaluation	1,613	1,850	6,500

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 to ensure the efficiency and effectiveness of WDTS programs. Non-financial resources, such as laboratory equipment and 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, the private sector, and other Federal agencies designed to fully leverage the WDTS investment in workforce development and STEM education programs.

Selected FY 2009 Accomplishments

- WDTS developed a consistent evaluation effort in FY 2009 that aligned programmatic goals to 6 leading indicators of success (retention, diversity, quality, content knowledge, competition with reward, and leveraging) and enabled WDTS to set uniform expectations for program management and success. A rigorous review process of undergraduate research abstracts was undertaken in FY 2009 that revealed inconsistencies in program management of the flagship SULI program and led to program changes, such as new scoring rubric for scientific abstracts, to improve the overall quality of the abstracts and effectiveness of the SULI, CCI, and PST programs.
- WDTS implemented a competitive solicitation process in FY 2009 for all of WDTS's DOE national laboratory-based programs, linked to WDTS's 6 leading indicators and overall evaluation processes. The result is an allocation of WDTS resources in FY 2010 that will be tied to program effectiveness at the DOE National Laboratories.
- In FY 2009, WDTS, in partnership with the DOE Office of Scientific and Technical Information (OSTI), successfully piloted the *ScienceEducation.gov* web portal, which provides a single location for students and faculty to identify content, experiments and other materials that originate from WDTS and the DOE national laboratories. The new website utilizes "web 2.0" technology to identify best practices based on community views and also utilizes a sophisticated new search protocol that enables students and educators to identify content by grade level based on state standards.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Laboratory Equipment Donation Program	**75**	**240**	**200**

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. 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. In FY 2009, more than 400 individual pieces of surplus scientific equipment from DOE national laboratories with an original value of more than $9,000,000 were donated to U.S. universities through the Laboratory Equipment Donation Program.

WDTS expanded this program in FY 2010 to middle schools and high schools and will pay for shipping costs to those institutions.

Evaluation Studies	**220**	**200**	**5,200**

In FY 2011, the Office of Science will initiate a research program to assess the effectiveness of investments in science, consistent with the federal interagency Science of Science Policy (SoSP) initiative. The Office of Science has worked closely with the Office of Science and Technology Policy, the National Science Foundation and other Federal agencies in the development of the SoSP effort, including the development of *The Science of Science Policy: A Federal Research Roadmap*, published in November 2008, and partnering in several community workshops. Research awards in FY 2011 will be competitively awarded on the basis of peer review.

Technology Development and On-Line Application	**441**	**400**	**300**

Technology Development and Online-Application Systems provides for a new IT architecture, which is a 3-year endeavor, to enhance and maintain the WDTS application and electronic portfolio system. Funding in FY 2011 will support the third year of the new design of all of the websites, on-line applications, DOE ACTS education portfolios, Graduate Fellowship, and pre- and post-surveys that participants complete during their internship/fellowship experiences.

Outreach	**302**	**610**	**400**

Outreach provides information to WDTS program alumni (from competitions, undergraduate research internships, educator programs, etc.) to encourage their continued participation in WDTS programs; creates a common database of internship opportunities, fellowships, and other research-based educational opportunities offered by WDTS; assists in the coordination of outreach activities with other Federal agencies; and enhances communication about WDTS programs to the public. A major emphasis of the outreach effort is to increase the participation of under-represented groups and institutions in WDTS programs. WDTS has established relationships with major associations representing under-represented groups and has been working with other Federal agencies, including NSF, to develop cooperative programs that leverage WDTS funds. This enables WDTS to maintain outreach efforts despite reduced funding.

	FY 2009	FY 2010	FY 2011
	(dollars in thousands)		
Workforce Studies	**575**	**300**	**300**

Workforce Studies focus on the critical skill gaps, by scientific discipline, which may exist within the Office of Science Federal and national laboratory workforces. These studies are designed to be long-term sustained efforts that provide a baseline of data to effectively manage WDTS programs and set overall strategic direction. Full implementation in FY 2009–2010 will provide in-depth and systematic reviews of workforce requirements and help determine the long-term benefits of WDTS program investments by tracking the progress of STEM students and workers who participate in WDTS programs.

Mentor Program	**0**	**100**	**100**

The Mentor Program is implemented in FY 2010 and has two components: a professional development effort designed to recruit and train 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 for WDTS programs and must be nurtured in a systematic manner to ensure a sufficient supply of mentors.

Total, Program Administration and Evaluation	**1,613**	**1,850**	**6,500**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Laboratory Equipment Donation Program	
FY 2010 included a one-time increase to expand the program to high-need middle and high schools.	-40
Evaluation Studies	
Increased funding supports participation in the federal interagency Science of Science Policy initiative.	+5,000
Technology Development and On-Line Application	
A major development effort for WDTS on-line technologies occurred from FY 2009–2010 and will be completed in FY 2011. Funding reflects the level of development activity needed to complete the project and sustain the WDTS technology investments.	-100
Outreach	
Cooperative programs with other federal agencies leverage WDTS funding.	-210
Total Funding Change, Program Administration and Evaluation	**+4,650**

Supporting Information

Operating Expenses, Capital Equipment and Construction Summary

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Operating Expenses	13,583	20,678	35,600

Science Laboratories Infrastructure

Funding Profile by Subprogram

(dollars in thousands)

	FY 2009 Current Appropriation	FY 2009 Current Recovery Act Appropriation[a]	FY 2010 Current Appropriation	FY 2011 Request
Science Laboratories Infrastructure				
Infrastructure Support	31,308	+103,873	6,599	6,645
Construction	114,072	+94,241	121,001	119,355
Total, Science Laboratories Infrastructure	145,380	+198,114	127,600	126,000

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 Science Laboratories Infrastructure (SLI) program mission is to support scientific and technological innovation at the 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. SLI also supports SC stewardship responsibilities for the Oak Ridge Reservation and the Federal facilities in the city of Oak Ridge, and provides Payments in Lieu of Taxes to local communities around the Argonne, Brookhaven, and Oak Ridge National Laboratories.

Background

In FY 2009, SC began an initiative to revitalize SC laboratories over ten years, with the goal of providing the modern laboratory infrastructure needed to deliver the advances in science the Nation requires to remain competitive in the 21st century. Through this initiative, SC is ensuring that SC laboratories have state-of-the-art facilities and utilities that are flexible, reliable, and sustainable, with environmentally stable research space and high performance computing space needed to support scientific discovery. New and renovated buildings and utilities will include the latest temperature and humidity controls, clean power, and isolation from vibration and electromagnetic interference where needed. Facility designs will ensure collaborative and interactive work environments and allow for the integration of basic and applied research and development. Once modernized, SC infrastructure will also aid in the recruitment and retention of the "best and brightest" to work at world-class laboratories.

Despite past investments in infrastructure, 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 described above. The Infrastructure Modernization Initiative will provide capital investment through the SLI program to make these needed improvements. The goals of the Infrastructure Modernization Initiative are to:

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[a] The Recovery Act Current Appropriation column reflects the allocation of funding as of September 30, 2009.

- Provide the modern laboratory infrastructure needed to deliver advances in science the 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 and 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 construction projects under the Infrastructure Modernization Initiative.

Benefits

The modern, safe, and environmentally-friendly laboratories provided by the SLI program will facilitate break-through discoveries for America's future. Accelerated demolition of inadequate facilities, including the Bevatron at Lawrence Berkeley National Laboratory, will remove safety and environmental hazards. Construction creates jobs that will benefit the manufacturing, transportation (freight), and construction industries. Subsequent research and development in these revitalized facilities will facilitate discovery of new technologies, expected to result in long-term economic growth and job creation in the American economy.

Budget Overview

The primary focus of the SLI budget is the ongoing Infrastructure Modernization. Ongoing line-item projects are continued and two new projects are initiated. 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 Infrastructure Modernization Initiative will be funded with laboratory overhead. With final funding of the Bevatron in FY 2009 under the Recovery Act, funding for the EFD activity has been discontinued in FY 2010.

Infrastructure Support

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Infrastructure Support			
Excess Facilities Disposition	24,844	0	0
Oak Ridge Landlord	5,079	5,214	5,260
Payments in Lieu of Taxes	1,385	1,385	1,385
Total, Infrastructure Support	31,308	6,599	6,645

Description

The Infrastructure Support subprogram provides SC stewardship responsibilities for the Oak Ridge Reservation and the Federal facilities in the city of Oak Ridge, and Payments in Lieu of Taxes (PILT) to local communities around the Argonne, Brookhaven, and Oak Ridge National Laboratories. In the past, the subprogram provided operating funds for the cleanup and removal of excess facilities at SC laboratories.

Selected FY 2009 Accomplishments

- *Continued demolition of the Building 51 and Bevatron Demolition Project at Lawrence Berkeley National Laboratory*. The project is eliminating 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. In FY 2009, the project completed isolation of utility systems feeding the structures to be demolished, removed hazardous materials (asbestos, lead dust, and depleted uranium), decontaminated surface radioactive materials present in the facility, and began removal and disposal of shielding blocks (about 13,000 tons of concrete).

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Excess Facilities Disposition (EFD)	**24,844**	**0**	**0**

Final funding for the Building 51 and Bevatron Demolition Project was provided in FY 2009. Cleanup and removal of future excess facilities at SC sites will be funded by laboratory overhead, via line-item construction projects, or by the Office of Environmental Management.

Oak Ridge Landlord	**5,079**	**5,214**	**5,260**

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 city of Oak Ridge. Supported activities include maintenance of roads, grounds and other infrastructure, support and improvement of environmental protection, safety and health, PILT to Oak Ridge communities, and other needs related to landlord responsibilities. These activities

	FY 2009	FY 2010	FY 2011
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)	**1,385**	**1,385**	**1,385**
Provides PILT to support assistance requirements for communities around the Argonne and Brookhaven National Laboratories. PILT payments are negotiated between the Department and local governments based on land values and tax rates.			
Total, Infrastructure Support	**31,308**	**6,599**	**6,645**

(dollars in thousands)

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Oak Ridge Landlord	
Increase to support reservation road repairs and other critical maintenance needs.	+46
Total Funding Changes, Infrastructure Support	**+46**

Construction

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Construction			
Utilities Upgrade at FNAL (11-SC-70)	0	0	7,524
Utility Infrastructure Modernization at TJNAF (11-SC-71)	0	0	7,828
Research Support Building and Infrastructure Modernization at SLAC (10-SC-70)	0	6,900	33,100
Energy Sciences Building at ANL (10-SC-71)	0	8,000	15,000
Renovate Science Laboratories, Phase II, at BNL (10-SC-72)	0	5,000	15,000
Seismic Life-Safety, Modernization, and Replacement of General Purpose Buildings, Phase II, at LBNL (09-SC-72)	12,495	34,027	20,103
Interdisciplinary Science Building, Phase I, at BNL (09-SC-73)	8,240	39,387	0
Technology and Engineering Development Facility at TJNAF (09-SC-74)	3,700	27,687	20,800
Modernization of Laboratory Facilities at ORNL (08-SC-71)	25,103	0	0
Physical Sciences Facility at PNNL (07-SC-05)	52,775	0	0
Science Laboratories Infrastructure Project (MEL-001)	11,759	0	0
Total, Construction	114,072	121,001	119,355

Description

The SLI Construction subprogram funds line item construction projects to maintain and enhance the general purpose infrastructure at SC laboratories. 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 Science Programs. Input is also solicited from the SC research program Associate Directors. Infrastructure Modernization Initiative investments are included in this subprogram and are focused on the accomplishment of long-term science goals and strategies at each SC laboratory.

Selected FY 2009 Accomplishments

- Significant progress was made on construction of the Physical Sciences Facility (PSF) at Pacific Northwest National Laboratory (PNNL). 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 2009, erection of structural steel and enclosure of the major new facilities was completed along with substantial progress on interior plumbing, HVAC, and electrical systems. The Documented Safety Analysis for the 325 Building, a category 2 nuclear facility that will be retained for continued use, was updated and the Safety Evaluation Report was approved. Safety performance on this project has been good, and the project is on track to meet its cost and schedule milestones.

- Construction began on a new chemical and materials science laboratory building at ORNL funded by the Modernization of Laboratory Facilities project. Construction is proceeding consistent with the project's cost and schedule baseline.
- A performance baseline for the renovation portion of the Seismic Life-Safety, Modernization, and Replacement of General Purpose Buildings, Phase II project at LBNL was established. The project received approval to start early demolition work in the existing Life Sciences building in preparation for modernizing this facility.
- Site preparation began in support of construction of the new Interdisciplinary Science Building at BNL.
- Three additional projects in the Infrastructure Modernization Initiative achieved approval of Critical Decision-1, Approve Alternative Selection and Cost Range. These projects will construct a new Research Support Building and renovate critical existing facilities at SLAC National Accelerator Laboratory, construct a new Energy Sciences Building at Argonne National Laboratory, and modernize the Physics and Chemistry buildings at Brookhaven National Laboratory.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Utilities Upgrade at FNAL (11-SC-70)	**0**	**0**	**7,524**

This project will upgrade the laboratory's industrial cooling water system and the high voltage electrical system. Both of these systems are critical for the current and future mission at the laboratory. System components are at the end of their design life and replacement parts are no longer available. FY 2011 funding will be used for Project Engineering and Design activities and to commence construction, including project management and associated support functions.

Utility Infrastructure Modernization at TJNAF (11-SC-71)	**0**	**0**	**7,828**

At TJNAF, the accelerator science core capability has an immediate need for investment to ensure the laboratory utilities infrastructure can continue to support the superconducting radio frequency mission in the research, development, and production of cryomodules. The project scope will include upgrades to the power distribution, cooling water, and communications systems. FY 2011 funding will be used for Project Engineering and Design activities and to commence construction, including project management and associated support functions.

Research Support Building and Infrastructure Modernization at SLAC (10-SC-70)	**0**	**6,900**	**33,100**

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 existing buildings onsite. FY 2010 funding is being used for Project Engineering and Design activities. FY 2011 construction funding will be used to commence construction activities, including project management and associated support functions.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Energy Sciences Building at ANL (10-SC-71)	**0**	**8,000**	**15,000**

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. FY 2010 funding is being used for Project Engineering and Design activities. FY 2011 construction funding will be used to commence construction activities, including project management and associated support functions.

Renovate Science Laboratories, Phase II, at BNL (10-SC-72)	**0**	**5,000**	**15,000**

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. FY 2010 funding is being used for Project Engineering and Design activities. FY 2011 construction funding will be used to commence construction activities, including project management and associated support functions.

Seismic Life-Safety, Modernization, and Replacement of General Purpose Buildings, Phase II, at LBNL (09-SC-72)	**12,495**	**34,027**	**20,103**

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). FY 2009 original and Recovery Act funding supported Project Engineering and Design activities, as well as early procurements and construction work. FY 2010 funds are being used for construction activities, project management, and support functions. FY 2011 funds will be used to continue construction activities, including project management and all associated support functions.

Interdisciplinary Science Building, Phase I, at BNL (09-SC-73)	**8,240**	**39,387**	**0**

This project at Brookhaven National Laboratory 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 includes demolition of offsetting space. FY 2009 original and Recovery Act funding supported Project Engineering and Design and early construction activities.

	FY 2009	FY 2010	FY 2011

(dollars in thousands)

FY 2010 funding for this project is being used to complete construction of the building, including project management and all associated support functions.

Technology and Engineering Development Facility at TJNAF (09-SC-74)	**3,700**	**27,687**	**20,800**

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 2009 funding was used for Project Engineering and Design activities. FY 2010 and FY 2011 funds will be used to commence and continue construction work, including project management and associated support activities.

Modernization of Laboratory Facilities at ORNL (08-SC-71)	**25,103**	**0**	**0**

Science operations of research groups housed in the ORNL 4500 Complex are affected by the functionality of the old, deteriorating building facilities. This project is constructing 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 FY 2009 original and Recovery Act funding for this project was used to complete construction of the building, including project management and all associated support functions. The project is on track to meet is performance baseline milestones, which include project completion in FY 2012.

Physical Sciences Facility at PNNL (07-SC-05)	**52,775**	**0**	**0**

This project is for the construction of new laboratory and office space on the PNNL site north of Horn Rapids Road and completion of life extension upgrades to the 325 Building to accommodate a portion of the existing research capabilities displaced as a result of the closure and cleanup of facilities in the Hanford 300 Area. The FY 2009 appropriation completed funding of the DOE portion of this project and is being used to continue project construction activities as well as facility start-up and readiness activities. The project is on track to meet its performance baseline milestones, which include project completion in FY 2011.

Science Laboratories Infrastructure Project (MEL-001)	**11,759**	**0**	**0**
▪ **OSTI Facility Improvements (MEL-001-052)**	**2,500**	**0**	**0**

The subproject provides critical roof replacement and upgrade of the fire safety protection system at the Office of Scientific and Technical Information (OSTI) facility in Oak Ridge, Tennessee housing DOE's historic and current paper and electronic collection of energy-related R&D results.

	FY 2009	FY 2010	FY 2011
▪ **Renovate Science Laboratory, Phase I, at BNL (MEL-001-050)**	**6,642**	**0**	**0**
This subproject upgrades and rehabilitates 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)**	**2,617**	**0**	**0**
This subproject addresses 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	**114,072**	**121,001**	**119,355**

(dollars in thousands)

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Utilities Upgrade at FNAL (11-SC-70)	
Project Engineering and Design and early construction activities are initiated.	+7,524
Utility Infrastructure Modernization at TJNAF (11-SC-71)	
Project Engineering and Design and early construction activities are initiated.	+7,828
Research Support Building and Infrastructure Modernization at SLAC (10-SC-70)	
Increased project funding per the preliminary Project Execution Plan.	+26,200
Energy Sciences Building at ANL (10-SC-71)	
Increased project funding per the preliminary Project Execution Plan.	+7,000
Renovate Science Laboratories, Phase II, at BNL (10-SC-72)	
Increased project funding per the preliminary Project Execution Plan.	+10,000
Seismic Life-Safety, Modernization, and Replacement of General Purpose Buildings, Phase II, at LBNL (09-SC-72)	
Decreased project funding per the preliminary Project Execution Plan.	-13,924
Interdisciplinary Science Building, Phase I, at BNL (09-SC-73)	
Funding was provided in FY 2010 to complete the project profile.	-39,387
Technology and Engineering Development Facility at TJNAF (09-SC-74)	
Decreased project funding per the preliminary Project Execution Plan.	-6,887
Total Funding Change, Construction	**-1,646**

Supporting Information

Operating Expenses, Capital Equipment, and Construction Summary

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Operating Expenses	31,208	6,499	6,545
General Plant Projects	100	100	100
Construction	114,072	121,001	119,355
Total, Science Laboratories Infrastructure	145,380	127,600	126,000

Construction Projects

(dollars in thousands)

	Prior Years	FY 2009	FY 2009 Recovery Act[a]	FY 2010	FY 2011	Outyears	Total
Utilities Upgrade at FNAL (11-SC-70)							
TEC	0	0	0	0	7,524	TBD	31,300–34,900
OPC[b]	0	0	0	1,100	0	0	1,100
TPC	0	0	0	1,100	7,524	TBD	32,400–36,000[c]
Utility Infrastructure Modernization at TJNAF (11-SC-71)							
TEC	0	0	0	0	7,828	TBD	24,300–29,200
OPC[b]	0	0	0	650	0	0	650
TPC	0	0	0	650	7,828	TBD	24,950–29,850[c]
Research Support Building and Infrastructure Modernization at SLAC (10-SC-70)							
TEC	0	0	0	6,900	33,100	TBD	80,000-96,000
OPC[b]	0	700	0	100	100	500	1,400
TPC	0	700	0	7,000	33,200	TBD	81,400–97,400[c]

[a] The Recovery Act 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.
[c] This project has not yet established a performance baseline. Cost and schedule estimates are preliminary.

(dollars in thousands)

	Prior Years	FY 2009	FY 2009 Recovery Act[a]	FY 2010	FY 2011	Outyears	Total
Energy Sciences Building at ANL (10-SC-71)							
TEC	0	0	0	8,000	15,000	TBD	84,500-95,000
OPC[b]	0	956	0	44	0	0	1,000
TPC	0	956	0	8,044	15,000	TBD	85,500–96,000[c]
Renovate Science Laboratories, Phase II, at BNL (10-SC-72)							
TEC	0	0	0	5,000	15,000	TBD	45,000-50,000
OPC[b]	0	737	0	63	0	0	800
TPC	0	737	0	5,063	15,000	TBD	45,800–50,800[c]
Seismic Life-Safety, Modernization, and Replacement of General Purpose Buildings, Phase II, at LBNL (09-SC-72)							
TEC	0	12,495	15,000	34,027	20,103	TBD	91,900-94,600
OPC[b]	1,945	309	0	2	104	120	2,480
TPC	1,945	12,804	15,000	34,029	20,207	TBD	94,380–97,080[c]
Interdisciplinary Science Building, Phase I, at BNL (09-SC-73)							
TEC	0	8,240	18,673	39,387	0	TBD	61,300-66,300
OPC[b]	500	0	0	0	0	0	500
TPC	500	8,240	18,673	39,387	0	TBD	61,800–66,800[c]
Technology and Engineering Development Facility at TJNAF (09-SC-74)							
TEC	0	3,700	0	27,687	20,800	20,013	72,200
OPC[b]	287	509	0	204	0	0	1,000
TPC	287	4,209	0	27,891	20,800	20,013	73,200
Modernization of Laboratory Facilities at ORNL (08-SC-71)							
TEC	9,329	25,103	60,568	0	0	0	95,000
OPC[ab]	1,100	100	0	0	100	0	1,300
TPC	10,429	25,203	60,568	0	100	0	96,300

[a] The Recovery Act Current 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.
[c] This project has not yet established a performance baseline. Cost and schedule estimates are preliminary.

(dollars in thousands)

	Prior Years	FY 2009	FY 2009 Recovery Act[a]	FY 2010	FY 2011	Outyears	Total
Physical Sciences Facility at PNNL (07-SC-05)							
TEC/TPC	45,669	52,775	0	0	0	0	98,444
Science Laboratories Infrastructure Project (MEL-001)							
TEC/TPC	17,472	11,759	0	0	0	0	29,231
Total, Construction							
TEC		114,072	94,241	121,001	119,355		
OPC[b]		3,311	0	2,163	304		
TPC		117,383	94,241	123,164	119,659		

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 $5,000,000 in FY 2011 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 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.

The following displays IGPP funding by site:

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Argonne National Laboratory	9,395	7,000	7,400
Brookhaven National Laboratory	5,720	7,059	7,306
Lawrence Berkeley National Laboratory	4,100	4,100	4,500
Oak Ridge National Laboratory	18,118	20,000	23,000
Pacific Northwest National Laboratory	2,000	5,000	5,000
SLAC National Accelerator Laboratory	1,000	1,000	1,000
Total IGPP	40,333	44,159	48,206

Facilities Maintenance and Repair

General purpose 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 1,400 operational buildings and real property trailers, with nearly 20 million gross square feet of space. The Department's facilities maintenance and repair activities are tied

[a] The Recovery Act Current 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.

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, the cost of these activities is allocated to 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 2009	FY 2010	FY 2011
Ames Laboratory	1,031	1,060	1,088
Argonne National Laboratory	31,402	31,402	36,433
Brookhaven National Laboratory	31,492	35,182	35,741
Fermi National Accelerator Laboratory	9,668	13,717	14,577
Lawrence Berkeley National Laboratory	17,800	20,300	21,700
Lawrence Livermore National Laboratory	2,563	2,614	2,666
Los Alamos National Laboratory	111	113	115
Oak Ridge Institute for Science and Education	381	334	341
Oak Ridge National Laboratory	41,053	41,997	42,921
Oak Ridge National Laboratory facilities at Y-12	588	602	615
Pacific Northwest National Laboratory	1,215	6,943	8,163
Princeton Plasma Physics Laboratory	5,813	6,392	6,611
Sandia National Laboratories	2,402	2,450	2,499
SLAC National Accelerator Laboratory	4,881	6,745	7,099
Thomas Jefferson National Accelerator Facility	3,540	3,700	3,855
Total, Indirect-Funded Maintenance and Repair	153,940	173,551	184,424

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. One example would be 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.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Brookhaven National Laboratory	3,337	2,419	3,560
Fermilab National Accelerator Facility	113	113	123
Notre Dame Radiation Laboratory	157	160	169
Oak Ridge National Laboratory	18,507	18,933	19,349
Oak Ridge Office	4,994	5,213	5,071
Office of Scientific and Technical Information	338	355	364
SLAC National Accelerator Laboratory	9,092	6,583	8,266
Thomas Jefferson National Accelerator Facility	57	59	61
Total, Direct-Funded Maintenance and Repair	36,595	33,835	36,963

Deferred Maintenance Backlog Reduction

The total deferred maintenance backlog at the end of FY 2009at SC sites is estimated to be $489,000,000. SC is working to reduce the backlog of deferred maintenance at its laboratories. The table below shows the expected deferred maintenance reduction funding from laboratory overhead except for the Oak Ridge Reservation, which is direct funded. These funding amounts are included in the previous tables on direct and indirect funded maintenance.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Brookhaven National Laboratory	5,374	10,900	10,600
Lawrence Berkeley National Laboratory	2,500	2,000	3,000
Oak Ridge Institute for Science and Education	40	40	40
Oak Ridge Office	1,000	1,000	500
Princeton Plasma Physics Laboratory	177	340	300
Total, Deferred Maintenance Backlog Reduction	9,091	14,280	14,440

The primary strategy for reducing deferred maintenance is SC’s 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. These reductions are not included in the table above, nor does the table include reductions resulting from IGPP, GPP and programmatic line items.

11-SC-70, Utilities Upgrade,
Fermi National Accelerator Laboratory, Batavia, Illinois
Project Data Sheet is for PED/Construction

1. Significant Changes

The most recent DOE O 413.3A approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on September 18, 2009. The anticipated preliminary Total Estimated Cost (TEC) range for this project is $31,300,000–$34,900,000.

A Federal Project Director at the appropriate level has been assigned to this project.

This Project Data Sheet is new for PED/Construction.

2. Design, Construction, and D&D Schedule

(fiscal quarter or date)

	CD-0	CD-1	PED Complete	CD-2	CD-3	CD-4	D&D Start	D&D Complete
FY 2011[a]	9/18/2009	TBD	TBD	TBD	TBD	TBD	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

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 2011	4,450	TBD	TBD[b]	1,100	TBD	1,100	TBD[b]

4. Project Description, Justification, and Scope

Maintaining a dependable base from which science programs can be accomplished is dependent on robust, redundant, maintainable, and flexible utility systems. The backbone of Fermilab's utility systems is its Industrial Cooling Water (ICW) and High Voltage Electrical (HV) systems. Without these systems, science at Fermilab cannot exist. This project will upgrade both of these systems.

The ICW system consists of ponds, pumping stations, and approximately 72,000 feet of underground network piping, supplying process cooling and fire protection water throughout the laboratory's 6,800 acre site. As most of the system was installed during the construction of the lab almost 40 years ago, most components of the system have reached the end of their useful life. The fragile state of the piping and valves currently in service, reduction in flows by biofouling as well as frequent pipe failures

[a] This project is pre-CD-2 and schedules are preliminary. Construction funds will not be executed without appropriate CD approvals.
[b] This project is pre-CD-2 and cost estimates are preliminary. The TEC range for this project is $31,300,000 to $34,900,000. The Total Project Cost (TPC) range for this project is $32,400,000 to $36,000,000.

jeopardize the reliability and maintainability of the ICW system. The current state of the system requires frequent and unscheduled repairs which are complicated by insufficient and often malfunctioning isolation valves, enlarging the disabled area being repaired. Reliable process cooling and fire protection water service cannot be provided to current accelerator and experimental facilities areas as well as those areas slated for development of future facilities unless substantial re-investment in the lab's ICW system is provided.

The high voltage electrical system consists of substations, switches, and transformers. Various elements of the high voltage distribution system are rated as poor based on their current condition, are unreliable, and will continue to deteriorate with age. Future science at Fermilab is dependent upon a robust, redundant, maintainable, and flexible high voltage electrical distribution system for both programmatic and conventional power needs. The master substation and numerous oil switches and transformers across the site were installed during the original construction of the laboratory in the early 1970's. Much of this equipment is now beyond its useful life, and substantial reinvestment in this system is required for continued science in support of the Fermilab mission.

This project will upgrade and expand these utilities to provide a reliable and flexible base to serve existing facilities and provide the backbone from which future projects will build to serve new facilities. This will establish a stable base from which to serve both programmatic and conventional requirements across the site. A detailed alternatives analysis using life-cycle costs will be conducted prior to CD-1. 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 Assetsand all appropriate project management requirements have been met. FY 2010 OPC funds, funded through laboratory overhead, are being used to complete the conceptual design in preparation for CD-1. FY 2011 PED funds will be used to complete preliminary and final designs for all aspects of the project. The total design period for this project is expected to be significantly less than 18 months. FY 2011 construction funds are being requested because the scope of the project is straight forward and the design duration will be short, thereby permitting transition to construction during the same fiscal year. FY 2011 construction funds will be used for procurement of long lead items and to start construction work as well as for project management and support activities.

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs
Total Estimated Cost (TEC)			
PED[a]			
FY 2011	4,450	4,450	4,450
Total, PED	4,450	4,450	4,450
Construction			
FY 2011	3,074	3,074	1,000
Outyears	TBD	TBD	TBD
Total, Construction	TBD	TBD	TBD
TEC			
FY 2011	7,524	7,524	5,450
Outyears	TBD	TBD	TBD
Total, TEC[b]	TBD	TBD	TBD
Other Project Cost (OPC)[c]			
OPC except D&D			
FY 2010	1,100	1,100	1,100
Total, OPC except D&D	1,100	1,100	1,100
Total Project Cost (TPC)			
FY 2010	1,100	1,100	1,100
FY 2011	7,524	7,524	5,450
Outyears	TBD	TBD	TBD
Total, TPC[b]	TBD	TBD	TBD

[a] All design will be complete in less than eighteen months.
[b] This project has not yet received approval of CD-2; therefore cost and schedule estimates are preliminary. The preliminary TEC range is $31,300,000 to $34,900,000. The TPC range for this project is $32,400,000 to $36,000,000.
[c] Other Project Costs are funded through laboratory overhead.

6. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design (PED)[a]			
Design	3,350	N/A	N/A
Contingency	1,100	N/A	N/A
Total, PED	4,450	N/A	N/A
Construction			
Construction	2,459	N/A	N/A
Contingency	615	N/A	N/A
Total, Construction	3,074	N/A	N/A
Total, TEC[b]	7,524	N/A	N/A
Contingency, TEC	1,715	N/A	N/A
Other Project Cost (OPC)[c]			
OPC except D&D			
Conceptual Planning	500	N/A	N/A
Conceptual Design	400	N/A	N/A
Contingency	200	N/A	N/A
Total, OPC except D&D	1,100	N/A	N/A
Total, OPC	1,100	N/A	N/A
Contingency, OPC	200	N/A	N/A
Total, TPC[b]	8,624	N/A	N/A
Total, Contingency	1,915	N/A	N/A

[a] All design will be complete in less than 18 months.
[b] This project has not yet received approval of CD-2; therefore construction and TEC estimated displayed only include anticipated activities through 2011. The preliminary TEC range for this project is $31,300,000 to $34,900,000. The TPC range for this project is $32,400,000 to $36,000,000.
[c] Other Project Costs are funded through laboratory overhead.

7. Funding Profile History

(dollars in thousands)

Request Year		FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	Total
FY 2011	TEC	0	7,524	TBD	TBD	TBD	TBD	TBD[a]
	OPC[b]	1,100	0	0	0	0	0	1,100
	TPC	1,100	7,524	TBD	TBD	TBD	TBD	TBD[a]

8. Related Operations and Maintenance Funding Requirements

Not applicable. Project does not have CD-2 approval.

9. Required D&D Information

Not applicable. Project does not have CD-2 approval.

10. Acquisition Approach

Not applicable. Project does not have CD-2 approval.

[a] This project has not yet received approval of CD-2; therefore cost and schedule estimates are preliminary. The preliminary TEC range for this project is $31,300,000 to $34,900,000. The TPC range for this project is $32,400,000 to $36,000,000.
[b] Other Project Costs are funded through laboratory overhead.

11-SC-71, Utility Infrastructure Modernization
Thomas Jefferson National Accelerator Facility
Newport News, Virginia
Project Data Sheet is for PED/Construction

1. Significant Changes

DOE O 413.3A Critical Decision (CD)-0, Approve Mission Need, was received September 18, 2009. The anticipated preliminary Total Estimated Cost (TEC) range for this project is $24,300,000–$29,200,000.

A Federal Project Director at the appropriate level has been assigned to this project.

This Project Data Sheet is new for PED/Construction.

2. Design, Construction, and D&D Schedule

(fiscal quarter or date)

	CD-0	CD-1	PED Complete	CD-2	CD-3	CD-4	D&D Start	D&D Complete
FY 2011[a]	9/18/2009	TBD	TBD	TBD	TBD	TBD	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

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 2011	1,800	TBD	TBD[b]	650	N/A	650	TBD[b]

4. Project Description, Justification, and Scope

The Thomas Jefferson National Accelerator Facility (TJNAF) cryogenic, power distribution, cooling water, and communication systems are experiencing failure at increasing frequencies and have insufficient capacity to meet current and forecasted need. These utility system gaps jeopardize the laboratory's capability to deliver its mission, to contribute to enabling technologies and emerging fields, and to support ongoing research programs at TJNAF, as well as other DOE national and international projects.

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[a] This project is pre-CD-2 and schedules are preliminary. Construction funds will not be executed without appropriate CD approvals.
[b] This project is pre-CD-2 and cost estimates are preliminary. The preliminary TEC range is $24,300,000 to $29,200,000. The preliminary Total Project Cost (TPC) range is $24,950,000 to $29,850,000.

The cryogenic, power distribution, cooling water, and communication systems are 20 to 40 years old, as they dating back to the previous owner. The cryogenic system has insufficient capacity and despite gains over the past several years on significantly improving the efficiency of major system components, there remains a need for overall system efficiency optimization. Currently, the cryogenic capacity is inadequate to support the needs in the Test Lab, which is the key facility for Superconducting Radiofrequency (SRF) development and production activities. The lack of adequate cryogenic capacity is a limiting factor on scheduling SRF activities. Cryogenic system operation at TJNAF accounts for over 90% of annual electricity costs. Therefore, efficiency gains in this system will significantly contribute to a reduction in overall operating costs. Electricity energy savings from an upgrade to the Cryogenic Test Facility, a key component in the cryogenic system, are estimated to be 36%.

The capacity of the power distribution system is currently taxed to its limit and will not support future projected needs. The power distribution system does not have the necessary redundancy to maintain operation of critical systems during partial power outages. The most critical element of this gap is the inability to restart the Central Helium Liquefier (CHL) from the alternate power feed when the primary feed has an outage. The CHL is the largest component in the site cryogenic system and is critical to maintaining constant cryogenic temperatures in the accelerator cryomodules, necessary to prevent degradation of accelerator performance and costly repairs. Electric feeders are at the end of their service life and are near failing. Insulation cracks have been observed on multiple feeders. Recent interruptions to accelerator operation due to failed components of the electrical supply heighten this concern.
The cooling water distribution system is suffering frequent failures and has insufficient capacity to support optimal experimental program scheduling, computer center heat loads, and future expected growth. Over the past year, failure of the cooling water distribution system has caused several weeks of down time for the Free Electron Laser facility. Cooling towers are well past their efficient life cycle utilization and are requiring ever increasing amounts of maintenance. In addition, there is an estimated energy savings from addressing this gap of 10%.

Subsurface communications systems are outdated and unreliable. Because some of these systems are over 40 years old, replacement components are often unavailable. Phone switch parts are difficult to locate and no additional cabling capacity is available for telecommunications or data lines. Inadequate capacity is impacting the ability to install communications to support staff growth and replace degraded cables as necessary. These systems have reached the end of their life cycle. Consequently, instances of phone outages are impacting the efficiency of operations. The underground copper wiring is also past its service life. In addition, installation of an Emergency Broadcast System is necessary to meet safety goals and improve efficiency of response.

The proposed solutions under this project to address the utility system performance gaps at TJNAF are relatively non-complex and include upgrades and expansion of cryogenic, electrical power distribution, cooling water, and communication systems. A detailed alternatives analysis using life-cycle costs will be conducted prior to CD-1.

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. FY 2010 OPC funds, funded through laboratory overhead, are used to complete the conceptual design in preparation for CD–1. FY 2011 PED funds will be used to complete preliminary and final designs for all aspects of the project. The total design period for this project is expected to be significantly less than 18 months. FY 2011 construction funds are being requested because the scope of the project is straight forward and the design duration will be short, thereby permitting transition to construction during the same fiscal year. FY 2011 construction funds will be used for procurement of long lead items and to start construction work as well as for project management and support activities.

5. Financial Schedule

(dollars in thousands)

	Appropriations	Obligations	Costs
Total Estimated Cost (TEC)			
PED[a]			
FY 2011	1,800	1,800	1,800
Construction			
FY 2011	6,028	6,028	2,000
Outyears	TBD	TBD	TBD
Total, Construction	TBD	TBD	TBD
TEC			
FY 2011	7,828	7,828	3,800
Outyears	TBD	TBD	TBD
Total, TEC[b]	TBD	TBD	TBD
Other Project Cost (OPC)[c]			
OPC except D&D			
FY 2010	650	650	650
Total Project Cost (TPC)			
FY 2010	650	650	650
FY 2011	7,828	7,828	3,800
Outyears	TBD	TBD	TBD
Total, TPC[b]	TBD	TBD	TBD

[a] Design will be complete in less than 18 months.
[b] This project has not yet received approval of CD-2; therefore cost and schedule estimates are preliminary. The preliminary TEC range is $24,300,000 to $29,200,000. The preliminary TPC range is $24,950,000 to $29,850,000.
[c] Other Project Costs are funded through laboratory overhead.

6. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design (PED)[a]			
Design	1,700	N/A	N/A
Contingency	100	N/A	N/A
Total, PED	1,800	N/A	N/A
Construction			
Other Construction	5,023	N/A	N/A
Contingency	1,005	N/A	N/A
Total, Construction	6,028	N/A	N/A
Total, TEC[b]	7,828	N/A	N/A
Contingency, TEC	1,105	N/A	N/A
Other Project Cost (OPC)[c]			
OPC except D&D			
Conceptual Planning	650	N/A	N/A
Start-Up	N/A	N/A	N/A
Total, OPC except D&D	650	N/A	N/A
D&D			
D&D	N/A	N/A	N/A
Contingency	N/A	N/A	N/A
Total, D&D	N/A	N/A	N/A
Total, OPC	650	N/A	N/A
Total, TPC[b]	8,478	N/A	N/A
Total, Contingency	1,105	N/A	N/A

[a] All design will be complete in less than 18 months.
[b] This project has not yet received approval of CD-2; therefore, construction and TEC estimate displayed only include anticipated activities through FY 2011. The preliminary TEC range is $24,300,000 to $29,200,000. The preliminary TPC range is $24,950,000 to $29,850,000.
[c] Other Project Costs are funded through laboratory overhead.

7. Funding Profile History

(dollars in thousands)

Request Year		FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	Total
FY 2011	TEC	0	7,828	TBD	TBD	TBD	TBD	TBD[b]
	OPC[a]	650	0	0	0	0	0	TBD
	TPC	650	7,828	TBD	TBD	TBD	TBD	TBD[b]

8. Related Operations and Maintenance Funding Requirements

Not applicable. Project does not yet have CD-2 approval.

9. Required D&D Information

Not applicable. Project does not yet have CD-2 approval.

10. Acquisition Approach

Not applicable. Project does not yet have CD-2 approval.

[a] Other Project Costs are funded through laboratory overhead.

[b] This project has not yet received approval of CD-2; therefore cost and schedule estimates are preliminary. The preliminary TEC range is $24,300,000 to $29,200,000. The preliminary TPC range is $24,950,000 to $29,850,000.

10-SC-70, Research Support Building and Infrastructure Modernization, SLAC National Accelerator Laboratory, Menlo Park, California
Project Data Sheet is for PED/Construction

1. Significant Changes

The most recent DOE O 413.3A Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, that was approved on November 3, 2009, 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 for PED/Construction.

2. Design, Construction, and D&D Schedule

(fiscal quarter or date)

	CD-0	CD-1	PED Complete	CD-2/3A	CD-3B	CD-4	D&D Start	D&D Complete
FY 2010	10/10/2008	1Q FY 2010	2Q FY 2011	TBD	TBD	TBD	TBD	TBD
FY 2011[a]	10/10/2008	11/3/2009	4Q FY 2011	4Q FY 2010	4Q FY 2012	1Q FY 2015	4Q FY 2011	2Q FY 2015

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	8,900	TBD	TBD	1,400	TBD	TBD	TBD
FY 2011[b]	8,900	87,100	96,000	1,400	N/A	1,400	97,400

4. Project Description, Justification, and Scope

SLAC National Accelerator Laboratory is an Office of Science 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

[a] This project is pre-CD-2, and the schedule is preliminary. Construction funds will not be executed without appropriate CD approvals.
[b] This project is pre-CD-2 and cost estimates are preliminary. The preliminary TEC range is $80,000,000 to $96,000,000. The preliminary Total Project Cost (TPC) range for this project is $81,400,000 to $97,400,000.

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 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 these 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 two buildings is proposed (028 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.

According to the latest preliminary project execution plan, new construction is anticipated to be in the range of 53,000 to 64,000 square feet; approximately 64,000 square feet of existing space will undergo renovation, and demolition of approximately 20,000 square feet will be completed to provide the site for the new construction. The remaining balance of gross square feet to be demolished to meet the one-for-one replacement will be from banked excess.

FY 2009 OPC funds, funded through laboratory overhead, were used to complete the Conceptual Design Report in preparation for CD-1, which was approved on November 3, 2009. FY 2010 and FY 2011 PED funding will be used for design of the project, including project management and all associated support functions. FY 2011 construction funding will support early procurement and construction activities, 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	Costs
Total Estimated Cost (TEC)			
PED[a]			
FY 2010	6,900	6,900	5,900
FY 2011	2,000	2,000	3,000
Total, PED	8,900	8,900	8,900
Construction			
FY 2011	30,200	30,200	19,200
FY 2012	19,700	19,700	TBD
FY 2013	36,300	36,300	TBD
FY 2014	0	0	TBD
Total, Construction	86,200	86,200	86,200
D&D			
FY 2011	900	900	900
Total, D&D	900	900	900
TEC			
FY 2010	6,900	6,900	5,900
FY 2011	33,100	33,100	22,200
FY 2012	19,700	19,700	TBD
FY 2013	36,300	36,300	TBD
FY 2014	0	0	TBD
Total, TEC[b]	96,000	96,000	96,000
Other Project Cost (OPC)[c]			
OPC except D&D			
FY 2009	700	700	700
FY 2010	100	100	100
FY 2011	100	100	100
FY 2012	150	150	150
FY 2013	300	300	300
FY 2014	50	50	50
Total, OPC except D&D	1,400	1,400	1,400

[a] All design will be complete in less than eighteen months.
[b] This project is pre-CD-2 and cost and schedule estimates are preliminary. The TEC range for this project is $80,000,000 to $96,000,000. The TPC range for this project is $81,400,000 to $97,400,000.
[c] Other Project Costs are funded through laboratory overhead.

(dollars in thousands)

	Appropriations	Obligations	Costs
Total Project Cost (TPC)			
FY 2009	700	700	700
FY 2010	7,000	7,000	6,000
FY 2011	33,200	33,200	22,300
FY 2012	19,850	19,850	TBD
FY 2013	36,600	36,600	TBD
FY 2014	50	50	TBD
Total, TPC[a]	97,400	97,400	97,400

6. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate[b]	Original Validated Baseline
Total Estimated Cost (TEC)			
Design (PED)[c]			
Design	6,675	6,675	N/A
Contingency	2,225	2,225	N/A
Total, PED	8,900	8,900	N/A
Construction			
Construction	69,200	TBD	N/A
Contingency	17,000	TBD	N/A
Total, Construction	86,200	TBD	N/A
D&D			
D&D	700	TBD	N/A
Contingency	200	TBD	N/A
Total, D&D	900	TBD	N/A
Total, TEC[a]	96,000	8,900	N/A
Contingency, TEC	19,425	2,225	N/A

[a] This project is pre-CD-2 and cost and schedule estimates are preliminary. The TEC range for this project is $80,000,000 to $96,000,000. The TPC range for this project is $81,400,000 to $97,400,000.
[b] Previous estimates shown only included partial funding.
[c] Design will be complete in less than 18 months.

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
OPC			
Other OPC	900	900	N/A
Start-Up	300	300	N/A
Contingency	200	200	N/A
Total, OPC	1,400	1,400	N/A
Total, TPC[a]	97,400	10,300	N/A
Total, Contingency	19,625	2,425	N/A

7. Funding Profile History

(dollars in thousands)

Request Year		FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	Total
FY 2010	TEC	0	8,900	TBD	TBD	TBD	TBD	TBD	TBD
	OPC[b]	500	900	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	500	9,800	TBD	TBD	TBD	TBD	TBD	TBD
FY 2011	TEC	0	6,900	33,100	19,700	36,300	0	0	96,000[a]
	OPC[a]	700	100	100	150	300	50	0	1,400
	TPC	700	7,000	33,200	19,850	36,600	50	0	97,400[a]

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2014
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	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	399	N/A	10,266	N/A
Maintenance	1,722	N/A	44,481	N/A
Total, Operations & Maintenance	2,121	N/A	54,747	N/A

[a] This project is pre-CD-2 and cost and schedule estimates are preliminary. The TEC range for this project is $80,000,000 to $96,000,000. The TPC range for this project is $81,400,000 to $97,400,000.
[b] Other Project Costs are funded through laboratory overhead.

9. Required D&D Information

This project will include demolition of approximately 20,000 square feet to clear the proposed site for the new construction. The remaining balance of gross square feet to be demolished to meet the one-for-one replacement will be from banked excess.

10. Acquisition Approach

Not applicable. Project does not have CD-2 at this time.

10-SC-71, Energy Sciences Building
Argonne National Laboratory, Argonne, IL
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 2, 2009, 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. The Federal Project Director is pursuing the appropriate certification level.

This Project Data Sheet is for PED/Construction

2. Design, Construction, and D&D Schedule

(fiscal quarter or date)

	CD-0	CD-1	PED Complete	CD-2	CD-3A	CD-3B	CD-4
FY 2010	10/10/2008	4Q FY 2009	2Q FY 2011	TBD	TBD	TBD	TBD
FY 2011[a]	10/10/2008	09/02/2009	2Q FY 2011	2Q FY 2011	2Q FY 2011	2Q FY 2012	4Q FY 2014

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Ranges
CD-2 – Approve Performance Baseline
CD-3A – Approve Start of Site Preparation
CD-3B – Approve Start of Building Construction
CD-4 – Approve Start of Operations or Project Closeout

(fiscal quarter or date)

	D&D Start	D&D Complete
FY 2010	TBD	TBD
FY 2011[a]	N/A	N/A

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[b] Except D&D	OPC, D&D	OPC, Total	TPC
FY 2010	10,000	TBD	TBD	1,000	TBD	TBD	TBD
FY 2011[c]	10,000	85,000	95,000	1,000	N/A	1,000	96,000

[a] This project is pre-CD-2, and the schedule is preliminary. Construction funds will not be executed without appropriate CD approvals.
[b] Other Project Costs are funded through laboratory overhead.
[c] This project is pre-CD2; preliminary cost estimates are shown for TEC and TPC. The preliminary TEC range for this project is $84,500,000 to $95,000,000. The preliminary Total Project Cost (TPC) range for this project is $85,500,000 to $96,000,000.

4. Project Description, Justification, and Scope

This project will provide between 125,000 and 150,000 gross square feet of new energy efficient and environmentally sustainable laboratory space at Argonne National Laboratory (ANL). The new facility 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, characterization, and application of new energy-related materials and processes. Efficient, high-accuracy heating, ventilation, and air conditioning 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 necessary furniture and equipment for the new facility as well as extension of existing site utilities to the new building.

Key areas of energy research to be housed in the ESB include discovery synthesis, biomimetics, solar energy, catalysis, fuel cell research, and electrical energy storage. These 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 non-compliances 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 and National Fire Protection Association 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.

FY 2009 OPC funds, funded through laboratory overhead, were used to complete the Conceptual Design Report in preparation for CD-1, approved on September 2, 2009. FY 2010 and FY 2011 PED funding will be used for design of the project, including project management and all associated support functions. FY 2011 construction funding will support early procurement and 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	Costs
Total Estimated Cost (TEC)			
PED[a]			
FY 2010	8,000	8,000	7,000
FY 2011	2,000	2,000	3,000
Total, PED	10,000	10,000	10,000
Construction			
FY 2011	13,000	13,000	10,000
FY 2012	45,000	45,000	TBD
FY 2013	27,000	27,000	TBD
FY 2014	0	0	TBD
Total, Construction	85,000	85,000	85,000
TEC			
FY 2010	8,000	8,000	7,000
FY 2011	15,000	15,000	13,000
FY 2012	45,000	45,000	TBD
FY 2013	27,000	27,000	TBD
FY 2014	0	0	TBD
Total, TEC[b]	95,000	95,000	95,000
Other Project Cost (OPC)[c]			
OPC except D&D			
FY 2009	956	956	956
FY 2010	44	44	44
Total, OPC except D&D	1,000	1,000	1,000
Total Project Cost (TPC)			
FY 2009	956	956	956
FY 2010	8,044	8,044	7,044
FY 2011	15,000	15,000	13,000

[a] All design will be complete in less than 18 months.
[b] This project is pre-CD-2. The preliminary TEC range for this project is $84,500,000 to $95,000,000. The preliminary TPC range for this project is $85,500,000 to $96,000,000.
[c] Other Project Costs are funded through laboratory overhead.

(dollars in thousands)

	Appropriations	Obligations	Costs
FY 2012	45,000	45,000	TBD
FY 2013	27,000	27,000	TBD
FY 2014	0	0	TBD
Total, TPC[c]	96,000	96,000	96,000

6. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate[a]	Original Validated Baseline
Total Estimated Cost (TEC)			
Design (PED)[b]			
Design	8,334	8,688	N/A
Contingency	1,666	1,312	N/A
Total, PED	10,000	10,000	N/A
Construction			
Other Construction	70,707	TBD	N/A
Contingency	14,293	TBD	N/A
Total, Construction	85,000	TBD	N/A
Total, TEC[c]	95,000	TBD	N/A
Contingency, TEC	15,959	TBD	N/A
Other Project Cost (OPC)[d]			
OPC except D&D			
Conceptual Planning	263	263	N/A
Conceptual Design	737	603	N/A
Contingency	0	134	N/A
Total, OPC except D&D	1,000	1,000	N/A
Total, OPC	1,000	1,000	N/A
Contingency, OPC	0	134	N/A
Total, TPC[c]	96,000	TBD	N/A
Total, Contingency	16,093	TBD	N/A

[a] Previous estimates shown only included partial funding.
[b] All design will be complete in less than 18 months.
[c] This project has not yet received approval of CD-2.The preliminary TEC range for this project is $84,500,000 to $95,000,000. The preliminary TPC range for this project is $85,500,000 to $96,000,000.
[d] Other Project Costs are funded through laboratory overhead.

7. Funding Profile History

(dollars in thousands)

Request Year		FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	Total
FY 2010	TEC	0	10,000	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	1,000	0	0	0	0	0	0	TBD
	TPC	1,000	10,000	TBD	TBD	TBD	TBD	TBD	TBD
FY 2011	TEC	0	8,000	15,000	45,000	27,000	0	0	95,000[b]
	OPC[a]	956	44	0	0	0	0	0	1,000
	TPC	956	8,044	15,000	45,000	27,000	0	0	96,000[b]

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2014
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	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	733	N/A	96,182	N/A
Maintenance	1,153	N/A	37,363	N/A
Total, Operations & Maintenance	1,886	N/A	133,545	N/A

9. Required D&D Information

This project has secured “banked space” from prior Nuclear Footprint Reduction efforts at Argonne as well as demolition projects at other Office of Science facilities to meet the one for one requirement for offsetting space.

10. Acquisition Approach

The ESB project Acquisition Strategy was approved on January 7, 2009.

The M&O Contractor, Argonne University of Chicago, LLC, will have prime responsibility for oversight of both the design and construction subcontracts.

Various acquisition alternatives were considered for this project. After considering all alternatives in relation to the schedule, size, and risk, the use of a tailored Design-Bid-Build approach with design by an Architectural/Engineering firm, construction management services through the industrial partnership, and construction by a General Contractor, all led by the M&O Contractor integrated project team, was

[a] Other Project Costs are funded through laboratory overhead.
[b] This project has not yet received approval of CD-2. The preliminary TEC range for this project is $84,500,000 to $95,000,000. The preliminary TPC range for this project is $85,500,000 to $96,000,000.

deemed to provide the best construction delivery method and the lowest risk. In addition, the M&O Contractor’s standard procurement practice is to use firm fixed-priced contracts, and the M&O Contractor has extensive experience in project management, construction management, and ES&H management systems in the acquisition of scientific facilities.

10-SC-72, Renovate Science Laboratories, Phase II
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 2, 2009, 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 for PED/Construction.

2. Design, Construction, and D&D Schedule

(fiscal quarter or date)

	CD-0	CD-1 (Design Start)	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	N/A	N/A
FY 2011[a]	10/10/2008	9/2/2009	2Q FY 2011	1Q FY 2011	4Q FY 2011	2Q FY 2014	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

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 2010	7,000	TBD	TBD	800	TBD	TBD	TBD
FY 2011[c]	7,000	43,000	50,000	800	TBD	800	50,800

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.

[a] This project is pre-CD-2, and schedules are preliminary. Construction funds will not be executed without appropriate CD approvals.
[b] Other Project Costs are funded through laboratory overhead.
[c] This project is pre-CD-2, and cost estimates are preliminary. Preliminary Total Estimated Cost (TEC) range is $45,000,000 to $50,000,000. Preliminary Total Project Cost (TPC) range is $45,800,000 to $50,800,000.

The laboratories in Building 510 for the Physics Department were constructed in 1962 and are desperately in need of 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, 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, poor lighting levels, decrepit lab facilities, poor temperature control and ventilation, significant particulate discharge from heating, ventilation, and air conditioning systems, high electromagnetic interference noise on electrical power in certain laboratories, and lack of fire sprinkler protection.

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 lab reconfiguration is needed to best meet advanced instrumentation needs.

The proposed 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 2 buildings, Building 510 Physics and Building 555 Chemistry.

FY 2009 other project costs (OPC) funds, funded through laboratory overhead, were used to complete the Conceptual Design Report in preparation for CD-1, which was approved September 2, 2009. FY 2010 and FY 2011 PED will be used for design of the project, including project management and all associated support functions. FY 2011 construction funds will be used to start construction on the project.

The project is being conducted in accordance with the project management requirements in DOE O 413.3A and all appropriate project management requirements have been met.

5. Financial Schedule

(dollars in thousands)

	Appropriations	Obligations	Costs
Total Estimated Cost (TEC)			
PED[a]			
FY 2010	5,000	5,000	3,000
FY 2011	2,000	2,000	4,000
Total, PED	7,000	7,000	7,000

[a] Design will be completed in less than 18 months.

	(dollars in thousands)		
	Appropriations	Obligations	Costs
Construction			
FY 2011	13,000	13,000	3,000
FY 2012	22,000	22,000	TBD
FY 2013	8,000	8,000	TBD
Total, Construction	43,000	43,000	TBD
TEC			
FY 2010	5,000	5,000	3,000
FY 2011	15,000	15,000	7,000
FY 2012	22,000	22,000	TBD
FY 2013	8,000	8,000	TBD
Total, TEC[a]	50,000	50,000	50,000
Other Project Cost (OPC)[b]			
OPC except D&D			
FY 2009	737	737	737
FY 2010	63	63	63
Total, OPC except D&D	800	800	800
Total Project Cost (TPC)			
FY 2009	737	737	737
FY 2010	5,063	5,063	3,063
FY 2011	15,000	15,000	7,000
FY 2012	22,000	22,000	TBD
FY 2013	8,000	8,000	TBD
Total, TPC[a]	50,800	50,800	50,800

[a] This project is pre-CD-2, and cost estimates are preliminary. Preliminary TEC range is $45,000,000 to $50,000,000. Preliminary TPC range is $45,800,000 to $50,800,000.
[b] Other Project Costs are funded through laboratory overhead.

6. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate[a]	Original Validated Baseline
Total Estimated Cost (TEC)			
Design (PED)[b]			
Design	6,200	6,200	N/A
Contingency	800	800	N/A
Total, PED	7,000	7,000	N/A
Construction			
Other Construction	34,400	N/A	N/A
Contingency	8,600	N/A	N/A
Total, Construction	43,000	N/A	N/A
Total, TEC[c]	50,000	N/A	N/A
Contingency, TEC	9,400	N/A	N/A
Other Project Cost (OPC)[d]			
OPC except D&D			
Conceptual Planning	150	150	N/A
Conceptual Design	650	600	N/A
Contingency	0	50	N/A
Total, OPC except D&D	800	800	N/A
Total, OPC	800	800	N/A
Contingency, OPC	0	50	N/A
Total, TPC[a]	50,800	7,800	N/A
Total, Contingency	9,450	850	N/A

[a] Previous estimates shown only included partial estimates.
[b] All design will be complete in less than 18 months.
[c] This project is pre-CD-2, and cost estimates are preliminary. Preliminary Total Estimated Cost (TEC) range is $45,000,000 to $50,000,000. Preliminary Total Project Cost (TPC) range is $45,800,000 to $50,800,000.
[d] Other Project Costs are funded through laboratory overhead.

7. Funding Profile History

(dollars in thousands)

Request Year		FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	Total
FY 2010	TEC	0	7,000	TBD	TBD	TBD	TBD
	OPC	800	0	0	0	0	800
	TPC	800	7,000	TBD	TBD	TBD	TBD
FY 2011	TEC	0	5,000	15,000	22,000	8,000	50,000[a]
	OPC[b]	737	63	0	0	0	800
	TPC	737	5,063	15,000	22,000	8,000	50,800[a]

8. Related Operations and Maintenance Funding Requirements

Project is a renovation of existing space within existing buildings. No additional Operations and Maintenance funding is required.

9. Required D&D Information

The project will not require demolition of a sufficient amount of excess facilities to meet space offsetting requirements for a new building at the BNL site. The project is a renovation of existing space. No new space shall be constructed.

10. Acquisition Approach

Design will be performed by an Architect-Engineer (A-E) with the subcontract managed by the BNL operating contractor. The A-E 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 offers will include consideration of each offeror's relative experience, safety record, and past performance in successfully completing similar construction projects. Award will then be made to one qualified responsible, responsive offeror.

09-SC-72, Seismic Life-Safety, Modernization, and Replacement of General Purpose Buildings, Phase II, 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-2A/2B/3A, Approve Performance Baseline (Phase A and B) and Approve Start of Construction (Phase A), which was approved on August 21, 2009. This project has a Total Estimated Cost (TEC) range of $91,900,000 to $94,600,000.

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

This Project Data Sheet (PDS) is for PED/Construction. This PDS is an update of the FY 2010 PDS.

2. Design, Construction, and D&D Schedule

(fiscal quarter or date)

	CD-0	CD-1	(PED Complete)	CD-2A/B	CD-2C	CD-3A	CD-3B	CD-3C
FY 2009	9/18/2007	2Q FY 2009	3Q FY 2010	N/A	TBD	N/A	N/A	TBD
FY 2010	9/18/2007	9/23/2008	4Q FY 2010	N/A	TBD	N/A	N/A	TBD
FY 2011[a]	9/18/2007	9/23/2008	1Q FY 2011	8/21/2009	4Q FY 2010	8/21/2009	2Q FY 2010	4Q FY 2011

CD-0 – Approve Mission Need

CD-1 – Approve Alternative Selection and Cost Range

CD-2A/2B – Approve Performance Baseline for Building 74 Demolition and Long Lead Procurement; and for Building 74 Modernization and Building 25 Demolition

CD-2C – Approve Performance Baseline for Remainder of Project

CD-3A – Approve Start of Building 74 Demolition and Long Lead Procurement

CD-3B – Approve Start of Construction for Building 74 Modernization and Building 25 Demolition

CD-3C – Approve Start of Construction for Remainder of Project

(fiscal quarter or date)

	CD-4A/B	CD-4C	D&D Start	D&D Complete
FY 2009	TBD	TBD	TBD	TBD
FY 2010	TBD	TBD	TBD	TBD
FY 2011[a]	1Q FY 2013	2Q FY 2015	4Q FY 2010	3Q FY 2014

CD-4A/4B – Complete Building 74 Demolition and Long Lead Procurement, and Approve Start of Operations for Building 74 Modernization and Building 25 Demolition

CD-4C – Approve Start of Operations

D&D Start – Start of Demolition & Decontamination (D&D) work

D&D Complete – Completion of D&D work for Remainder of Project

[a] This project has not been fully baselined and the schedule is preliminary. Construction funds will not be executed without appropriate CD approvals.

3. Baseline and Validation Status

(dollars in thousands)

	TEC, PED	TEC, Construction	TEC, Total	OPC[a] Except D&D	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
FY 2011[b]	9,680	84,920	94,600	2,480	N/A	2,480	97,080

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 to 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.

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, through the provision of the new GPL and the upgrades to the existing building systems, 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.

[a] Other Project Costs are funded through laboratory overhead.
[b] This project is pre-CD-2. Preliminary cost estimates are shown for TEC and TPC. The TEC range for this project is $91,900,000 to $94,600,000. The TPC range is $94,380,000 to $97,080,000.

FY 2009 and FY 2010 PED funding is being used for design of the project, including project management and all associated support functions. FY 2009 Recovery Act funding will provide for most of Building 74 construction work. FY 2009 appropriated funds were originally forecast to be used for early procurements; however, actual costs are expected to be less than originally estimated. Remaining FY 2009 funds, not used for early procurements, will be used for remaining construction on the project. FY 2010 construction funding is being used to continue construction activities including project management and all associated support functions. FY 2011 funding 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 Costs				
PED[a]				
FY 2009	8,680	8,680	0	2,673
FY 2010	1,000	1,000	0	6,208
FY 2011	0	0	0	799
Total Design	9,680	9,680	0	9,680
Construction				
FY 2009	3,815	3,815	0	0
FY 2009 Recovery	15,000	15,000	1	0
FY 2010	33,027	33,027	5,699	6,517
FY 2011	20,103	20,103	9,300	19,600
FY 2012	12,975	12,975	0	25,012
FY 2013	0	0	0	17,509
FY 2014	0	0	0	1,282
Total Construction	84,920	84,920	15,000	69,920
Total, TEC[b]	94,600	94,600	15,000	79,600

[a] All design will be completed in less than 18 months.
[b] This project is not yet fully baselined. The TEC range for this project is $91,900,000 to $94,600,000. The TPC range is $94,380,000 to $97,080,000.

	(dollars in thousands)			
	Appropriations	Obligations	Recovery Act Costs	Costs
Other Project Cost (OPC)[a]				
OPC except D&D				
FY 2008	1,945	1,945	0	1,945
FY 2009	309	309	0	309
FY 2010	2	2	0	2
FY 2011	104	104	0	104
FY 2013	120	120	0	120
Total, OPC	2,480	2,480	0	2,480
Total Project Cost (TPC)				
FY 2008	1,945	1,945	0	1,945
FY 2009	12,804	12,804	0	2,982
FY 2009 Recovery	15,000	15,000	1	0
FY 2010	34,029	34,029	5,699	12,727
FY 2011	20,207	20,207	9,300	20,503
FY 2012	12,975	12,975	0	25,012
FY 2013	120	120	0	17,629
FY 2014	0	0	0	1,282
Total, TPC[b]	97,080	97,080	15,000	82,080

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate[c]	Original Validated Baseline
Total Estimated Cost (TEC)			
Design (PED)[d]			
Design	8,311	8,027	N/A
PED Contingency	1,369	1,653	N/A
Total, PED	9,680	9,680	N/A

[a] Other Project Costs are funded through laboratory overhead.
[b] This project is not yet fully baselined. The TEC range for this project is $91,900,000 to $94,600,000. The TPC range is $94,380,000 to $97,080,000.
[c] Previous estimates shown only included partial funding.
[d] All design will be complete in less than eighteen months.

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate[a]	Original Validated Baseline
Construction			
Site Preparation	9,394	0	N/A
Other Construction	60,758	43,202	N/A
Construction Contingency	14,768	8,640	N/A
Total Construction	84,920	51,842	N/A
Total TEC[b]	94,600	61,522	N/A
Contingency, TEC	16,137	10,293	N/A
Other Project Cost (OPC)[c]			
OPC except D&D			
Conceptual Planning and Design	2,300	2,142	N/A
Startup and Testing	150	0	N/A
Contingency	30	158	N/A
Total, OPC	2,480	2,300	N/A
Contingency, OPC	30	158	N/A
Total, TPC[c]	97,080	TBD	N/A
Total Contingency	16,167	TBD	N/A

[a] Previous estimates shown only included partial funding.
[b] This project has not yet received approval of CD-2. The preliminary total estimated cost range for this project is $91,900,000–$94,600,000. The preliminary TPC range is $94,380,000 to $97,080,000.
[c] Other Project Costs are funded through laboratory overhead.

7. Funding Profile History

(dollars in thousands)

Request Year		Prior Years	FY 2009	FY 2009 Recovery Act	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	Total
FY 2009	TEC	0	12,495	0	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	2,250	50	0	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	2,250	12,545	0	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2010	TEC	0	12,495	15,000	34,027	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	2,250	50	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	2,250	12,545	15,000	34,027	TBD	TBD	TBD	TBD	TBD	TBD
FY 2011	TEC	0	12,495	15,000	34,027	20,103	12,975	0	0	0	94,600[a]
	OPC[b]	1,945	309	0	2	104	0	120	0	0	2,480
	TPC	1,945	12,804	15,000	34,029	20,207	12,975	120	0	0	97,080[a]

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	640	19,203	19,203
Maintenance	1,407	1,407	42,219	42,219
Total, Operations & Maintenance	2,047	2,047	61,422	61,422

9. Required D&D Information

	Square Feet
Area of new construction	35,000–43,000
Area of existing facility(s) being replaced	20,663[c]
Area of additional D&D space to meet the "one-for-one" requirement[d]	14,337–22,337

[a] This project has not yet received approval of CD-2. The preliminary total estimated cost range for this project is $91,900,000–$94,600,000. The preliminary TPC range is $94,380,000 to $97,080,000.
[b] Other Project Costs are funded through laboratory overhead.
[c] Building 25 (20,303 SF) and Building 25B (360 SF) will be demolished to make way for the new General Purpose Laboratory.
[d] This project includes demolition of appropriate offsetting space to meet this requirement prior to CD-4.

10. Acquisition Approach

A building program and design criteria has been developed by the LBNL Facilities Department incorporating detailed functional requirements for all phases (A, B, and C) of the project. An architect and engineering firm with appropriate multidisciplinary design experience was selected, based on qualifications, for design services. A lump sum Construction Management /General Contracting (CM/GC) subcontract has been negotiated and awarded by the University of California. Independent reviews of the structural design and construction cost estimate have been arranged by LBNL.

Additional specific CD-3A considerations: In order to have the Seismic Phase 2 Building 74 modernization work follow the seismic upgrade work under the Seismic Phase 1 project, the Seismic Phase 1 CM/GC will be used to perform the interior demolition scope of work. The CM/GC will competitively bid this lump sum scope of work. The early procurement of long lead equipment will be competitively bid as a lump sum contract.

09-SC-74, Technology and 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-2, Approve Performance Baseline, which was approved on November 12, 2009, with a Total Estimated Cost (TEC) of $72,200,000.

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

Project Data Sheet (PDS) is for PED/Construction. This PDS is an update of the FY 2010 PDS.

2. Design, Construction, and D&D Schedule

(fiscal quarter or date)

	CD-0	CD-1	PED Complete	CD-2	CD-3A	CD-3B
FY 2009	09/18/2007	09/23/2008	TBD	TBD	N/A	TBD
FY 2010	09/18/2007	09/23/2008	3Q FY 2010	TBD	N/A	TBD
FY 2011	09/18/2007	09/23/2008	3Q FY 2010	11/12/2009	2Q FY 2010	4Q FY 2010

CD-0 – Approve Mission Need

CD-1 – Approve Alternative Selection and Cost Range

CD-2 – Approve Performance Baseline

CD-3A – Approve Start of Early Construction and Long Lead Procurements

CD-3B – Approve Start of Balance of Construction

(fiscal quarter or date)

	CD-4A	CD-4B	D&D Start	D&D Complete
FY 2009	N/A	TBD	N/A	N/A
FY 2010	N/A	TBD	N/A	N/A
FY 2011	2Q FY 2012	2Q FY 2014	N/A	N/A

CD-4A – Approve Start of Operations for New Construction

CD-4B – Approve Start of Operations for Renovation

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 2009	3,700	TBD	TBD	1,000	TBD	TBD	TBD
FY 2010	3,700	TBD	TBD	1,000	N/A	TBD	TBD
FY 2011	3,700	68,500[a]	72,200	1,000	N/A	1,000	73,200

[a] Construction will not start until the appropriate CD-3 approvals are obtained

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 90,000 to 120,000 square feet of needed workspace for critical technical support functions including mechanical and electrical engineering; cryogenics engineering and fabrication; and environment, safety, and health.

The project will significantly improve the efficiency of workflow and provide a safer and sustainable work environment for multi-program functions such as 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 Thomas Jefferson National Accelerator Facility (TJNAF) Secretarial Waiver (9/15/2006) provides offsetting space for the Technology and Engineering Development Facility (TEDF) 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 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 as a National SRF Center of Exellence, 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 that were 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 improvements to the work environment this project provides will improve the morale of staff currently 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 are being used to complete preliminary and final designs for both the new construction and the renovation work. FY 2010 construction funds will be used to begin construction work on the new buildings, including project management and associated support activities. FY 2011 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	Costs
Total Estimated Cost (TEC)			
PED			
FY 2009	3,700	3,700	1,900
FY 2010	0	0	1,800
Total PED	3,700	3,700	3,700
Construction			
FY 2010	27,687	27,687	8,000
FY 2011	20,800	20,800	35,000
FY 2012	20,013	20,013	20,000
FY 2013	0	0	5,500
Total, Construction	68,500	68,500	68,500
TEC			
FY 2009	3,700	3,700	1,900
FY 2010	27,687	27,687	9,800
FY 2011	20,800	20,800	35,000
FY 2012	20,013	20,013	20,000
FY 2013	0	0	5,500
Total, TEC	72,200	72,200	72,200
Other Project Cost (OPC)[a]			
OPC except D&D			
FY 2008	287	287	287
FY 2009	509	509	509
FY 2010	204	204	204
Total OPC except D&D	1,000	1,000	1,000
Total Project Cost (TPC)			
FY 2008	287	287	287
FY 2009	4,209	4,209	2,409
FY 2010	27,891	27,891	10,004
FY 2011	20,800	20,800	35,000
FY 2012	20,013	20,013	20,000
FY 2013	0	0	5,500
Total, TPC	73,200	73,200	73,200

[a] Other Project Costs are funded through laboratory overhead.

6. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate[a]	Original Validated Baseline
Total Estimated Cost (TEC)			
Design (PED)			
Design	3,350	3,350	3,350
Contingency	350	350	350
Total, PED	3,700	3,700	3,700
Construction			
Site Preparation/Early Proc.	4,411	3,900	4,411
Equipment	1,966	N/A	1,966
Other Construction	50,295	18,187	50,295
Contingency	11,828	5,600	11,828
Total Construction	68,500	27,687	68,500
Total, TEC	72,200	N/A	72,200
Contingency, TEC	12,178	N/A	12,178
Other Project Cost (OPC)[b]			
OPC except D&D			
Conceptual Planning	200	150	200
Conceptual Design	800	770	800
Contingency	0	80	0
Total, OPC except D&D	1,000	1,000	1,000
Total, TPC	73,200	N/A	73,200
Total, Contingency	12,178	N/A	12,178

[a] Previous total estimate included only anticipated activities through FY 2010.
[b] Other Project Cost are funded through laboratory overhead.

7. Funding Profile History

(dollars in thousands)

Request Year		Prior Years	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	Total
FY 2009	TEC	0	3,700	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	1,000	0	0	0	0	0	0	0	1,000
	TPC	1,000	3,700	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2010	TEC	0	3,700	27,687	TBD	TBD	0	0	0	TBD
	OPC	1,000	0	0	0	0	0	0	0	1,000
	TPC	1,000	3,700	27,687	TBD	TBD	0	0	0	TBD
FY 2011	TEC	0	3,700	27,687	20,800	20,013	0	0	0	72,200
	OPC	287	509	204	0	0	0	0	0	1,000
	TPC	287	4,209	27,891	20,800	20,013	TBD	TBD	TBD	73,200

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	
▪ New Construction	2Q FY 2012
▪ Renovation	2Q FY 2014
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	1Q 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	478	23,900	23,900
Maintenance	1,120	1,120	56,000	56,000
Total, Operations & Maintenance	1,598	1,598	79,900	79,900

9. Required D&D Information

The approved TJNAF Secretarial Waiver (9/15/2006) provides offsetting space for the TEDF 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.

10. Acquisition Approach

Design is being performed by an Architect-Engineer (A-E) with the subcontract managed by the TJNAF operating contractor, Jefferson Science Associates (JSA). The A-E subcontractor was competitively selected based on demonstrated competence and qualifications to perform the required design services at a fair and reasonable price.

A Construction Management/General Contractor (CM/GC) subcontract will be awarded by JSA during the final phase of design. The CM/GC subcontractor will be competitively selected based on the demonstrated competence and qualifications of potential firms to perform the required CM/GC services at a fair and reasonable price. The subcontract with the CM/GC will be for two phases of fixed-price work. The base contract will be for the CM/GC to provide support services to the A-E, including input regarding material selection, equipment, construction feasibility, and factors relating to construction and cost estimates including cost estimates of alternative designs or materials. The CM/GC will also provide TJNAF with cost and schedule validation services and provide recommendations of actions designed to minimize the impact of labor or material shortages, and time duration estimates for scheduling procurements and construction activities. The contract option will be to execute the construction project, including the management, ES&H oversight, and the administration of construction subcontracts. The option will be inclusive of all material, labor, equipment, etc. necessary to perform the work in accordance with the contractual requirements in order to meet the defined scope and schedule.

All work performed by the CM/GC will be monitored by TJNAF personnel, with support from the A-E. The site office will provide oversight to ensure safety and quality performance.

Safeguards and Security

Funding Profile by Subprogram

	(dollars in thousands)		
	FY 2009 Current Appropriation	FY 2010 Current Appropriation	FY 2011 Request
Safeguards and Security			
Protective Forces	33,708	34,567	36,471
Security Systems	7,857	8,347	8,475
Information Security	4,494	4,550	4,141
Cyber Security	18,993	19,824	20,752
Personnel Security	5,517	6,412[a]	7,257[a]
Material Control and Accountability	2,238	2,249	2,413
Program Management	7,796	7,051	6,991
Total, Safeguards and Security	80,603	83,000	86,500

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 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, and the health and safety of DOE and contractor employees, the public, and the environment.

Background

Successfully executing the SC mission requires national and international information sharing and open scientific collaboration. SC laboratories collaborate with universities and research facilities at every corner of the globe through virtual interconnections. Therefore the SC physical and virtual security posture must be flexible and responsive to efforts to functionally integrate international research. In addition, some laboratories must implement security measures to protect classified information, special nuclear material, irreplaceable Departmental property, or shared tools of discovery.

Subprograms

The S&S program functional areas include:

Protective Forces: Security officers/access control officers and security police officers assigned to protect S&S interests.

[a] For security investigations, FY 2010 includes direct appropriations funding of $184,000 for federal field personnel; an additional estimate of $5,816,000 will be used from chargebacks for contractors. The respective amounts for FY 2011 are $178,000 and $5,822,000.

Security Systems: Personnel, equipment, hardware and software structures, and plans and procedures used to protect S&S interests.

Information Security: Personnel for execution of the administrative policies and procedures for identifying, marking, and protecting classified and sensitive unclassified information and materials from unauthorized disclosure.

Cyber Security: Personnel for 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: Personnel for execution of policies, procedures, processing security clearance applications and activities for granting individuals access to classified matter and/or special nuclear material and allowing Foreign Nationals access to DOE facilities.

Material Control and Accountability: Personnel, systems, and procedures necessary to establish and track nuclear material inventories, control access to and detect loss or diversion of nuclear material.

Program Management: Personnel, policy, oversight, and administration that establish the general requirements for S&S planning associated with the preceding programs. The process also includes reviews of program activities.

Benefits

The S&S program protects DOE assets and resources, thereby allowing the programmatic mission 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 utilizes a graded approach enabling each facility to design a security protection program that meets facility and science-specific threat scenarios.

Program Planning and Management

S&S planning and management identify the resources necessary to ensure protection of Department assets and identify changes in resource requirements (operational requirements, capital equipment, and general plant projects). Planning and management also entails a review of line item construction projects that directly or indirectly impact risk. The source of directional changes usually comes from revised S&S policy, directives, guidance, or other Departmental requirements. Management and oversight activities include contractor self-assessments and external audits, inspections, surveys, and program reviews conducted by the Department's Inspector General, the Office of Health, Safety and Security, the SC Deputy Director for Field Operations, and the Integrated Support Center. Addressing the results of these oversight activities informs tactical and strategic five-year plans.

Budget Overview

In June 2009, the Office of Health, Safety and Security held a Security Director's Conference which resulted in emerging themes for policy changes within the Department that addressed how policy is developed and implemented. Additionally, plans to manage a revised risk acceptance model, methods the Department can use to change the risk adverse culture, and the role of S&S oversight were overarching topics discussed at this meeting. The Office of the Chief Information Officer also conducted a review of Departmental directives. The resulting recommendation for cyber security was that the Department replace all cyber security related directives with National Institute of Standards and Technology standards. SC has initiated a security industry best practices study. As this study moves forward, adjustments to the functional areas and funding reallocations within the S&S program may be required. The outcome of the best practices study is intended to inform the revision and standardization of baseline requirements across SC, which will clarify minimum standards and codify a set of principles on which future budget requests can be built.

The FY 2011 submission provides direct funding for S&S for the SC base program. Costs of routine security for Work for Others will be provided via full cost recovery. Extraordinary security requirements for the Work for Others projects will be directly charged to customers. Site security activities that pertain to the institutional security requirements will be charged to either indirect or general and administrative costs.

Estimates of Security Cost Recovered by Science, Safeguards and Security

	(dollars in thousands)		
	FY 2009 Current Appropriation	FY 2010 Current Appropriation	FY 2011 Request
Safeguards and Security			
Ames National Laboratory	0	0	26
Argonne National Laboratory	0	0	1,044
Brookhaven National Laboratory	0	0	810
Lawrence Berkeley National Laboratory	0	0	932
Pacific Northwest National Laboratory	0	0	1,000
Princeton Plasma Physics Laboratory	0	0	29
Oak Ridge National Laboratory	0	0	3,900
Oak Ridge Institute for Science and Education	0	0	400
SLAC National Accelerator Laboratory	0	0	50
Total, Security Cost Recovered	**0**	**0**	**8,191**

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Ames Laboratory	**1,067**	**980**	**1,007**

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 Ames Laboratory with the buildings and activities of Iowa State University has implications for site security planning and site utilization.

Argonne National Laboratory	**9,787**	**8,742**	**8,985**

Argonne National Laboratory has been allocated 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 the transition.

Brookhaven National Laboratory	**11,824**	**11,632**	**11,955**

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 of Investigation. In addition, the Suffolk County

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

Police Department has identified the laboratory as one of the most likely targets of an attack and includes it on their "Critical Infrastructure List." The laboratory's protection strategies consider the adversary capabilities associated with local threat documents and the site's facility protection categories.

Chicago Office	**1,222**	**1,222**	**0**

FY 2009 and FY 2010 funding provides for protective force services at Fermi National Accelerator Laboratory which is transferred to Fermi National Accelerator laboratory in FY 2011, consistent with the contract period.

Fermi National Accelerator Laboratory	**2,024**	**2,169**	**3,486**

As a basic science research laboratory facilitating scientific excellence, Fermi National Accelerator Laboratory is engaged in providing unclassified, open, and collaborative work environments.

Lawrence Berkeley National Laboratory	**5,529**	**5,059**	**5,201**

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 the 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	**1,710**	**1,626**	**1,671**

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	**9,094**	**8,895**	**9,144**

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 supports research 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	**19,174**	**19,357**	**19,895**

The Oak Ridge Office oversees and manages S&S programs at the Oak Ridge National Laboratory and the Oak Ridge Site Office. This request primarily provides funding for protective forces for these sites.

Office of Scientific and Technical Information	**583**	**490**	**504**

The Office of Scientific and Technical Information's mission is to collect, preserve, disseminate, and leverage the scientific and technical information resources of DOE. A primary objective is 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	**11,256**	**11,163**	**11,476**

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

	FY 2009	FY 2010	FY 2011
Management.			
Princeton Plasma Physics Laboratory	**2,242**	**2,178**	**2,237**

Princeton Plasma Physics Laboratory is effectively integrated with the security controls implemented by Princeton University. The laboratory is considered a property protection area. The tritium inventory is located in four areas within a secured perimeter and a restricted access area.

SLAC National Accelerator Laboratory	**2,679**	**2,643**	**2,716**

The security interests for SLAC include protection of designated property protection areas for people 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	**1,504**	**1,432**	**1,470**

Entry to the laboratory is controlled to limit access to individuals who have an official purpose at the research facility. No areas are defined as security areas; security interests are protected by employing logical protection strategies. Unclassified sensitive information requiring protection is controlled by employees who are in possession of the documents or information technology system. High value property is protected by the employee custodian of the property.

All Other	**908**	**5,412**	**6,753**

All Other supports the continuation and management of a consistent cyber security approach across the Office of Science laboratory complex, Federal security clearances, and program management needs for SC. Funding will be allocated based on the highest priority needs at the conclusion of scheduled programmatic reviews.

Total, Safeguards and Security	**80,603**	**83,000**	**86,500**

Explanation of Changes

	FY 2011 vs. FY 2010 ($000)
Ames Laboratory	
Increased funding maintains S&S activities at the current level of effort.	+27
Argonne National Laboratory	
Increased funding maintains S&S activities at the current level of effort.	+243
Brookhaven National Laboratory	
Increased funding maintains S&S activities at the current level of effort.	+323

	FY 2011 vs. FY 2010 ($000)
Chicago Office	
Security contract funding is transferred to Fermi National Accelerator Laboratory, consistent with contract.	-1,222
Fermi National Accelerator Laboratory	
Increased funding is provided to support the security contract transfer from the Chicago Office and to ensure a current level of effort.	+1,317
Lawrence Berkeley National Laboratory	
Increased funding maintains S&S activities at the current level of effort.	+142
Oak Ridge Institute for Science and Education	
Increased funding maintains S&S activities at the current level of effort.	+45
Oak Ridge National Laboratory	
Increased funding maintains S&S activities at the current level of effort.	+249
Oak Ridge Office	
Increased funding maintains S&S activities at the current level of effort.	+538
Office of Scientific and Technical Information	
Increased funding maintains S&S activities at the current level of effort.	+14
Pacific Northwest National Laboratory	
Increased funding maintains S&S activities at the current level of effort.	+313
Princeton Plasma Physics Laboratory	
Increased funding maintains S&S activities at the current level of effort.	+59
SLAC National Accelerator Laboratory	
Increased funding maintains S&S activities at the current level of effort.	+73
Thomas Jefferson National Accelerator Facility	
Increased funding maintains S&S activities at the current level of effort.	+38
All Other	
An increase in funding is included for security investigations, and those funds will be distributed upon evaluation of site requirements.	+1,341
Total Funding Change, Safeguards and Security	**+3,500**

Supporting Information

Operating Expenses, Capital Equipment and Construction Summary

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Operating Expenses	80,581	83,000	86,500
General Plant Projects	22	0	0
Total, Safeguards and Security	80,603	83,000	86,500

Science Program Direction

Funding Profile by Category

(dollars in thousands/whole FTEs)

	FY 2009 Current Appropriation	FY 2009 Current Recovery Act Appropriation[a]	FY 2010 Current Appropriation	FY 2011 Request
Science Program Direction				
Salaries and Benefits	133,325	0	146,360	161,643
Travel	3,732	0	4,336	4,919
Support Services	23,904	4,960	16,311	23,667
Other Related Expenses	25,734	640	22,370	24,208
Total, Science Program Direction	186,695	5,600	189,377	214,437
Full Time Equivalents[b]	1,012	0	1,077	1,135

Program Overview

Mission

The mission of the Science Program Direction (SCPD) program is to support and sustain a skilled and motivated Federal workforce that oversees the Office of Science (SC) investments in world-leading scientific research. The SC workforce is responsible for developing and shaping the science program, executing and managing science funding, and overseeing construction of large scientific user facilities. Oversight includes the health and safety of the workforce and overall security requirements. Additionally, the Federal workforce provides administrative, business, legal, and technical management of research grants and contracts, the oversight of the management and operating (M&O) contracts for 10 of the 17 DOE national laboratories, and public access to DOE's research and development (R&D) results.

Background

Carrying out SC's mission—to deliver the scientific discoveries and major scientific tools that transform our understanding of nature and to advance the energy, economic, and national security of the United States—requires not only highly skilled scientific and technical expert program and project managers, but experts in the area of acquisition; finance; legal; construction and infrastructure management; and environment, safety, and health. With growing national challenges in energy, environmental stewardship, and nuclear security, and the need to maintain U.S. innovation and scientific competitiveness, SC continues to be called upon to support world-leading science and research capabilities that will lead to transformational solutions to these challenges and train the next generation of science and engineering leaders in the U.S. Oversight of DOE's basic research portfolio, which includes grants and contracts supporting over 27,000 researchers, as well as oversight of major construction projects, is an exclusively Federal responsibility calling upon a diverse set of knowledge and skills.

SC directly funds, oversees, and manages research programs in condensed matter and materials physics, chemistry, biology, climate and environmental sciences, applied mathematics, computational science,

[a] The Recovery Act Current Appropriation column reflects the allocation of funding as of September 30, 2009.
[b] Responsibility for the High Flux Isotope Reactor was transferred in FY 2009 to SC from the Office of Nuclear Energy. Therefore all FY 2009 funding ($899,000) and FTEs (4) are reflected in SC.

high energy physics, nuclear physics, plasma physics, and fusion energy sciences. SC also provides the nation's researchers with state-of-the-art user facilities—the large machines of modern science. 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.

With a highly skilled and experienced Federal workforce, SC is able to plan, execute, and manage science programs that meet critical national needs. Specifically:

- The SC Headquarters (HQ) Federal workforce is responsible for oversight of the Federal funds that are awarded to over 300 universities, all 17 DOE national laboratories, and private research institutions. This includes scientific program planning, execution, and management across a broad spectrum of scientific disciplines and program offices and oversight of the design, construction, and operation of large-scale scientific user facilities at laboratories and universities. Program management and oversight includes regular rigorous evaluation of research programs, facilities, and projects by external peer review. Working in collaboration with the laboratory and university communities, the SC HQ Federal staff set the policies and direction for DOE science investment and provides the required Federal oversight.
- SC is responsible for 10 of the 17 DOE national laboratories. Site Office Federal staff, located at each of the 10 SC national laboratories, are responsible for implementing the SC program within the framework established by HQ policy. Site Office staff are also responsible for the day-to-day oversight of $4 billion per year and manage DOE's performance-based M&O contracts for the safe, secure, and effective operation of the laboratories. Site Office staff provide the on-site SC Federal presence with authority encompassing contract management, program and project implementation, and internal operations.
- The Integrated Support Center at the Chicago and Oak Ridge Offices offers administrative, business, legal, and technical support across the entire SC enterprise. These operations include financial management; human resources; grant and contract processing; safety, security, and health management; labor relations, intellectual property and patent management; environmental compliance; infrastructure operations and maintenance; and information systems development and support.
- Federal staff at 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's collection from the mid-1990's to the present is available entirely on line. The transition to a purely digital collection has resulted in significant economies. 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.

Benefits

SCPD provides resources necessary for the Office of Science to execute its mission. Maintaining a highly skilled workforce enables the Office of Science to develop and sustain world-class science programs that deliver the scientific discoveries and technological innovations needed to solve our Nation's energy and environmental challenges, and enable the U.S. to maintain its global competitiveness. Providing easy access to scientific findings leverages the Federal science investment and advances the scientific enterprise. With adequate staffing levels and a workforce balanced with appropriate skills, education, and experience, the Office of Science is an effective and efficient steward of taxpayer dollars for maximum national benefit.

Program Planning

The following factors influenced the FY 2011 SCPD budget request:

- *Increased funding for SC research and scientific facilities investment in FY 2009 and FY 2010*. This growth is driven by the increased Federal investment in basic research and research capabilities. The increased SC research, construction, and general plant project funding in FY 2009 and FY 2010 necessarily creates an additional workload on the Federal staff across numerous areas across the SC complex. In FY 2009, grant and contract awards (excluding laboratory field work proposals) increased by 30% over the FY 2008 level, placing significant demands on the current acquisition workforce at HQ and in the field. Increased funding allotments, accelerated execution of those allotments, and the Administration's goal of greater transparency and accountability places greater financial management and oversight responsibilities on program, budget, financial, and accounting offices across the complex. New construction projects and general plant projects will require additional project management, facility, and safety oversight. The plan to double the budget for key research agencies such as the DOE Office of Science will continue to increase the need for effective oversight.
- *Challenges and expectations facing the current SC workforce*. The increased need for highly skilled Federal program and project management requires an SCPD budget that keeps pace with growth in science program funding. However, prior to the FY 2011 budget request, SCPD budgets and workforce have not kept pace with total SC budget increases. From FY 2006 to FY 2010, total SC funding grew at an annualized growth rate of 7.8%; in contrast, SCPD funding only increased at an annualized rate of 4.4% for the same timeframe.
- *Committee of Visitors' (COV) report findings*. SC charges its Federal Advisory Committees every three years to form COVs to externally review its research programs, including how those programs are being managed. Since FY 2002, 17 COV reports have cited the need for additional SC HQ Program Managers and support staff for virtually all research program offices. The HQ Program Manager is responsible for scientific program development, oversight and management, and working in collaboration with the laboratory and university communities. Some reports have noted that staff levels are insufficient for adequate review, oversight, and management of programs.
- *Succession planning across the Office of Science.* The FY 2011 request supports recruitment initiatives, such as local job fairs, Student Career Experience Program, Student Temporary Employment Program, and Intern Programs to attract, keep, and reward the best and brightest—the next generation needed to maintain the U.S. preeminent position in science and technology. These professionals will participate in SC mentorship programs led by high-performing Federal managers. Currently, the average age of SC employees is 51 and 301 employees (31%) are eligible for voluntary retirement in FY 2010; by FY 2011, 321 employees (32%) will be eligible for voluntary retirement.

Budget Overview

The FY 2011 SCPD budget request includes support for salaries and benefits for 1,135 FTEs responsible for executing, managing, and overseeing SC sponsored research programs and providing required oversight. The FY 2011 FTE ceiling includes an increase of 58 FTEs or a 5% increase over the FY 2010 FTE ceiling of 1,077.

The SCPD request also supports travel of SC Federal employees and Advisory Committee members, and support services, including information management systems, grants and contracts management systems, career development related training, and education opportunities.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Salaries and Benefits	**133,325**	**146,360**	**161,643**

The SC Federal HQ workforce has a broad range of responsibilities including scientific program planning, execution, and management across a broad spectrum of scientific disciplines and program offices, and oversight of the design, construction, and operation of large-scale scientific user facilities at laboratories and universities. Program management and oversight includes regular rigorous evaluation of research programs, facilities, and projects by external peer review, the majority of which is led by SC Program Managers. SC Program Managers play a central role in the Office of Science's support for world leading research. They represent their programs and the Office of Science in communicating to the scientific community research interests and priorities. They are responsible for selecting appropriate expert peer reviewers and ensuring rigorous merit review of research proposals and evaluation of research programs, and are ultimately responsible for award recommendations informed by peer review. They also have responsibility for maintaining a balanced research portfolio that includes high-risk, high-return research to maximize the Program's potential to achieve mission goals and objectives. Program Managers in the Office of Science are experts in their fields. They stay informed by attending scientific meetings to listen to the cutting edge discussions, communicating with investigators, and staying abreast of the latest scientific and technical literature. Their expertise enables them to recognize new opportunities for quality, cutting-edge research areas important for advancing the scientific fields within their programs. In FY 2009, some 3,500 new and renewal laboratory, university, nonprofit and private industry proposals were awarded, while another 2,500 additional, ongoing awards were managed.

The SC Site Office personnel at SC's 10 national laboratories are the government representatives charged with ensuring mission execution and serve as the government agent in the contractual relationship with the laboratory's operating contractor. These contracts are one of the principal mechanisms utilized to execute the annual budget for the Office of Science to support world-leading science and development and operation of scientific facilities for the Nation. SC and the Department establish plans and expected outcomes for each of the contractors. The SC Site Office personnel responsibilities, many of which are inherently government actions and cannot be performed by contractors, include oversight of contractor activities for the purpose of providing performance evaluation of the contractor, and ensuring timely delivery of Government-furnished services and items, including required Federal approvals and acceptance of contract deliverables and processing of transactions. Contract deliverables and transactions include, but are not limited to, contract funding modifications, reports required by law and statute, program work authorizations, approvals to operate hazardous facilities, leases, property transfers, subcontracts above the Department-authorized thresholds, grants, and activity approvals dictated by law, regulation, and DOE requirements.

These activities are performed by a small number of Federal staff (about 15 to 30 at each site, compared to contractor staffing levels of several thousand in many cases) led by a management representative with the authority to act on the sponsoring programs' behalf, exercising management discretion as appropriate to enable the contractor to deliver on the DOE mission. The manager is supported by Federal contracting officers with the authority and associated warrant to enter the government into binding agreements. The contracting officers are supported by a variety of business specialists who provide accounting, budget, and other business process evaluations and analysis in support of contracting officer decisions and determinations. This is essential given that activities at the laboratories must be conducted on a full cost recovery basis for the government. The site office also has technical staff to evaluate complex, integrated laboratory activities, often including nuclear, radiological, and other complex hazards, as well as qualified Federal project directors to facilitate execution of line item and other construction projects. These technical evaluations inform the government's contractually required evaluation of contractor performance and also provide the basis for acceptance of technical risk by the government.

Effectively supporting the administration of thousands of grants and contracts each year requires a skilled team of Federal staff with procurement, business, legal, and broad range technical expertise. The Integrated Support Center (ISC), comprised of capabilities of both the Chicago and Oak Ridge Offices, provides this support to the SC programs. Likewise, each SC Site Office is supported by the ISC, which is the legal DOE allottee that manages multi-appropriation, multi-program allotments for all of the SC national laboratories. The ISC also holds human resource and real property authorities, and provides additional staff as required to the Site Offices in the areas of information management, environmental safety and health, security, and legal support. The ISC provides support to the SC programs for solicitations and is responsible for the negotiation, award, and administration of contracts and financial assistance awards. The ISC processed well over 4,800 award actions in FY 2009 alone; this number has doubled in the last 7 years.

In FY 2011, funding is requested for 1,135 Federal FTEs for the SC workforce. Funds will support staff with the responsibility for science program development; program and project execution and management; the administrative, business, and technical management of research grants and contracts; oversight of 10 of the 17 DOE national laboratories; and providing public access to the DOE's R&D results.

This requested FTE level, an increase of 58 FTEs from the FY 2010 FTE ceiling, directly responds to the significant increase in workload associated with multi-year funding increases for SC research and scientific facilities, succession planning needs associated with an aging workforce to ensure the next generation of scientific and technical experts are available to maintain the U.S. leadership in science and technology, and is supported and validated by multiple COV reports over the past 7 years.

The 58 additional new FTEs requested in FY 2011 include:

- 22 additional Program Manager and support staff FTEs for the SC HQ program offices to ensure that the necessary resources and infrastructure exist 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 succession planning and staff development requirements.
- 36 additional staff FTEs across the SC Field complex will ensure that acquisition (grants and contracts), financial, human resources, 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.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Travel	**3,732**	**4,336**	**4,919**

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 changes of station (PCS).

Federal staff travel is required to enable effective management of a broad spectrum of scientific research programs and construction and operation of user facilities, and to perform contractor oversight at geographically dispersed facilities at national laboratories and universities. Management and oversight of research grants across all of the SC research programs requires regular external review, including site visits. Review of large and complex research or facility proposals may also require site visits during the course of the peer review process. In addition, travel by Federal staff is necessary 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; and operational policy and process reviews.

Support for travel to meetings, conferences, and training for skill maintenance and/or certification enables the Office of Science to build and maintain the highly technical and skilled workforce that is required.

The request also provides for travel expenses for over 150 members making up the six individual SC Federal Advisory Committees. Committee members consist of representatives from universities, national laboratories, and industry and include 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	**23,904**	**16,311**	**23,667**

Provides both technical expertise and general administrative services and activities as follows: Maintenance, operation, and cyber security management of SC mission-specific information management systems and infrastructure and SC-corporate Enterprise Architecture and Capital Planning Investment Control management; 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; 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; and staffing for 24-hour emergency communications centers and safeguards and security (S&S) oversight functions.

Other Related Expenses	**25,734**	**22,370**	**24,208**

Provides SC's contribution of $8,681,000 to the Department's Working Capital Fund (WCF) for common administrative services at HQ, such as rent and building operations, telecommunications, network connectivity, supplies/equipment, printing/graphics, copying, mail, contract closeout, and purchase card surveillance. In addition, WCF services assessed to and used by HQ, OSTI, and the Field

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

include online training, the Corporate Human Resource Information System, payroll processing, and the Project Management Career Development Program.

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.

$750,000 is provided for the Under Secretary of Science to sponsor studies and workshops in furtherance of the role for his Office as defined by the Energy Policy Act of 2005 in 42 USC 7132(b)(4), subparagraphs (A)-(F). These roles include serving as the Science and Technology Advisor to the Secretary, identifying any undesirable duplication or gaps in R&D programs, monitoring the well-being and management of the multipurpose laboratories, examining the effectiveness of grants and other forms of financial assistance, and leading the long-term planning, coordination, and development of a strategic R&D framework for the Department. These responsibilities are not exclusively related to programs within the Office of Science.

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 an E-Gov fee for the Integrated Acquisition Environment.

	FY 2009	FY 2010	FY 2011
Total, Science Program Direction	**186,695**	**189,377**	**214,437**

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Salaries and Benefits	
Salaries and Benefits funds current payroll and all other payroll-related expenses across the SC complex for a net increase of 58 FTEs over FY 2010. This assumes a 1.4% pay raise in January 2011 and 4.5% escalation for personnel/pay related activities for employee health insurance and retirement benefits. Effective October 1, 2010 (FY 2011), this also includes an increase for the employing agency contribution of 0.6% for Civil Service Retirement System employees and 0.5% for Federal Employees Retirement System employees.	+15,283
Travel	
This increase provides support for travel requirements related to additional Program Managers and increased program management oversight of a significantly increased SC research portfolio at HQ (+$175,000); increased travel requirements by technical and administrative staff supporting acquisitions, finance, ES&H, and training certifications and qualifications (+$360,000); and 1.1% escalation (+$48,000) for non-pay activities.	+583

	FY 2011 vs. FY 2010 ($000)
Support Services	
FY 2010 expenses at Headquarters and OSTI for the maintenance and operation of SC mission-specific IT systems and support, day-to-day operation of the HQ mailroom and travel processing office, and administration of the DOE Small Business Innovative Research (SBIR) program are being partially supported using prior year balances. $2,275,000 of the increase in FY 2011 supports maintaining a constant level of effort in these areas. Training will be increased $239,000, consistent with additional planned new hires and emphasis on career development, and $96,000 of the increase at Headquarters/OSTI is related to escalation.	
As at Headquarters, FY 2010 expenses in the field for support services including 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, and maintenance and operation of SC mission-specific IT systems and support are being partially supported using prior year balances. $4,473,000 of the increase in FY 2011 supports maintaining a constant level of effort in these areas. Training will be increased $190,000, consistent with additional planned new hires and emphasis on career development, and $83,000 of the increase in the field is related to escalation.	+7,356
Other Related Expenses	
FY 2010 expenses at Headquarters for other services and IT software and hardware requirements are being partially supported using prior year balances. $652,000 of the increase in FY 2011 supports maintaining a constant level of effort in these areas. $750,000 of the increase supports activities by the Under Secretary of Science as defined by the Energy Policy Act of 2005. $232,000 of the increase is related to the SC Working Capital Fund contribution due to increases for rent, building operations, utilities, communications, and additional FY 2011 new hires and $141,000 of the increase is related to escalation.	
In the field, FY 2010 expenses for other services and fixed requirements such as building operations, utilities, communications are being partially supported using prior year balances. $63,000 of the increase in FY 2011 supports maintaining a constant level of effort in these areas.	+1,838
Total Funding Change, Science Program Direction	**+25,060**

Supporting Information

Operating Expenses, Capital Equipment and Construction Summary

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Operating Expenses	186,695	189,377	214,437

Funding Profile by Category by Site

(dollars in thousands/whole FTEs)

	FY 2009	FY 2010	FY 2011
Headquarters			
Salaries and Benefits	43,391	52,709	60,207
Travel	2,198	2,876	2,968
Support Services	7,213	7,926	10,332
Other Related Expenses	14,986[a]	11,750	13,729
Total, Headquarters	67,788	75,261	87,236
Full Time Equivalents	279	352	374
Office of Scientific and Technical Information			
Salaries and Benefits	6,226	6,904	6,953
Travel	90	86	84
Support Services	1,573	859	1,063
Other Related Expenses	1,264	1,067	863
Total, Office of Scientific and Technical Information	9,153	8,916	8,963
Full Time Equivalents	58	57	57
Field Offices			
Chicago Office			
Salaries and Benefits	23,604	24,180	26,855
Travel	380	365	525
Support Services	3,152	2,052	4,483
Other Related Expenses	2,835	2,495	1,697
Total, Chicago Office	29,971	29,092	33,560
Full Time Equivalents	193	190	204

[a] In FY 2009, the OSTI WCF activity ($41,000) is included in Headquarters. The FY 2010 ($41,000) and FY 2011 ($43,000) amounts are included in OSTI.

(dollars in thousands/whole FTEs)	FY 2009	FY 2010	FY 2011
Oak Ridge Office			
Salaries and Benefits	28,404	28,217	30,655
Travel	403	360	536
Support Services	9,396	3,449	6,163
Other Related Expenses	5,280	5,808	4,903
Total, Oak Ridge Office	43,483	37,834	42,257
Full Time Equivalents	262	247	260
Ames Site Office			
Salaries and Benefits	517	561	609
Travel	18	22	12
Support Services	1	2	0
Total, Ames Site Office	536	585	621
Full Time Equivalents	4	4	4
Argonne Site Office			
Salaries and Benefits	3,075	3,418	4,138
Travel	76	0	55
Support Services	15	0	115
Total, Argonne Site Office	3,166	3,418	4,308
Full Time Equivalents	21	23	26
Berkeley Site Office			
Salaries and Benefits	3,485	4,032	4,272
Travel	68	80	89
Support Services	62	250	105
Other Related Expenses	70	100	120
Total, Berkeley Site Office	3,685	4,462	4,586
Full Time Equivalents	23	25	24

(dollars in thousands/whole FTEs)

	FY 2009	FY 2010	FY 2011
Brookhaven Site Office			
Salaries and Benefits	3,883	4,370	4,631
Travel	36	110	110
Support Services	6	363	354
Other Related Expenses	5	277	350
Total, Brookhaven Site Office	3,930	5,120	5,445
Full Time Equivalents	25	27	28
Fermi Site Office			
Salaries and Benefits	2,092	2,326	2,597
Travel	19	9	63
Support Services	1	8	40
Other Related Expenses	0	20	0
Total, Fermi Site Office	2,112	2,363	2,700
Full Time Equivalents	15	16	17
New Brunswick Laboratory			
Salaries and Benefits	3,774	4,128	4,462
Travel	87	92	75
Support Services	1,349	1,145	509
Other Related Expenses	922	767	1,969
Total, New Brunswick Laboratory	6,132	6,132	7,015
Full Time Equivalents	27	30	33
Oak Ridge National Laboratory Site Office			
Salaries and Benefits	3,893	4,076	4,354
Travel	63	70	42
Support Services	551	161	22
Other Related Expenses	58	50	39
Total, Oak Ridge National Laboratory Site Office	4,565	4,357	4,457
Full Time Equivalents	30	30	32

	(dollars in thousands/whole FTEs)		
	FY 2009	FY 2010	FY 2011
Pacific Northwest Site Office			
Salaries and Benefits	4,970	5,014	5,450
Travel	143	147	172
Support Services	277	67	221
Other Related Expenses	174	36	330
Total, Pacific Northwest Site Office	5,564	5,264	6,173
Full Time Equivalents	34	35	36
Princeton Site Office			
Salaries and Benefits	1,728	1,805	1,920
Travel	4	0	46
Support Services	2	0	12
Other Related Expenses	0	0	80
Total, Princeton Site Office	1,734	1,805	2,058
Full Time Equivalents	12	12	12
SLAC Site Office			
Salaries and Benefits	2,524	2,672	2,476
Travel	63	52	60
Support Services	301	24	220
Other Related Expenses	60	0	73
Total, SLAC Site Office	2,948	2,748	2,829
Full Time Equivalents	16	16	15
Thomas Jefferson Site Office			
Salaries and Benefits	1,759	1,948	2,064
Travel	84	67	82
Support Services	5	5	28
Other Related Expenses	80	0	55
Total, Thomas Jefferson Site Office	1,928	2,020	2,229
Full Time Equivalents	13	13	13

	FY 2009	FY 2010	FY 2011
	(dollars in thousands/whole FTEs)		
Total Field Offices			
Salaries and Benefits	83,708	86,747	94,483
Travel	1,444	1,374	1,867
Support Services	15,118	7,526	12,272
Other Related Expenses	9,484	9,553	9,616
Total, Field Offices	109,754	105,200	118,238
Full Time Equivalents	675	668	704
Total SCPD			
Salaries and Benefits	133,325	146,360	161,643
Travel	3,732	4,336	4,919
Support Services	23,904	16,311	23,667
Other Related Expenses	25,734	22,370	24,208
Total, SCPD	186,695	189,377	214,437
Full Time Equivalents[a]	1,012	1,077	1,135

Support Services by Category

	FY 2009	FY 2010	FY 2011
	(dollars in thousands)		
Technical Support			
Development of Specifications	360	140	146
System Definition	250	110	162
System Review and Reliability Analyses	750	400	510
Surveys or Reviews of Technical Operations	2,028	1,121	161
Total, Technical Support	3,388	1,771	979

[a] Responsibility for the High Flux Isotope Reactor (HFIR) was transferred in FY 2009 to SC from the former Office of Nuclear Energy (NE). Therefore all FY 2009 funding ($899,000) and FTEs (4) are reflected in SC.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Management Support			
Automated Data Processing	10,878	6,292	10,465
Training and Education	806	929	1,352
Analyses of DOE Management Processes	0	86	0
Reports and Analyses, Management, and General Administrative Services	8,832	7,233	10,871
Total, Management Support	20,516	14,540	22,688
Total, Support Services	23,904	16,311	23,667

Other Related Expenses by Category

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Other Related Expenses			
Rent to GSA	808	837	825
Rent to Others	1,365	1,737	100
Communications, Utilities, and Miscellaneous	1,776	1,596	2,151
Printing and Reproduction	40	35	73
Other Services	3,237	3,517	7,221
Operation and Maintenance of Equipment	1,123	1,358	99
Operation and Maintenance of Facilities	1,989	1,835	2,042
Supplies and Materials	1,540	1,241	738
Equipment	1,571	1,747	2,278
Working Capital Fund	12,285	8,467	8,681
Total, Other Related Expenses	25,734	22,370	24,208