Fusion Energy Sciences

Funding Profile by Subprogram

	(dollars in thousands)	
	FY 2010 Current Appropriation	FY 2012 Request
Fusion Energy Sciences		
Science	169,045	177,816
Facility Operations	223,002	195,882
Enabling R&D	25,603	26,002
Total, Fusion Energy Sciences	417,650[a]	399,700

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"
Public Law 111–358, "America COMPETES Act of 2010"

Program Overview

Mission

The Fusion Energy Sciences (FES) mission is to expand the fundamental understanding of matter at very high temperature and density and to build the scientific foundation needed to develop a fusion energy source. This is accomplished by studying plasma and its interactions with its surroundings across wide ranges of temperature and density, developing advanced diagnostics to make detailed measurements of its properties and dynamics, and creating theoretical and computational models to resolve the essential physics principles.

Background

The pursuit of fusion energy embraces the challenge of bringing the energy-producing power of a star to earth for the benefit of humankind. The promise is enormous—an energy system whose fuel is obtained from seawater and from plentiful supplies of lithium in the earth, whose resulting radioactivity is modest, and which yields zero carbon emissions to the atmosphere. The pursuit is one of the most challenging programs of scientific research and development that has ever been undertaken. With the support of FES, a devoted, expert, and innovative scientific and engineering workforce has been responsible for the impressive progress in harnessing fusion energy since the earliest fusion experiments over sixty years ago. As a result, we are on the verge of a new age in fusion science during which researchers will undertake fundamental tests of fusion energy's viability. Establishing a deep scientific understanding of the requirements for harnessing and optimizing this process on earth is critical, and the progress has been dramatic.

The science underpinning much of fusion energy research is plasma physics. Plasmas—the fourth state of matter—are hot gases, hot enough that electrons have been knocked free of atomic nuclei, forming an ensemble of ions and electrons that can conduct electrical currents and can respond to electric and magnetic fields. The science of plasmas is elegant, far-reaching, and impactful. Comprising over 99% of

[a] Total reduced by $8,350,000; $7,455,000 of which was transferred to the Small Business Innovation Research (SBIR) program and $895,000 of which was transferred to the Small Business Technology Transfer (STTR) program.

the visible universe, plasmas are also pervasive. It is the state of matter of the sun's center, corona, and solar flares. Plasma dynamics are at the heart of the extraordinary formation of galactic jets and accretion of stellar material around black holes. On earth it is the stuff of lightning and flames. Plasma physics describes the processes giving rise to the aurora that gently illuminates the far northern and southern nighttime skies. Practical applications of plasmas are found in various forms of lighting and semiconductor manufacturing, and of course plasma televisions.

On earth, fusion is in fact routinely created and controlled in our research laboratories; leading experiments have generated millions of watts of fusion power for seconds at a time. In the vision of a working reactor, some of the energy will be captured by the plasma itself, and the plasma will self-heat, enabling more fusion to take place. The energy of the energetic ions and neutrons escaping the plasma will be captured and converted into heat. This heat will drive conventional power plant equipment to boil water, generate steam, and turn turbines to put electric power on the grid.

The foremost challenge for fusion is controllable, stable confinement of the hot plasma. The leading approach to fusion energy being pursued in the world is confining the hot fusion fuel with magnetic-field. Presently, this "magnetic fusion energy" approach is the primary focus of the FES program. A second approach is to compress the fuel and then raise its temperature rapidly so as to reach fusion conditions and rely on the inertia of the fuel itself to keep it confined long enough for fusion to happen. This "inertial fusion energy" approach is being studied by the National Nuclear Security Administration (NNSA) and FES together in a joint sponsored program researching high energy density states of matter relevant to inertial fusion.

In the last two decades, progress in our understanding of plasma systems and their control requirements has enabled the fusion community to move to the edge of a new era, the age of self-sustaining "burning" plasmas. For both magnetic and inertial fusion, new experimental plans are being developed to make historic first studies of fusion systems where the energy produced in the fusion process is substantially greater than the energy applied externally to heat and control the plasma. In a burning plasma, energy confinement, heating, and stability affect each other in ways we need to predict, and the scientific issues associated with creating and sustaining power-producing plasma can be explored directly. The flagship program of this new era is the ITER project, an international fusion research project being constructed in Cadarache, France, that will realize magnetically confined burning plasmas for the first time.

A second great challenge for fusion is developing materials that can tolerate the extreme conditions of a fusion reactor. A plasma at a high enough temperature and density to undergo nuclear fusion in a reactor, while generating close to a billion watts of fusion power, will present a uniquely hostile environment to the materials comprising the reactor. The extreme heat fluxes inflicted on a reactor vessel's walls—at rates of tens of millions of watts per square meter—present significant materials science challenges. Furthermore, in a fusion reactor, material near the burning plasma is bathed in a harsh shower of neutrons that will displace its constituent atoms, alter its volume and shape, and thus qualitatively change its strength and other characteristics in unknown ways. The advances in material science required for reactor components that can withstand exposure to the enormous heat and neutron fluxes emanating from prolonged fusion burns are likely to benefit other technologies, including fission power.

Experimental research reveals to us how to scale the results from present fusion experiments to those required for energy production. Increasingly, this research is grounded in a deep, experimentally validated theoretical understanding that is growing in parallel with the empirical accomplishments. High-end computation is playing an integral role in this effort. Theory-based computational modeling and simulation are improving our ability to predict the performance of experimental systems. In many areas once regarded as too complex to allow anything except an empirical approach, modeling and simulation are being used as tools for discovery and are guiding experimental choices, a sign of increasing maturity of the scientific field and increasing readiness for the engineering challenges of fusion energy development. It is this progress that has laid the foundation for the Fusion Simulation Program, a computational initiative 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 Fusion Simulation Program is led by FES with cross-office support from Advanced Scientific Computing Research.

Advances in fusion science are also fostering discoveries outside the realm of fusion. An example is our increasing understanding of the anomalous heating of the solar corona, where studies in plasma physics are helping to unravel this mystery. Fusion's theory-based computational tools have also been used recently to explain the unexpectedly low brightness of the accretion plasma in the extraordinary environment surrounding super massive black holes in the center of our galaxy. In the past 20 years, similar computational tools have helped to increase dramatically our understanding of the nonlinearly saturated state of plasma turbulence and the resulting energy transport.

FES has 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 scientifically linked goals synthesize the input from the National Academies, the Fusion Energy Sciences Advisory Committee (FESAC), and the U.S. fusion community.

FES research activities have led to significant advances in fusion related sciences, such as increasing the fusion power output in laboratory experiments by 12 orders of magnitude over the past three decades, developing 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 demonstrating control of plasma states that scale favorably to burning plasmas and future fusion reactors. The U.S. leads the world in developing the tools and the operating scenarios that impact the plans for ITER operations and design, and in developing the foundations for a validated predictive capability that will enable ITER scenario development and interpretation of the results obtained from this device. Importantly, FES is also establishing the basis for a strong move into the frontier fields of materials science needed for managing the fusion environment and for harnessing its power.

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 plasma properties, dynamics, and interactions with surrounding materials. The greatest emphasis is presently weighted towards understanding the plasma state relevant to stable magnetically confined fusion systems, but increasing emphasis is expected in the areas of plasma-material interaction physics and the materials science associated with the high heat and neutron fluxes that will be encountered in a burning plasma environment. This subprogram also addresses fundamental scientific questions on high-energy-density laboratory plasmas (HEDLP), non-neutral and single-component plasmas, ultra cold plasmas, dusty plasmas, low-temperature plasmas, space and astrophysical plasma physics, plasma control and dynamics, plasma-related atomic and molecular physics, plasma diagnostic techniques, plasma sources, magnetic-field-line reconnection and self-organization, and plasma waves, turbulence, structures, and flows. Since these efforts are typically carried out in university environments, they also serve a critical function in educating and training scientific and technical personnel.

- 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—the 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 and to address a subset of the materials science issues required to manage the intense heat and particle fluxes of a fusion reactor. All three are operated as national collaborative user facilities and involve users from many laboratories, industries, 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. 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.

Understanding the plasma science and the materials science associated with magnetic fusion energy environments are essential to the development of practical 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. Fusion reactor design studies suggest that electricity from fusion could cost about the same as electricity from other sources.

Studies of the extreme states of matter in HEDLP are scientifically relevant to inertial fusion energy, a potential alternate path to a fusion energy source. This research is also related to the NNSA stockpile stewardship program and, hence, indirectly supports DOE's national security mission.

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.[a] 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* in September 2008. FES organized a community-wide effort that, in June 2009, culminated in a Magnetic Fusion Energy Sciences (MFES) Research Needs Workshop (ReNeW) to describe the scientific research required during the ITER era to develop the knowledge needed for a practical fusion power source. The report *Research Needs for Magnetic Fusion Energy Sciences* was published in September 2009. 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*.[b]

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. The report was published in October 2010. 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. SC and NNSA have jointly appointed FESAC as the Federal Advisory Committee for the FES-NNSA joint program in HEDLP. 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, composed primarily of researchers from outside the host facility, 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.

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 COV charge was given to FESAC in November 2008 asking FESAC to review the entire FES research program and report its findings. The COV has conducted its review, meeting with the FES program staff in August 2009. The COV presented its findings to the full committee at the FESAC meeting on March 9-10, 2010. The final FESAC report on this COV activity entitled: "*Fusion Energy Sciences Advisory*

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[a] The 2008/2009 reports are located at http://www.science.doe.gov/ofes/programdocuments.shtml.
[b] Available at http://www.nap.edu/catalog.php?record_id=11960.

Committee: Report on A Committee of Visitors-Review of Procedures and Processes Used to Solicit and Fund Research at Universities, National Laboratories and Industrial Firms", April 2010, has been published.

Basic and Applied R&D Coordination

FES and NNSA have a joint program in HEDLP to provide stewardship of high-energy-density laboratory plasma physics. High energy density plasmas are defined as having pressures exceeding one million atmospheres (1 megabar). The FES high energy density physics program includes discovery-driven fundamental research as well as inertial fusion related science. 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, heavy-ion-beam driven warm dense matter, compressible and radiative hydrodynamics, laser-plasma interactions, material properties under extreme conditions, and laboratory astrophysics. The joint SC and NNSA program in HEDLP coordinates solicitations, peer reviews, scientific workshops, and Federal Advisory Committee input between the two offices.

Budget Overview

FES is the primary supporter of research in the field of plasma physics in the United States. The FY 2012 budget request is designed to optimize the scientific productivity of the program. FES funds activities involving over 1,240 researchers and students in 31 states at approximately 63 universities, 9 industrial firms, 10 DOE national laboratories, and 2 other Federal laboratories. Some of the key activities of the FES program and their status in the FY 2012 budget request follow:

- The United States will continue to meet our obligations during construction of the U.S. Contributions to the 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. 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. Attention will increase on these facilities regarding research important to materials science and solutions for managing the intense energy fluxes of future fusion devices.

- The planning phase of the Fusion Simulation Program (FSP), a computational initiative aimed at the development of an experimentally validated, predictive simulation capability for magnetically confined fusion plasmas in the regimes and geometries relevant for practical fusion energy, is expected to be completed by FY 2012. While no specific FSP activities are planned in FY 2012, the planning report will help FES prepare future solicitations for the eventual launching of this program.

- Plasma Science Centers (PSCs) support multi-institutional teams to work on some of the most integrated and challenging plasma science problems of our time. The three PSCs are intended to foster scientific collaborations and contribute significantly to the education and training of plasma scientists.

- FES investments in emerging scientific opportunities in HEDLP have strengthened U.S. leadership in this growing field of plasma science and will continue basic research on the science of fast ignition, laser-plasma interaction, magnetized high energy density plasmas, and warm dense matter. FES and NNSA continue 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 Stanford Linear Accelerator Center (SLAC) will permit studies of high energy states of matter with unprecedented precision after project completion in 2013. 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.
- A modest increase in fusion-related materials science research is requested in this budget. One of the clearest recommendations that comes from the magnetic fusion community from the ReNeW process and underscored by the FESAC *Priorities, Gaps, and Opportunities report*, 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 collaboration with other research programs in the Department, including those stewarded by Basic Energy Sciences.
- A modest increase in magnetic fusion research conducted at overseas facilities is requested. This research positions the U.S. to leverage international investments in unique facilities focused on long pulse, steady-state research through the use of superconducting magnet technology. Potential future international engagement includes development of research on the world's largest tokamak, the Joint European Torus (JET) in the United Kingdom, as a prototype for ITER scenarios and tools, and joint research on assessing the physics requirements for operating tokamaks of compact geometry such as NSTX as a potential volume source of neutrons for future materials and component testing. A mature research approach on international facilities will also need to be developed to gain maximal scientific benefit from ITER.

Annual Performance Results and Targets

The Department is in the process of updating its strategic plan, and has been actively engaging stakeholders including Congress. The draft strategic plan is being released for public comment concurrent with this budget submission, with the expectation of official publication this spring. The draft plan and FY 2012 budget are consistent and aligned. Updated measures will be released at a later date and available at the following link http://www.mbe.doe.gov/budget/12budget.

Funding Schedule by Activity

(dollars in thousands)

	FY 2010 Current Appropriation	FY 2012 Request
Science		
Tokamak Experimental Research	52,381	60,900
Alternative Concept Experimental Research	65,942	59,290
Theory	25,105	24,348
Advanced Fusion Simulations	11,182	8,312
General Plasma Science	14,435	16,780
SBIR/STTR	0	8,186
Total, Science	169,045	177,816

Description

Plasmas are ionized gases composed of a mixture of ions and electrons that are influenced by magnetic and electric fields either externally applied or generated by the plasma itself. The Science subprogram seeks to understand the fundamental nature of plasmas, especially fusion-relevant plasmas, through an integrated program of experiments, theory, and simulation.

The Science subprogram focuses on the physical processes that govern the behavior of a plasma, and the creation, confinement, heating, and control of a burning plasma to make fusion power a reality.

The Science subprogram supports preparation for the exploration of burning plasmas by developing a range of advanced computational simulation tools, taking advantage of petascale computing resources, to understand the behavior of burning plasma. This effort will yield the integrated computational tools needed to fully utilize ITER and 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 magnetic confinement fusion power.

Selected FY 2010 Accomplishments

- *Improved understanding of intrinsic rotation in tokamak plasmas*: The phenomenon of spontaneous rotation—where the plasma spins in the toroidal direction without any apparent external momentum input—has been observed experimentally in almost all tokamaks and has significant performance implications for ITER and burning plasmas, since plasma rotation can reduce the loss of heat from the plasma and can help stabilize macroscopic instabilities. Recent simulations by researchers at the Scientific Discovery through Advanced Computing (SciDAC) Center for Gyrokinetic Particle Simulation of Turbulent Transport in Burning Plasmas (GPS-TTBP) significantly advanced our understanding of the physical mechanisms responsible for this rotation in tokamak plasmas. The GPS-TTBP simulations—enabled by the SC High Performance Computing resources at Oak Ridge National Laboratory and National Energy Research Scientific Computing Center—confirmed the role of hypothesized symmetry breaking mechanisms such as electric field shear and identified new rotation-inducing mechanisms such as variations in the turbulent fluctuation amplitude.

- *Exploration of the new "I"-mode advanced operating scenario on Alcator C-Mod:* Good confinement involves large values of temperature and density, stationary conditions, and small heat and particle loss. New operational parameter regimes were found that combine a stronger barrier to thermal loss and the elimination of edge-localized loss perturbations over a duration that is larger by ten additional intervals of pertinent confinement-time units. In scaled terms, the achievement exceeds certain requirements of ITER, reinforcing confidence in the ITER design. In actual numbers, the achievement nearly matches plasma pressure and fusion reactivity records under any operating scenario mode ever documented in the Alcator C-Mod.
- *Innovative diagnostic developments for turbulence and transport measurement and visualization:* High resolution in time and space is crucial for validating experimental observations with theoretical and numerical predictions. The advanced, dual array Electron Cyclotron Emission Imaging system, which began collecting data on the DIII-D tokamak on March 1, 2010, has demonstrated the ability to resolve coherent fluctuations in electron temperature of less than 0.1% on millisecond time scales. The spatially resolved imaging and this degree of temporal resolution is a vast improvement over previously used methods that average over the plasma volume and need time to gather information from the overwhelming majority of velocity components in the electron population. The new information makes possible comparisons to computer models that need this resolution to discriminate between what, when, and where for validation purposes.
- *Advanced divertor configurations yield improved performance in NSTX:* Handling the very high heat flux expected in future fusion devices and controlling the amount of impurities that enter the plasma will be a significant problem. Operation with a "snowflake" divertor configuration in NSTX resulted in a significant reduction in heat flux to the divertor and improved impurity screening. Peak heat flux was reduced about a factor of two and carbon impurity concentrations were also reduced by about a factor of two. Another option for handling the high divertor heat flux is to operate with a liquid lithium coating on the divertor plates. The use of liquid lithium coatings in NSTX produced improved confinement and higher electron and ion temperatures in the plasma along with a reduction of impurities.

Detailed Justification

(dollars in thousands)

	FY 2010 Current Appropriation	FY 2012 Request
Tokamak Experimental Research	**52,381**	**60,900**

The tokamak magnetic confinement concept is presently the most effective approach for magnetically 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. Through participation in 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.

Tokamak experimental research is advancing rapidly through improvements to plasma control, new plasma measurements of unprecedented detail and accuracy, and ever-stronger 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. The distribution of current in the plasma, vital to reaching the optimal equilibrium state, is controlled with electromagnetic wave heating and current drive. The interface between the plasma edge and the material walls of the confinement vessel, vital to

	(dollars in thousands)	
	FY 2010 Current Appropriation	FY 2012 Request

maintaining the desired boundary conditions for minimizing outflow of energy and particles, 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 scientific user 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 resume research operations in 2011 after recent hardware modifications and as the new superconducting tokamak programs in China (Experimental Advanced Superconducting Tokamak, or EAST) and Korea (Korean Superconducting Tokamak Advanced Research, or KSTAR) advance their research operations, increases in international collaborations are planned. These planned collaborations are intended to address ITER physics, steady-state physics, and technology issues, and three-dimensional magnetic field configurations that are not currently being addressed in U.S. facilities.

▪ **DIII-D Research**	**27,255**	**28,888**

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 ITER-relevant fusion plasma topical areas including transport, stability, plasma-wave physics, and boundary layer physics.

In the first part of FY 2012, hardware and diagnostics improvements will take place and the 7th gyrotron will begin operations in support of experiments, substantially increasing the DIII-D research capabilities for support of burning plasma physics and ITER. The DIII-D program will strengthen collaborations with the international community by accommodating joint experiments, thereby improving the potential for the U.S. leverage of foreign facilities.

▪ **Alcator C-Mod Research**	**9,035**	**10,454**

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

	(dollars in thousands)	
	FY 2010 Current Appropriation	FY 2012 Request

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 2012, Alcator C-Mod will continue its research program, while providing support of ITER. Experiments will continue to address issues with the undesirable consequences of plasma-sheath generation in the proximity of radio frequency (RF) antennae during RF heating of the plasma discharge. A new RF antenna, designed for the ion cyclotron frequency range that better matches the geometry of the C-Mod magnetic field lines will be installed and utilized for experiments this year. Current drive experiments using a second advanced microwave launcher for the lower hybrid frequency range will also be possible at high power in FY 2012 with the completion of the auxiliary heating upgrades in FY 2011 with Recovery Act funding.

Other ITER- and power plant-relevant topics that the Alcator C-Mod team will focus on in FY 2012 include impurity seeding and power handling studies with a high heat flux divertor, fuel retention and surface studies with new diagnostic capabilities, study of the combined effects of lower hybrid RF power and ion cyclotron RF power, steady-state scenario studies, lower hybrid RF-power efficiency experiments, and exploration of unique improved confinement regimes. A primary effort in understanding particle and energy transport will be to provide data to universities and DOE laboratories to validate theoretical models. C-Mod will also continue its participation in joint international experiments.

▪ **International Research**	**5,075**	**7,435**

In addition to work on domestic experiments, FES-funded researchers will participate in scientific experiments at fusion facilities in Europe, Japan, China, South Korea, Russia, and India to conduct comparative studies of underlying physics of fusion plasmas. FES, in return, hosts visiting scientists from the international community, who participate in experiments on U.S. facilities. This international collaboration provides U.S. scientists access to the unique capabilities of several foreign fusion facilities, including 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 on two new superconducting tokamaks, one in China (EAST) and one in South Korea (KSTAR). These collaborations provide a valuable link with the 80% of the world's ITER-related fusion research that is conducted outside the U.S.

The JET and ASDEX-U tokamaks will be restarting in 2011 after shutdowns for major modifications involving ITER-like walls and internal control coils. The KSTAR and EAST tokamaks will be adding increased auxiliary heating power and diagnostics during the next few years. Increased funding in FY 2012 will provide an opportunity to expand collaborations and joint experiments on these unique and powerful foreign facilities.

In FY 2012, the U.S. will also continue to be a major participant in the ITPA, which identifies experimental and computational studies needed to resolve high priority ITER physics design needs

	(dollars in thousands)	
	FY 2010 Current Appropriation	FY 2012 Request

and implements the studies through collaborative work among the world's leading experimental and theoretical research teams. Planned studies include experiments in the areas of plasma wall interactions, plasma instabilities, and first wall design considerations for ITER.

▪ **Diagnostics**	**3,911**	**3,519**

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 2012, 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 to provide data and analyses to validate theoretical models and fusion simulation codes in support of the FES goal to develop an experimentally validated predictive capability for magnetically confined fusion plasmas.

▪ **Other**	**7,105**	**10,604**

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 (FESAC). 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	**65,942**	**59,290**

The FES Alternative Concepts Research program has the long-term performance measure of demonstrating enhanced fundamental understanding of magnetic confinement and improving the basis for future burning plasma experiments through research on magnetic confinement configuration optimization, including knowledge arising from research on the spherical torus and the stellarator. In FY 2012, the spectrum of this program element is sharpened by addressing three changes to the focus. The magnetic-fusion-relevant component will become more concentrated on projects that solve problems that hinder the tokamak approach to controlling plasma dynamics and improving plasma parameters. This component deepens the scientific foundations of understanding the tokamak concept, provides experimental data in regimes of relevance to the FES mainline magnetic confinement and materials science efforts, and validates theoretical models and simulation codes in support of the FES goal to develop an experimentally-validated predictive capability for magnetically-confined fusion plasmas. The warm-dense-matter-relevant component will see a modest increase for the purpose of starting research activity on new Recovery Act-funded facilities. The magnetized high-energy-density plasma component will become more concentrated on discovery-oriented fundamental science.

	(dollars in thousands)	
	FY 2010 Current Appropriation	FY 2012 Request
▪ **NSTX Research**	**16,868**	**17,549**

The National Spherical Torus Experiment (NSTX) is one of two large research facilities in the world designed to explore the physics of plasmas magnetically confined in a spherical torus (ST) configuration; the other is the Mega Amp Spherical Tokamak (MAST) in the United Kingdom. The ST configuration is characterized by a more spherical doughnut shape with a narrow hole through the center. The ST is an innovative confinement configuration that can achieve a higher plasma pressure relative to the applied magnetic field than a conventional tokamak. The unique operating regimes of NSTX allow it to address several important physics issues relevant to burning plasmas and thereby contribute to optimizing the performance of ITER. The NSTX program investigates the attractiveness of the ST configuration as 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 scientific user 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 2012, NSTX will continue to make significant progress in understanding 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 fusion facilities. Using a liquid lithium divertor to confront the harsh plasma environment and new diagnostic capabilities developed with Recovery Act funding, NSTX researchers will perform critical experiments to understand and increase non-inductive current drive at reduced collisionality, understand and improve H-mode confinement at low collisionality, and demonstrate non-inductive start-up and ramp-up of the plasma current. In addition, they will investigate means to handle the large heat and particle fluxes that will fall on the surface of the divertor and seek to understand the relationship between electron energy confinement and fluctuations in the plasma density and electron temperature. NSTX researchers will continue studying macroscopic instabilities and will focus on sustaining the plasma pressure at or above the magnetohydrodynamic limit for a plasma without a nearby conducting wall. 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 focus on 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 will focus on reducing impurity influx during co-axial helicity injection start-up and using radio frequency waves to ramp-up the plasma current to 400–500 kiloamperes.

	(dollars in thousands)	
	FY 2010 Current Appropriation	FY 2012 Request
▪ **Experimental Plasma Research**	**17,494**	**11,000**

Experimental Plasma Research provides experimental data in regimes of relevance to the FES mainline magnetic confinement and materials science efforts and helps validate theoretical models and simulation codes in support of the FES goal to develop an experimentally validated predictive capability for magnetically confined fusion plasmas.

A peer review of all projects in the program took place in FY 2010. The goal of the program is to generate sufficient experimental data to elucidate the underlying physics principles upon which concepts of toroidal confinement are based and, as needed, to develop computational models 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 2012, experimental plasma research will continue to examine stellarator and spherical torus configurations that address potential deficiencies in the tokamak and support development of instability mitigation techniques for ITER.

▪ **High Energy Density Laboratory Plasmas**	**24,538**	**24,741**

High-energy-density laboratory plasma (HEDLP) physics is the study of ionized matter at extremely high density and temperature, specifically when matter is heated and compressed 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 1 million atmospheres. Such conditions exist in the interior of the Sun, in supernovae, in accretion disks around black holes, near pulsars, and astrophysical jets. On Earth, such conditions can only be created transiently in the laboratory by using intense pulses of lasers, particle beams (electrons or ions), or pulsed magnetic field pressure.

Through the Joint NNSA-SC Program in HEDLP Science, FES-funded research by universities, private industry, and DOE laboratories takes place on small-scale-size and medium-scale-size facilities at universities and at DOE laboratories. There are two key elements in the FES HEDLP program. The first element focuses on the basic science of high energy density plasmas without regards to specific applications. This will include facilitating user access to the several, geographically distributed, supporting and complementary facilities, as well as NIF; developing diagnostics and experimental platforms for general high energy density science; funding university and laboratory researchers to develop and field experiments in HEDLP science; and supporting theory and modeling. The second element focuses on inertial fusion energy science (IFES). On-going research in IFES explores science related to fast ignition, shock ignition, heavy-ion fusion, and magnetized high-energy-density plasmas.

In FY 2012, FES and NNSA will jointly hold a solicitation. One of the three areas presently receiving funding in HEDLP, magnetized high-energy-density plasmas, will be significantly redirected and re-sized toward basic science. Also, 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, which will initiate research activities in FY 2012, for which partial first-year funds are newly included. LCLS is the world's first coherent hard x-ray laser; the MEC instrument will provide researchers with the ability to utilize LCLS's capabilities to probe

	(dollars in thousands)	
	FY 2010 Current Appropriation	FY 2012 Request

and control high energy density matter with unprecedented spatial and temporal resolution. Recovery Act funding is also being spent on constructing the Neutralized Drift Compression Experiment-II (NDCX-II) at Lawrence Berkeley National Laboratory which will facilitate studies of heavy-ion driven warm dense matter and the high energy density physics intrinsic to the science of heavy ion fusion.

▪ **Madison Symmetrical Torus**	**7,042**	**6,000**

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 validation of models by experimental investigation. The RFP is geometrically similar to a tokamak, but with a much weaker externally applied magnetic field that reverses direction near the edge of the plasma. Research in the RFP's self-organization properties has astrophysical applications and may lead to a more cost-effective fusion system. The plasma dynamics that limit the energy confinement and plasma pressure, as well as novel means to the sustainment of the plasma current, are being investigated in this experiment. MST is one of the four leading RFP experiments in the world and is unique in that it pioneered the reduction of magnetic fluctuations by current density profile control.

In FY 2012, the major plans for the MST program are plasma current enhancement by oscillating field current drive with twice the pulse length, investigation of neutral beam (NB) injection, and pellet and supersonic gas injection. The transformation of MST from a fusion-oriented program to a validation-oriented program will be accompanied by reductions to support higher priority activities. Staffing will be reduced and the number of run weeks will decrease from 7 to 5.

Theory	**25,105**	**24,348**

The Theory program is a broad-based program with researchers located at six national 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 innovative validation being carried out on smaller experiments, experimental platforms, or work on more fundamental problems in plasma physics while training the next generation of fusion plasma scientists.

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 associated fundamental processes that determine equilibrium, stability, and confinement for each concept. The theory program also provides

	(dollars in thousands)	
	FY 2010 Current Appropriation	FY 2012 Request

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.

In FY 2012, 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 high confinement modes in tokamaks;
- the formation of edge and internal transport barriers;
- a first-principles formulation of moment closures in extended magnetohydrodynamics models;
- studies of how to improve the stellarator concept and find configurations that are less prone to the formation of islands;
- understanding fast magnetic reconnection in high temperature fusion plasmas; and
- development of predictive integrated computational models for tokamak plasmas.

Advanced Fusion Simulations	**11,182**	**8,312**

The FES Advanced Fusion Simulations program includes projects funded under the auspices of the Scientific Discovery through Advanced Computing (SciDAC) program as well as the Fusion Simulation Program (FSP) which, after an initial planning phase, will focus on the development of an experimentally validated simulation capability for magnetically confined plasmas.

▪ **SciDAC**	**7,182**	**8,312**

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 by exploiting the emerging capabilities of high performance “ultrascale” computing. The SciDAC program encourages and enables a new model of interdisciplinary multi-institutional collaboration among physical scientists, applied mathematicians, computer scientists, and computational scientists where distributed resources and expertise are combined to address complex questions that no single institution or investigator can manage alone.

The FES SciDAC portfolio is aimed at advancing scientific discovery in fusion plasma science by exploiting the emerging capabilities of petascale computing and associated progress in software and algorithm development and contributes to the FES goal of developing a validated predictive capability for magnetically confined plasmas. The current portfolio includes eight projects focused on burning plasmas and ITER. Of these, five are focused on topical “single physics” science areas (macroscopic stability, plasma turbulence, interaction of radiofrequency waves with plasmas, and energetic particles) while the remaining three, also known as Fusion Simulation Prototype Centers or proto-FSPs, are focused on code integration and computational framework development in the areas of edge plasma transport, interaction of radiofrequency waves with magnetohydrodynamic instabilities, and the coupling of the edge and core regions of tokamak plasmas.

(dollars in thousands)

	FY 2010 Current Appropriation	FY 2012 Request

The FES SciDAC Centers have been very successful in taking advantage of the SC leadership computing facilities to develop high-performance computational tools that have provided new and significant insights into questions of fundamental importance in fusion plasma science.

The five “single physics” projects in the FES SciDAC portfolio were recompeted in 2010. Five multi-institutional Centers—comprising 10 universities, 3 national laboratories, and 5 private companies—were selected for funding (one new and four renewals) with a funding distribution of 39% to universities, 40% to national laboratories, and 21% to private industry. These projects will continue to focus their efforts on grand challenge scientific questions of importance to burning plasmas and ITER. More specifically, in FY 2012, the projects in the FES SciDAC portfolio will focus on:

- the development of high fidelity models for core interactions of radio-frequency waves with energetic ions and electrons for a better understanding of how these energetic species affect power flow in the confined plasma;
- the performance of realistic simulations with extended magnetohydrodynamic codes to understand and control performance-limiting macroscopic instabilities and related effects such as edge localized modes, resonant magnetic perturbations, resistive wall modes, neoclassical tearing modes, and sawteeth, as well as the development of computational capabilities for assessing, mitigating, and avoiding damaging disruptions;
- the further understanding of the role of plasma turbulence in driving particle, momentum and heat transport from the core and the edge of magnetically confined plasmas with emphasis on experimental validation; and
- the prediction of energetic particle transport in burning plasmas in the presence of energetic-particle driven modes as well as the coupling of energetic particle driven meso-scale turbulence with the background thermal plasma micro-scale turbulence.

The three proto-FSP projects expire in FY 2011 and this part of the FES SciDAC portfolio will be recompeted as part of the SC-wide SciDAC review scheduled for mid-2011. In addition, the increase in funding in FY 2012 will allow FES to add a new computational materials project in its SciDAC portfolio, reflecting the importance of materials science for the FES mission.

▪ **Fusion Simulation Program**	**4,000**	**0**

The Fusion Simulation Program (FSP) is a computational initiative aimed at the development of a world-leading, experimentally validated, predictive simulation capability for magnetically confined fusion plasmas in the regimes and geometries relevant for practical fusion energy. Once launched, a successful FSP will advance the fundamental science of magnetically confined plasmas by enabling scientific discovery of important new plasma phenomena with associated understanding that emerges only upon integration, will maximize the return of the U.S. investment in ITER, and reduce risk in the design of future devices.

	(dollars in thousands) FY 2010 Current Appropriation	FY 2012 Request

The FSP planning activity, a two-year effort initiated in mid-2009 to carry out a detailed design study for the FSP, will submit a report once planning activities are completed. While no FSP activities are planned in FY 2012, the FSP planning report will help FES prepare a set of future solicitations for the competitive selection of interdisciplinary multi-institutional teams to develop, verify, and validate integrated science applications targeting the highest priority science drivers identified in the planning report.

General Plasma Science	**14,435**	**16,780**

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 significant benefit to progress is derived by the multi-expertise, 5-year funding model of a center.

In FY 2012, 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 applications received for PSC funding in FY 2009, one new center (in low-temperature plasma science) was selected for funding with regular appropriations and two additional centers were selected (one fully funded for five years and the second funded at the 50% level) using Recovery Act funding. In FY 2012, regular appropriations funding is provided for the third PSC continuation. Also in FY 2012, the U.S. component of a Joint Center for Plasma Research, between Princeton Plasma Physics Laboratory and Germany's Max-Planck-Institute for Plasma Physics, will have funds available to support several postdoctoral researchers who will work on cross-disciplinary (astrophysics and fusion) research projects. The Atomic and Molecular Physics program is being reduced by approximately 50%. This is being accomplished by by closing out the atomic physics program at ORNL while retaining the atomic physics work at NIST. The Atomic and Molecular Physics program at ORNL is being closed out because it has lost its cross-SC-office support and outlived its relevance to the FES program.

SBIR/STTR	**0**	**8,186**

In FY 2010, $7,455,000 and $895,000 were transferred to the congressionally mandated Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, respectively. The FY 2012 amount is the estimated requirements for the continuation of these programs.

Total, Science	**169,045**	**177,816**

Explanation of Funding Changes

	FY 2012 vs. FY 2010 Current Approp. ($000)
Tokamak Experimental Research	
▪ **DIII-D Research**	
The increased funding will support the research staff at General Atomics and researchers from collaborating institutions to plan, conduct, and analyze the data from experiments on the DIII-D tokamak for the planned 13 weeks of operation using the upgrades provided by Recovery Act funding.	+1,633
▪ **Alcator C-Mod Research**	
The increase in funding will support the research staff at the Massachusetts Institute of Technology and the national program collaborators to plan, conduct, and analyze experiments on the Alcator C-Mod tokamak for the planned 17 weeks of research operation.	+1,419
▪ **International Research**	
The increase in funding will allow for continued support of burning plasma research, ITER physics, and stellarator research through collaboration with foreign programs. The increase will be used to enhance collaborations with JET in the areas of ELM mitigation and ITER-like wall programs and will enhance support for KSTAR and other international collaboration through remote participation.	+2,360
▪ **Diagnostics**	
The decrease will cause a small reduction in the number of activities supported.	-392
▪ **Other**	
The increase in funding will allow for additional support of a number of activities including educational activities such as research at historically black colleges and universities, postgraduate fellowships in fusion science and technology, summer internships for undergraduates, U.S. Burning Plasma Organization, and FESAC.	+3,499
Total, Tokamak Experimental Research	**+8,519**
Alternative Concept Experimental Research	
▪ **NSTX Research**	
The increased funding will support the research staff needed to plan, conduct, and analyze experiments on NSTX during the planned 10 weeks of operation and prepare for the shutdown to carry out planned upgrades.	+681
▪ **Experimental Plasma Research**	
The decrease will narrow the portfolio of university and DOE laboratory projects as this program shifts to funding projects that meet the expectations	

	FY 2012 vs. FY 2010 Current Approp. ($000)
of the newly re-directed program. The new emphasis is on tokamak-related confinement-relevant physics, on the physics at the interface of plasma and plasma-facing components, and on the linkage between prediction and measurement for scientific leverage in testing the theories and scaling the phenomena that are relevant to future burning plasma systems. Key program issues include initiation and increase of plasma current; dissipation of plasma exhaust power; symmetric-torus confinement prediction; stability, continuity, and profile control of symmetric tori; quasi-symmetric and three-dimensional shaping benefits to toroidal confinement performance; divertor design for three-dimensional magnetic confinement configurations.	-6,494
▪ **High Energy Density Laboratory Plasmas (HEDLP)**	
There is an increase of funds in the warm-dense-matter area for cultivating the development of a user population on the Recovery Act-funded facilities at SLAC and at LBNL in the partial first year of their research activities after project completion in mid-FY 2012.	+203
▪ **Madison Symmetrical Torus**	
The decrease will result in suspending the lower-hybrid RF heating development, the electron Bernstein wave project development, the multi-phase Thomson scattering, the new boundary diagnostics project, and the new ion Doppler spectrometer. The number of weeks with all diagnostics operating will decrease from 7 to 5 and the staff will be reduced.	-1,042
Total, Alternative Concept Experimental Research	**-6,652**
Theory	
The decrease will reduce support in non-tokamak-related theory.	-757
Advanced Fusion Simulations	
▪ **SciDAC**	
The increase in funding will support a new computational materials project that will address the interactions of different materials that will be located in and around the fusion chamber with the plasma.	+1,130
▪ **Fusion Simulation Program**	
The decrease in funding reflects the decision by FES to first evaluate the results of the two-year planning phase of the FSP, which will be completed before proceeding with the initiation of the full program.	-4,000
Total, Advanced Fusion Simulations	**-2,870**

	FY 2012 vs. FY 2010 Current Approp. ($000)
General Plasma Science	
The increase will allow the U.S. to initiate a new Joint Center for Plasma Research between PPPL and MPI (Germany) and to fund fully a Plasma Science Center which was started with Recovery Act funding.	+2,345
SBIR/STTR	
The support for SBIR/STTR is funded at the mandated level.	+8,186
Total Funding Change, Science	**+8,771**

Facility Operations

Funding Schedule by Activity

	(dollars in thousands)	
	FY 2010 Current Appropriation	FY 2012 Request
Facility Operations		
DIII-D	37,830	39,731
Alcator C-Mod	17,424	18,042
NSTX	21,320	17,504
NSTX Upgrade (MIE)	8,950	14,630
Other, GPE and GPP	2,478	975
U.S. Contributions to ITER (MIE TPC)	135,000	105,000
Total, Facility Operations	223,002	195,882

Description

The mission of the Facility Operations subprogram is to provide for the operation, maintenance, and minor modifications of the major fusion research user 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. Operations, maintenance, and upgrades are balanced 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 user 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.

The *National Spherical Torus Experiment* (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 and more economical fusion research facilities in the future.

ITER will be the first magnetic fusion facility to achieve self-sustaining “burning” plasmas, and will thus open a new era in fusion energy science. The study of burning plasmas is essential to demonstrate the scientific feasibility of fusion energy and study its underlying physics, making ITER an important step between today’s facilities and a demonstration fusion power plant. An international collaboration of scientists and engineers led the design of this burning plasma physics experiment. ITER is presently under construction in Cadarache, France by the seven project partners: China, the European Union (EU), India, Japan, Russia, South Korea, and the United States.

Selected FY 2010 Accomplishments

- *DIII-D:* Long-term trapping of tritium in the vessel walls is a critical issue in minimizing the tritium inventory on site of a fusion burning plasma device such as ITER. Recent experiments on DIII-D have demonstrated the ability to remove a significant fraction of hydrogen isotopes that are trapped in hard films on the vessel surfaces using a technique known as thermal oxidation (or oxygen bake). In this technique, the vessel walls are heated to 350° C and then oxygen gas (mixed with helium for safety) is introduced to a moderate pressure. Consistent with lab tests of this technique, these DIII-D experiments show virtually all of deuterium trapped in hardened carbon-deuterium films to be removed. Subsequent experiments showed that even though the vessel walls were exposed to large quantities of oxygen, good confinement plasmas could be re-established within a few plasma shots, indicating that this technique can be used on ITER without risk to subsequent plasma operations. DIII-D is now in a maintenance period to conduct major facility modifications, such as the tilting of one neutral beam line to provide off-axis heating and current drive, which is needed for improved plasma control.

- *Alcator C-Mod:* The new advanced lower hybrid heating (LH) and current drive antenna was installed, and initial experiments were conducted to investigate the coupling of the LH waves to the plasma. Lower hybrid heating and current drive will give Alcator C-Mod the capability to achieve significant non-inductive current drive, a capability that will be needed in a fusion power plant. Also, a new infrared camera diagnostic viewing the divertor region provided important data in the examination of heat flow to the divertor.

- *NSTX:* In early FY 2010, NSTX technicians installed a new liquid lithium divertor, consisting of four heated plates with a porous molybdenum surface. A thin film of lithium can be deposited on the plates using lithium evaporators. The heaters in the plates maintain the temperature above the melting point of lithium, thereby creating a thin film of liquid lithium on the plates that absorbs impinging deuterium. Early indications with the liquid lithium coated divertor plates are that the edge density and the plasma collisionality are reduced, implying and resulting in higher edge temperatures, improved confinement, increased central temperatures, and the elimination of edge localized modes that induce losses of hot ions and electrons.

- *ITER:* Throughout the life of the ITER Project, the U.S. has insisted that it be properly managed to improve the chances of an on-schedule, on-cost completion. To this end, the U.S. has advocated that the project be baselined and managed according to international best practices and that the management team be staffed and structured to take on a construction project of this scope and complexity. In July 2010, the ITER Council approved the project baseline and appointed a new Director General with significant experience in fusion facility construction and gave him the authority to implement sweeping management changes and pursue cost savings throughout the ITER project.

Detailed Justification

	(dollars in thousands)	
	FY 2010 Current Appropriation	FY 2012 Request
DIII-D	**37,830**	**39,731**

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 13 weeks (40 hours per week) of experimental operations beginning in April 2012 after a shutdown at the beginning of the fiscal year for facility modifications. The Recovery Act funding for the DIII-D Upgrades provided for additional electron cyclotron heating (a 7th gyrotron), which will become fully operational in FY 2012. Operations will continue to support experiments addressing ITER design and operations issues and developing the advanced tokamak concept for fusion energy. Experiments in FY 2012 will take advantage of the off-axis neutral beam and the additional electron cyclotron heating.

	FY 2010	FY 2012
Achieved Operating Hours	608	N/A
Planned Operating Hours	560[a]	520
Optimal Hours	1,000	1,000
Percent of Optimal Hours	61%	52%
Unscheduled Downtime	9.8%	N/A
Number of Users	235	230

Alcator C-Mod	**17,424**	**18,042**

Support is provided for operation, maintenance, minor upgrades, and improvement of the Alcator C-Mod facility. The upgrades include installation of a second advanced 4-strap ion cyclotron radio frequency antenna to explore higher heating power, addition of a second advanced lower hybrid launcher for increased current drive capability and plasma control, and the installation of a high temperature tungsten divertor for plasma material interaction studies relevant to ITER. In FY 2012, Alcator C-Mod will be operated for 17 weeks, focusing on ITER design and operations issues and addressing high field and density issues.

[a] Planned hours do not include Recovery Act supported operations in FY 2010. Utilizing Recovery Act funding, DIII-D had an additional 120 hours of planned operations in FY 2010. All of these additional operating hours were achieved.

(dollars in thousands)

	FY 2010 Current Appropriation	FY 2012 Request

	FY 2010	FY 2012
Achieved Operating Hours	512	N/A
Planned Operating Hours	416[a]	544
Optimal Hours	800	800
Percent of Optimal Hours	64%	68%
Unscheduled Downtime	4.7%	N/A
Number of Users	195	194

NSTX **21,320** **17,504**

Support is provided for operation and maintenance of NSTX. In FY 2012, there is funding for 10 weeks of operation to explore issues of sustained spherical torus (ST) operation and study ST confinement at high fields relevant to evaluating the science base for high-heat flux and plasma nuclear science initiatives. In FY 2012, NSTX will complete experiments with the present configuration and shut down for approximately two years to install a new "center stack" and a second neutral beam (see NSTX Upgrade MIE below). The new center stack will allow operation at nearly twice the toroidal field (1 Tesla versus 0.6 Tesla) and twice the plasma current (2 MA versus 1 MA) and the second neutral beam will greatly increase the current that can be driven in NSTX. The upgrade will enable higher performance and longer pulses, which will provide the physics data needed to evaluate the viability of the ST for high-heat flux and plasma nuclear science applications.

	FY 2010	FY 2012
Achieved Operating Hours	576	N/A
Planned Operating Hours	560[b]	400
Optimal Hours	1,000	1,000
Percent of Optimal Hours	58%	40%
Unscheduled Downtime	9.8%	N/A
Number of Users	145	145

NSTX Upgrade (MIE) **8,950** **14,630**

Support is provided to complete design work and begin fabrication of a major upgrade of NSTX to keep its world-leading status. After the design work is completed in mid-FY 2012, NSTX will be shut down for approximately two years to carry out the upgrade work. The NSTX Upgrade project comprises two major improvements to the device: a new center stack magnet assembly, which will double the magnetic field and plasma current and increase the pulse length from one second to a maximum of five seconds,

[a] Planned hours do not include Recovery Act supported operations in FY 2010. Utilizing Recovery Act funding, C-Mod had an additional 160 hours of planned operations in FY 2010. All of these additional operating hours were achieved.
[b] Planned hours do not include Recovery Act supported operations in FY 2010. Utilizing Recovery Act funding, NSTX had an additional 40 hours of planned operations in FY 2010. All of these additional operating hours were achieved.

	(dollars in thousands)	
	FY 2010 Current Appropriation	FY 2012 Request

and installation of a second neutral beam line, which will double the neutral beam heating power. Critical Decision 2 (CD-2), approval of the performance baseline was achieved in December 2010.

Other, GPE, and GPP	**2,478**	**975**

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. Due to the receipt of Recovery Act funding that was used to improve PPPL's infrastructure, the need for GPP funding is reduced in FY 2012.

U.S. Contributions to ITER Project (MIE)	**135,000**	**105,000**

Background: The U.S. ITER Project represents 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 between the United States and the former Soviet Union held 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.

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. The ITER Council serves as ITER's executive governing board and includes representatives from all of 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. Beyond that, the United States has agreed to fund 13% of the cost for subsequent operation, deactivation, and decommissioning of the ITER device. As the Host, the EU is obligated to provide 5/11 (45.45%) of ITER's construction value. An Annex to 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 is currently at 400 professional staff.

An international design review in 2007 recommended several 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.

(dollars in thousands)

FY 2010 Current Appropriation	FY 2012 Request

The IO's efforts to complete work on the overall ITER design and systems engineering are almost done and the IO has made recent strides to work from these approved technical, schedule, and cost baselines as agreed by the ITER Council in July 2010. Concurrently, the Administration gained agreement from the ITER Council and IO for a range of U.S. initiatives to implement management reforms at the IO and to accelerate ITER construction with the goal of minimizing the overall cost of the Construction Phase for the U.S. and the other ITER Members.

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. The Council formally agreed upon a revised ITER technical, schedule, and cost baseline in July 2010; now the U.S. ITER Project Office will be able to develop schedule and cost baselines for the U.S. ITER Project scope in preparation for CD-2, Approve Performance Baseline. CD-2 is currently projected to occur in mid-FY 2012.

Estimated ITER TPC Range: In late 2007, the TPC range approved at CD-1 accounts for the magnitude of cost risks that were identified. The identified sources of potential cost growth within the CD-1 range have been and continue to be: actions taken by the ITER Council and the IO to address technical, cost, and schedule issues; external factors outside of the ITER project; and industry input/design maturity for several very complicated systems/components. As the project has proceeded, these risks are better understood and are being retired by the IO. As part of this effort, the IO has committed to pursuing significant cost savings on the ITER project without reducing essential scope. These cost savings will be assessed by the ITER Council and the Members to ensure that they do not adversely affect the ITER research mission. The U.S. has requested an assessment of cost savings ranging up to 20%. The information derived from the IO efforts will feed into U.S. formulation of our CD-2 cost, schedule, and technical baseline.

As a Member of the ITER Council, the U.S. can exercise a veto over annual budgets and project cost increases, both of which can be used to control project cost growth.

Among the aspects under the IO's purview which drive the cost are the overall project schedule, design changes and other actions affecting hardware scope and manufacturing costs, and French and EU licensing/regulatory requirements. However, in July 2010, the ITER Council approved the IO's integrated technical, cost, and schedule baseline for the construction phase that includes detailed inputs from the seven Members, and placed the entire project under a formal change control project management regime, consistent with U.S. DOE project management practices.

External project cost risk factors include changes in Dollar/Euro exchange rates, escalation rates, commodity prices, changes agreed under formal change control, and market conditions for hardware procurement. The JIA requires funding contributions from the Members to be made in euros, which introduces the possibility of 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 a significant concern. 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 million and will be funded through 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 contingency amount equal to 27% of the hardware cost at the time. The difference between $1.45 billion and the top end of the TPC range, $2.2 billion, provides additional contingency for known risks in the above categories as well as an amount for unidentified risks. SC has assessed the costs associated with the schedule delays to date and believes they are manageable within the existing CD-1 cost range.

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	TBD	TBD	TBD
2012	90,000	15,000	105,000
Outyears	TBD	TBD	TBD

The $105 million requested for the U.S. ITER Project in FY 2012 is a reflection of the accelerated pace of ITER construction as of mid-2010. As discussed above, the Administration, working with the USIPO, successfully pursued a range of initiatives to implement management reforms at the IO and to 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 2012 funding request will be used to make progress on all of the design, R&D, and long-lead procurement activities for the U.S. hardware contribution. Emphasis will continue to be given to industrial involvement in completing design work in preparation for subsequent large-scale fabrication activities. In particular, designs will be completed with industry input for the majority of U.S. hardware needed for first plasma, including the largest U.S. hardware subsystems: Central Solenoid Magnets and Tokamak Cooling Water. Long-lead items for magnet materials and Ion/Electron Cyclotron heating systems will be initiated and R&D will continue to support finalization of design efforts for diagnostics and other systems. Purchase of hardware for the U.S share of the Steady State Electrical system will also be initiated.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

[a]A complete baseline funding profile, including the outyears, will be established at CD-2, which is anticipated to be in mid FY 2012.

(dollars in thousands)

	FY 2010 Current Appropriation	FY 2012 Request

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		
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 2010 Current Appropriation	FY 2012 Request
Total, Facility Operations	**223,002**	**195,882**

Explanation of Funding Changes

	FY 2012 vs. FY 2010 Current Approp. ($000)
DIII-D	
The increased funding is needed to support increased personnel and electrical power costs.	+1,901
Alcator C-Mod	
The increased funding will support an additional two weeks of operation.	+618
NSTX	
The decrease in funding for the NSTX Facility is applied to the increase for the NSTX Upgrade MIE project. This budget will support 10 weeks of plasma operation during the first half of the fiscal year prior to the shutdown for the upgrade.	-3,816

	FY 2012 vs. FY 2010 Current Approp. ($000)
NSTX Upgrade (MIE)	
The increase in funding will provide for continued work on the two 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 profile. The two upgrades will enable higher plasma pressures to be obtained.	+5,680
Other, GPE, and GPP	
This funding decrease reflects the receipt of Recovery Act funding which was used to improve PPPL's infrastructure that, in turn, reduced the burden on GPP funding needed in FY 2012.	-1,503
U.S. Contributions to ITER Project (MIE)	
The decrease in funding reflects the Administration's assessment of the level of effort required to sustain U.S. commitments to ITER in FY 2012 and to fully transition from the design, engineering, and planning phase to the construction phase.	-30,000
Total Funding Change, Facility Operations	**-27,120**

Enabling R&D

Funding Schedule by Activity

(dollars in thousands)

	FY 2010 Current Appropriation	FY 2012 Request
Enabling R&D		
Engineering Research	19,136	18,273
Materials Research	6,467	7,729
Total, Enabling R&D	25,603	26,002

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 2010 Accomplishments

- *Understanding materials under fusion conditions:* A unique aspect of the fusion environment is substantial production of helium in the materials that confine the plasma. The microstructure properties of fusion materials can be degraded by the presence of helium. Oak Ridge National Laboratory (ORNL), working with others in the fusion materials community has made progress toward solving this very difficult problem by using novel experimental techniques and advanced computer simulations to better understand and mitigate the degradation caused by large amounts of helium. From an experimental standpoint, ORNL has been able to simulate helium in the microstructure by covering the surface of a sample with a coating of a nickel-bearing alloy before placing the sample in the High Flux Isotope Reactor at ORNL. Under neutron irradiation energetic helium atoms are produced in the coating and injected into the sample. These experiments show that a new class of materials, nanocomposited ferritic alloys, appears to offer an effective way to manage helium and mitigate radiation damage. While these early experimental results are promising, there is still a significant amount of research required to demonstrate that these alloys can survive in a fusion environment.
- *Plasma Edge Disturbance Mitigation Technique Demonstrated on DIII-D:* The plasma edge in a magnetic fusion device can have a periodic disturbance known as an edge localized mode (ELM) that can potentially damage the plasma chamber from pulsed high thermal loads. ORNL has developed a technique to mitigate these effects by injecting small solid hydrogen pellets into the edge of the plasma frequently. The pellets are fired by a pneumatic gun using the same technology developed by ORNL for fueling fusion plasmas. The pellets are able to trigger very small ELMs that have a much lower pulsed thermal load than the naturally occurring high thermal loads but lower frequency ELMs. This technique has been used on the DIII-D tokamak at General Atomics to demonstrate the reduction of ELM energy onto the plasma chamber by a factor of four. This technique can potentially be employed on ITER to prevent large ELMs from occurring that can reduce the lifetime of the plasma facing components in the chamber and thus increase the machine availability for burning plasma research.

- *Addressing ITER operational issues:* The chemical erosion of carbon surfaces, in an area called the divertor region, is expected to be the dominant mechanism responsible for tritium accumulation in ITER, which can be a safety concern. Previous experiments performed in a small linear plasma device at the University of California at San Diego revealed the mitigation of carbon chemical erosion by the presence of beryllium impurities contained within a plasma. The beneficial mitigation effect is expected to occur naturally in the ITER device due the transport of beryllium into the divertor region. However, operation of the divertor requires that there be carbon radiation in this region to achieve an effective plasma. Without carbon radiation, an additional radiating species, such as argon, must be intentionally added. It was feared that that addition of argon to the plasma might cause increased erosion and remove the protective beryllium carbide surface layer that is responsible for the mitigation. Fortunately, it has recently been experimentally verified that the beneficial mitigation effect survives.

Detailed Justification

(dollars in thousands)

	FY 2010 Current Appropriation	FY 2012 Request
Engineering Research	**19,136**	**18,273**

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**	**15,772**	**13,906**

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 Tritium Irradiation Thermofluid American-Japanese Network (TITAN), a collaborative program on plasma facing and blanket materials for use in future facilities, will be continued.

In FY 2012, 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.

	(dollars in thousands)	
	FY 2010 Current Appropriation	FY 2012 Request

- 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.

▪ **Advanced Design**	**3,364**	**4,367**

FES supports a system studies design team that carries out conceptual fusion power plant studies for various fusion confinement concepts, such as the tokamak, stellarator, reverse field pinch, spherical torus, and tandem mirror. Fusion researchers use these studies to compare technical requirements of an attractive fusion system with present achievements to identify remaining technical challenges that must be addressed to develop a commercial fusion power plant. FES uses this knowledge to guide the research program. The systems studies team is composed of a multi-institutional core group of individuals that have a wealth of experience in fusion science and technology. The core team is augmented by experts in whatever fusion concept is being studied at a given time. The team is known in the community for its objective approach and its ability to develop innovative solutions to a wide range of scientific and technological problems. The team has also participated in pre-conceptual design efforts of nearer-term test facilities and experimental devices.

In FY 2010, the systems design team initiated a 3-year integrated study to determine the advances needed in the plasma materials interface (PMI) science area to achieve practical fusion energy. This effort is built on the results of a broad study the results of which are contained in the June 2009 report Research Needs for Magnetic Fusion Energy Sciences. In FY 2012, the team will be nearing completion of this study. In FY 2010, FES directed the team to participate in the Fusion Nuclear Science planning activity to assist in identifying approaches for moving the U.S. fusion nuclear sciences research program forward in parallel with the ITER program. This may result in a six to nine month delay in the completion of the PMI study.

Materials Research	**6,467**	**7,729**

Fusion reactor materials will be required to function in an extraordinarily demanding environment that includes various combinations of high temperatures, chemical interactions, time-dependent thermal and mechanical loads, and intense neutron fluxes. In addition, radiation damage degrades materials properties through processes that include hardening, embrittlement, phase instabilities, segregation, precipitation, irradiation creep, volumetric swelling, and radiation-induced conductivity. Developing materials for use in a fusion environment is a long-standing feasibility issue. The challenge for the Materials Research element is to focus its efforts to address all of these issues with a strong science-based program that will eventually lead to materials that can be used in future facilities. This element leverages the substantial work on nanosystems and computational materials science being funded by other programs such as Basic Energy Sciences. 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.

	(dollars in thousands)	
	FY 2010 Current Appropriation	FY 2012 Request

The FY 2012 request will maintain and grow a Materials Research program that addresses significant challenges involved with operating in this extraordinarily demanding environment. 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 supports 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 combined effects of helium, which is produced by transmutation reactions, and neutron bombardment on the microstructural evolution, damage accumulation, and property changes of fusion materials in this environment. This research will be coordinated among the Office of Science, Office of Nuclear Energy, and the National Nuclear Security Administration.

Total, Enabling R&D	**25,603**	**26,002**

Explanation of Funding Changes

	FY 2012 vs. FY 2010 Current Approp. ($000)
Engineering Research	
▪ **Plasma Technology**	
The decrease will cause an overall reduction in support for planned upgrades to a plasma material testing facility located at Sandia National Laboratories.	-1,866
▪ **Advanced Design**	
The increase will result in a higher level of effort in the advanced concepts studies that are examining possible pre-conceptual designs for a new facility in the U.S.	+1,003
Total, Engineering Research	**-863**
Materials Research	
The increase will support both modeling and experimental research on nano-composited high strength structural materials such as oxide-dispersion strengthened steels; tungsten, the leading candidate for a plasma facing material; and other fusion chamber materials.	+1,262
Total Funding Change, Enabling R&D	**+399**

Supporting Information

Operating Expenses, Capital Equipment and Construction Summary

	(dollars in thousands)	
	FY 2010 Current Approp.	FY 2012 Request
Operating Expenses	290,651	292,288
Capital Equipment	125,506	106,947
General Plant Projects	1,493	465
Total, Fusion Energy Sciences	417,650	399,700

Funding Summary

	(dollars in thousands)	
	FY 2010 Current Approp.	FY 2012 Request
Research	194,648	203,818
Scientific User Facilities Operations	76,574	75,277
Major Items of Equipment	143,950	119,630
Other (GPP, GPE and Infrastructure)	2,478	975
Total, Fusion Energy Sciences	417,650	399,700

Scientific User Facilities Operations and Research

	(dollars in thousands)	
	FY 2010 Current Approp.	FY 2012 Request
DIII-D		
Operations	37,830	39,731
Facility Research	27,255	28,888
Total DIII-D	65,085	68,619
Alcator C-Mod		
Operations	17,424	18,042
Facility Research	9,035	10,454
Total Alcator C-Mod	26,459	28,496
NSTX		
Operations	21,320	17,504
Facility Research	16,868	17,549
Total NSTX	38,188	35,053

	(dollars in thousands)	
	FY 2010 Current Approp.	FY 2012 Request
Scientific User Facilities Operations and Research		
Operations	76,574	75,277
Facility Research	53,158	56,891
Total, Scientific User Facilities Operations and Research	129,732	132,168

Facility Hours and Users

	FY 2010 Current Approp.	FY 2012 Request
DIII-D National Fusion Facility		
Achieved Operating Hours	608	N/A
Planned Operating Hours	560[a]	520
Optimal Hours	1,000	1,000
Percent of Optimal Hours	61%	52%
Unscheduled Downtime	9.8%	N/A
Number of Users	235	230
Alcator C-Mod		
Achieved Operating Hours	512	N/A
Planned Operating Hours	416[a]	544
Optimal Hours	800	800
Percent of Optimal Hours	64%	68%
Unscheduled Downtime	4.7%	N/A
Number of Users	195	194
National Spherical Torus Experiment		
Achieved Operating Hours	576	N/A
Planned Operating Hours	560[a]	400
Optimal Hours	1,000	1,000
Percent of Optimal Hours	58%	40%
Unscheduled Downtime	9.8%	N/A
Number of Users	145	145

[a] Planned hours do not include Recovery Act supported operations in FY 2010. Utilizing Recovery Act funding, DIII-D had an additional 120 hours of planned operations, C-Mod had an additional 160 hours of planned operations and NSTX had an additional 40 hours of planned operations in FY 2010. All of these additional operating hours were achieved.

	FY 2010 Current Approp.	FY 2012 Request
Total, Facilities Hours and Users		
Achieved Operating Hours	1,696	N/A
Planned Operating Hours	1,536[a]	1,464
Optimal Hours	2,800	2,800
Percent of Optimal Hours	61%	53%
Unscheduled Downtime	N/A	N/A
Number of Users	575	569

Major Items of Equipment (MIE)

(dollars in thousands)

	Prior Years	FY 2010 Current Approp.	FY 2011 CR	FY 2012 Request	Outyears	Total
MIEs						
NSTX Upgrade						
TEC	0	3,550	9,000	14,630	56,485	83,665
OPC	5,235	5,400	0	0	0	10,635
TPC	5,235	8,950	9,000	14,630	56,485	94,300
ITER						
TEC	189,366	115,000	113,000	90,000	TBD	TBD
OPC	40,019	20,000	13,000	15,000	TBD	TBD
TPC	229,385	135,000	126,000	105,000	TBD	TBD
Total MIEs						
TEC		118,550	122,000	104,630		
OPC		25,400	13,000	15,000		
TPC		143,950	135,000	119,630		

Facility Operations MIEs:

- ***National Spherical Torus Experiment Upgrade Major Item of Equipment Project***

  The NSTX Upgrade Project supports 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

[a] Planned hours do not include Recovery Act supported operations in FY 2010. Utilizing Recovery Act funding, DIII-D had an additional 120 hours of planned operations, C-Mod had an additional 160 hours of planned operations and NSTX had an additional 40 hours of planned operations in FY 2010. All of these additional operating hours were achieved.

Independent Project Review was completed in December 2009. The Departmental review and approval of CD-1 was completed on April 15, 2010. CD-2 was achieved on December 20, 2010.The performance baseline for the MIE project is $94.3M with completion in September 2015. In FY 2012, PPPL will focus on completing design and R&D required for both the magnet and neutral beam upgrades and initiate some small advanced procurements.

- ***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 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, the majority of which should be completed in FY 2012, and assisting the IO with establishing a functionally mature project management organization.

The $105,000,000 requested for the U.S. ITER Project in FY 2012 is a reflection of the accelerated pace of ITER construction as of mid-2010. The Administration has successfully 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 2010 estimate	FY 2012 estimate
# University Grants	307	310
# Laboratory Projects	171	175
# Permanent Ph.D's (FTEs)	760	774
# Postdoctoral Associates (FTEs)	116	124
# Graduate Students (FTEs)	342	347
# Ph.D.'s awarded	42	44