Fusion Energy Sciences

Funding Profile by Subprogram

(dollars in thousands)

	FY 2008 Current Appropriation	FY 2009 Original Appropriation	FY 2009 Additional Appropriation[a]	FY 2010 Request
Fusion Energy Sciences				
Science	155,032	172,387	+56,511	176,067
Facility Operations	116,968	207,253	+34,512	221,742
Enabling R&D	22,933	22,910	—	23,191
Total, Fusion Energy Sciences	294,933[bc]	402,550	+91,023	421,000

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

Program Overview

Mission

The mission of the Fusion Energy Sciences (FES) program is to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundations needed to develop a fusion energy source. This is accomplished by studying plasmas under a wide range of temperature and density conditions, developing advanced diagnostics to make detailed measurements of plasma properties, and creating theoretical/computational models to resolve the essential physics.

Background

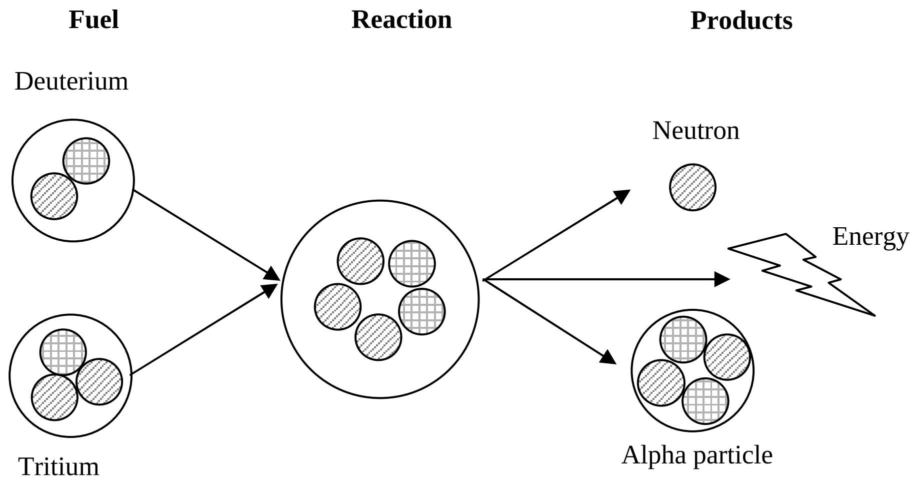
Since 1929, when the American chemist Irving Langmuir first used the word *plasma* (from the Greek for "moldable substance") to describe a collection of charged particles—electrons and ions—in electric discharges, research in plasma physics has grown considerably. Early research in plasma physics was limited to gas discharges, ionospheric physics, and astrophysics; however, today plasma physics is a broad and rich discipline. Progress in our understanding of plasma behavior has had significant impacts on applications of commercial interest—such as semiconductor processing, displays and lighting, and other low temperature plasma applications—where science-based methods have replaced empirical approaches.

The field of plasma physics experienced significant growth in the early 1950s when the U.S. and other nations decided to pursue fusion as a possible energy source. Understanding the behavior of fusion plasmas quickly emerged as a critical scientific issue, and fusion became the main driver for plasma physics research from the late 1950s to the present day. Fusion energy offers the promise of a fundamentally new and attractive energy source based on the nuclear fusion process. FES is developing

[a] The additional Appropriation column reflects the planned allocation of funding from the American Recovery and Reinvestment Act of 2009, P.L. 111–5. See the Department of Energy Recovery website at http://www.energy.gov/recovery for up-to-date information regarding Recovery Act funding.
[b] Includes $15,500,000 provided by the Supplemental Appropriations Act, 2008, P.L. 110–252.
[c] Total is reduced by $7,115,000: $6,353,000 of which was transferred to the SBIR program and $762,000 of which was transferred to the STTR program.

the scientific underpinnings of potential fusion energy systems. In order to carry out this charge, FES has emerged as the nation's primary steward of the field of plasma physics and, in cooperation with the National Nuclear Security Administration (NNSA), the field of high energy density laboratory plasmas (HEDLP).

Since the earliest work on fusion energy, most fusion reactor concepts have shared a common "recipe" the fusion fuel (usually a mixture of the hydrogen isotopes deuterium and tritium) is heated to extremely high temperatures (on the order of 100 million degrees) creating a plasma of ionized deuterium and tritium. Under these conditions, the deuterium and tritium nuclei fuse, releasing substantial amounts of energy.



The Fusion Process

Creating a burning plasma is the crucial next step in the magnetic fusion energy science (MFES) program. A burning plasma is fundamentally different from the plasmas that have been created in research facilities to date, which have all been sustained entirely by external energy sources. In a burning plasma, the plasma temperature is sustained primarily by the self-heating by the alpha particles produced by the fusion reactions.

To sustain the fusion reaction process and keep the fusion fuel at thermonuclear temperatures, the plasma must be contained and prevented from coming into contact with the comparatively cool walls of the confining vessel. In the decades that followed the first attempts at controlled thermonuclear fusion, two main approaches for confining fusion plasmas emerged: magnetic confinement and inertial confinement. FES supports research programs in MFES and in plasma science, including activities to investigate the fundamental science of HEDLP needed to make inertial fusion energy attractive.

The MFES program is now moving into the burning plasma regime through its participation in ITER, an international fusion research facility under construction in Cadarache, France, which is designed to achieve and investigate the characteristics of a burning plasma. Under the ITER Joint Implementation Agreement (JIA), the United States is a full Member of the International ITER project—an unprecedented international scientific endeavor to explore the physics of burning plasmas. Our 9.09% share of ITER gives the U.S. access to all scientific data, gives the U.S. the right to propose and carry out experiments, and creates new opportunities for U.S. industry to manufacture high-technology components to fulfill a large part (roughly 80%) of our contribution. In addition to ITER, the United States collaborates with these partners on current fusion research facilities and programs through International Energy Agency (IEA) and bilateral agreements.

With the initiation of the ITER project and the recent completion of the NNSA's National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory (LLNL), plasma science research is at the threshold of new discoveries that will transform the field. Magnetic fusion science has progressed to the point where the community has the knowledge not only to design a burning plasma device (ITER), but also to identify the broader scientific and technical questions that remain to be answered on the path to fusion energy. It is thus an opportune time for the FES program to tackle a wide range of scientific and technical challenges to the development of practical fusion energy.

The FES mission is advanced by three strategic goals reflecting the structure of our program and a synthesis of input from the National Academies, the Fusion Energy Sciences Advisory Committee (FESAC), and the U.S. fusion community. These distinct but strongly linked and synergistic goals are unified by fundamental plasma science, the scientific foundation for a fusion energy source.

- Advance the fundamental science of magnetically confined plasmas to develop the predictive capability needed for a sustainable fusion energy source;
- Pursue scientific opportunities and grand challenges in high energy density plasma science to better understand our universe, to enhance national security and economic competitiveness, and to explore the feasibility of the inertial confinement approach as a fusion energy source; and
- Increase the fundamental understanding of basic plasma science, including low temperature plasma science and engineering, to enhance economic competiveness and to create opportunities for a broader range of science-based applications.

The research activities supported by FES have led to a wide range of advances in fusion related sciences. Some representative advances include the achievement of an increase in fusion power output in laboratory experiments by 12 orders of magnitude over the past 3 decades, the development of advanced computation and simulation capability in the areas of energy transport and plasma stability needed to design a tokamak capable of achieving a burning plasma with significant fusion energy output, and the initiation of the 35-year U.S. participation in the ITER project.

Subprograms

To accomplish its mission and address the strategic goals described above, the FES program is organized into three subprograms—Science, Facility Operations, and Enabling R&D.

- The *Science* subprogram is developing a predictive understanding of fusion plasmas in a range of plasma confinement configurations. The emphasis is presently weighted towards understanding the plasma state and its properties for stable fusion systems, but increasing emphasis is expected in the areas of plasma-material interaction and the simultaneous effects of high heat and neutron fluxes that will be encountered in a burning plasma environment. This subprogram contains research activities in magnetic fusion energy science and in plasma science, including activities to investigate the fundamental science of HEDLP needed to make inertial fusion energy attractive.
- The *Facility Operations* subprogram includes efforts to build, operate, maintain, and upgrade the large facilities needed to carry out research on fusion energy science. The U.S. is a full partner in the international program to design and build ITER, the first fusion facility large enough to sustain a burning plasma. The Facility Operations subprogram includes the funding for the U.S. share of the ITER project. The three major experimental facilities in the FES program—DIII-D tokamak at General atomics in San Diego, California; the Alcator C-Mod tokamak at the Massachusetts Institute of Technology (MIT) in Cambridge, Massachusetts; and the National Spherical Torus Experiment (NSTX) at Princeton Plasma Physics Laboratory (PPPL) in Princeton, New Jersey - provide the essential tools for the U.S. research community to explore and solve fundamental issues of fusion

plasma physics. All three are operated as national facilities and involve users from many laboratories and universities. The funding for facility operations includes expenses for running the facility, providing the required plasma diagnostics, and for facility maintenance, refurbishment, and minor upgrades. The balance between maintenance, upgrades, and experimental operations is judiciously adjusted to ensure safe operation of each facility, provide modern experimental tools such as heating, fueling, and exhaust systems, and provide maximum operating time for the scientists.

- The *Enabling R&D* subprogram supports research to improve the components and systems that are used to build fusion facilities, thereby enabling both existing and future U.S. fusion facilities to achieve improved performance and bring us closer to the goal of achieving practical fusion energy.

Benefits to Society

The development of plasma science during the past 50 years has been motivated by a diverse set of applications such as astrophysics, space science, plasma processing, national defense, and fusion energy. Advances in plasma science have led to significant present day applications, such as plasma processing of semiconductors and computer chips, material hardening for industrial and biological uses, waste management techniques, lighting and plasma displays, space propulsion, and has led to the development of non-contact infection-free surgical scalpels. Particle accelerators and free electron lasers also rely on plasma science concepts.

Plasma science is essential to the development of fusion energy. Fusion has the potential to provide an energy source that is virtually inexhaustible and environmentally benign, producing no combustion products or greenhouse gases. While fusion is a nuclear process, the products of the fusion reaction (helium and a neutron) are not intrinsically radioactive. Short-lived radioactivity may result from interactions of the fusion products with the reactor walls, but with proper design a fusion power plant would be passively safe, and would produce no long-lived radioactive waste. Design studies show that electricity from fusion should eventually cost about the same as electricity from present day sources.

The extreme states of matter studied in HEDLP and encountered in inertial confinement fusion studies may offer an alternate path to a fusion energy source. This research is related to the NNSA stockpile stewardship program and, hence, indirectly supports the national security program of DOE. Related areas of science addressed in these research programs include turbulence and complex systems, multiphase interactions and plasma-material interactions, self-organization of complex systems, astrophysics, geodynamics, and fluids.

Program Planning and Management

FES uses a variety of external entities to gather input for making informed decisions on programmatic priorities and allocation of resources. As part of this effort, FES has developed a system of planning and priority setting that draws on advice from groups of outside experts. FES has also instituted a number of peer review and oversight measures designed to assess productivity and maintain effective communication and coordination among participants in FES activities.

In 2004, a National Academies Press report entitled *Burning Plasma—Bringing a Star to Ear*th indicated that ITER "should be the top priority in a balanced US fusion science program." To coordinate the near term support for ITER, and to prepare for the eventual operation and participation by U.S. scientists in ITER, the FES set up the U.S. Burning Plasma Organization (USBPO). The USBPO Director is also the chief scientist for the U.S. ITER Project Office (USIPO), thus providing close coupling between the ITER Project activities and these scientific activities. The U.S. is also a very active member of the International Tokamak Physics Activity (ITPA) which facilitates international coordination of tokamak research in support of ITER.

The National Research Council (NRC) Plasma Science Committee, which serves as a continuing connection to the general plasma physics community, completed a review in 2007 of plasma science. The report, entitled *Plasma Science-Advancing Knowledge in the National Interest* concluded that expanding the scope of plasma research creates an abundance of new scientific opportunities and challenges. This recommendation supports and informs the FES effort to create a balanced U.S. fusion science program with the FES program as the stewards of general plasma science.

FES is currently engaged in a community-wide effort, culminating in a MFES Research Needs Workshop (ReNeW) scheduled for June 2009, to describe the scientific research required in the ITER era to close knowledge gaps. The information from this activity, along with input from other sources including research needs workshops in Plasma Sciences and HEDLP, will be used by DOE in developing a long-range strategic plan for the FES program.

FES also takes into consideration reports and recommendations from the Fusion Energy Sciences Advisory Committee (FESAC)—a standing committee organized in accordance with the Federal Advisory Committee Act (FACA). Two recent FESAC reports, “Priorities, Gaps and Opportunities: Towards a Long-Range Strategic Plan for Magnetic Fusion Energy” and “Report of the FESAC Toroidal Alternates Panel” have provided a foundation for long-range strategic planning for the MFES part of the program. Those reports, together with earlier reports on burning plasma and ITER research issues, document the full spectrum of science and technology issues and knowledge gaps arising on the ITER path to fusion energy. These reports were used as the technical basis for the ReNeW workshop, which will be input for a new strategic plan for the U.S. fusion science program due to completed in FY2010.

FESAC also completed in 2009 a study of the scientific issues and opportunities in HEDLP entitled, “Advancing the Science of High Energy Density Laboratory Plasmas.” This report documents the issues and opportunities in both fundamental and mission-driven HEDLP that can be pursued over the next decade through the joint FES-NNSA program in HEDLP. This report will be used as the technical basis for the HEDLP ReNeW workshop that will be held in August 2009. The output from this workshop will support the HEDLP portion of the new strategic plan.

FES has required the three major experimental facilities supported by the program to have Program Advisory Committees (PACs). The PACs serve an extremely important role in providing guidance to the facility directors in the form of program review and advice regarding allocation of facility run-time. Composed primarily of researchers from outside the host facility, these PACs also include non-U.S. members.

FESAC also convenes a Committee of Visitors (COV) panel to review FES program management practices every three years. A new COV charge was given to FESAC in November 2008. It asks FESAC to review the entire FES program and report its findings to DOE by August 2009.

Basic and Applied R&D Coordination

As recommended in 2007 by the National Science and Technology Council in the *Report of the Interagency Task Force on High Energy Density Physics*, FES and NNSA have established a joint program in HEDLP to provide stewardship of high energy density laboratory plasma physics. The benefits of this joint program are that it will avoid duplication of effort, provide better leverage for the FES high energy density physics projects of the NNSA high energy density (HED) facilities, and stimulate synergies between the two programs and interactions among the researchers. High energy density plasmas are plasmas with pressures exceeding one million atmospheres (greater than 1 megabar). The science of high energy density plasmas is important to science-based nuclear stockpile stewardship as well as to the research on inertial fusion energy. The FES high energy density physics program includes energy-related science and other fundamental research (e.g., laboratory astrophysics).

At the present time this research includes the science of fast ignition, laser-plasma interaction, magnetized high energy density plasmas, high-density high Mach-number plasma jets, and heavy-ion-beam driven warm dense matter. This research overlaps with other areas of HEDLP that are being funded by the NNSA and are important to nuclear stockpile stewardship including compressible and radiative hydrodynamics, laser-plasma interactions, material properties under extreme conditions, and laboratory astrophysics. The research activities of FES and NNSA in HEDLP are being coordinated under a joint program, with coordinated solicitations, peer reviews, scientific workshops, and Federal advisory functions.

Budget Overview

The FES program is the primary supporter of research in the field of plasma physics. The FY 2010 budget request of $421,000,000 is designed to optimize, within these resources, the scientific productivity of the program. The FES program funds activities involving over 1,100 researchers and students at approximately 67 universities, 10 industrial firms, 11 national laboratories, and 2 Federal laboratories, all of which are located in 31 states. Some of the key activities of the FES program and their status in the FY 2010 budget year are:

- The United States will fully fund our share of the Construction Phase of the ITER Project (U.S. Contributions to ITER Project) including research and development of key components, long-lead procurements, and contributions of personnel and funds to the ITER Organization (IO). In addition, the U.S., working in conjunction with the other partners, will continue to advocate the establishment of formal, coherent, and disciplined project management practices by the IO as a means to control schedule and cost.
- Research at the major experimental facilities in the FES program—DIII-D, Alcator C-Mod, and NSTX—will continue to focus on providing solutions to key high–priority ITER issues and build a firm physics basis for ITER design and operation. More specifically, these facilities will conduct experiments to improve active control of various plasma parameters, measure the effects and mitigation of disruptions in the plasma, develop a better understanding of the physics of the plasma edge in the presence of large heat flows, control the current density profile for better stability, and develop a scientific basis of advanced operating scenarios for ITER.
- The planning study of the Fusion Simulation Program (FSP) continues following a modest start in FY 2009. The FSP is a computational initiative led by FES with collaborative support from the Office of Advanced Scientific Computing Research (ASCR). It is aimed at the development of a world-leading, experimentally validated, predictive simulation capability for fusion plasmas in the regimes and geometries relevant for practical fusion energy.
- As part of stewardship of plasma science, FES will continue to provide support for the operation of one to two plasma science centers (PSCs). The PSCs are intended to establish academic centers of excellence that will focus on fundamental issues of widely recognized importance to plasma science. The education and training of plasma scientists is a major goal of this program.
- FES is also well underway in implementing a joint program of research with NNSA in HEDLP that was started in FY 2008. This program will advance the exploration of a number of fields of research indentified as priorities by both the National Academies and FESAC. In particular, it will continue its support of basic research on the science of fast ignition, laser-plasma interaction, magnetized high energy density plasmas, plasma jets, and warm dense matter.

Significant Program Shifts

FES terminated the National Compact Stellarator Experiment (NCSX) project at PPPL in FY 2008. Funding that was planned for the continuation of NCSX in FY 2009 and FY 2010 is being redirected to increase operating time of the three large facilities, enhance the research programs on smaller stellarators, and initiate an upgrade of NSTX at PPPL. NSTX upgrades will help us better understand the physics required to successfully operate and fully exploit the investment in ITER and may provide important insights into the design of a future domestic facility.

Strategic and GPRA Unit Program Goals

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

- GPRA Unit Program Goal 3.1/2.49.00: Bring the Power of the Stars to Earth—Answer the key scientific questions and overcome enormous technical challenges to harness the power that fuels our Sun.

Contribution to GPRA Unit Program Goal 3.1/2.49.00, Bring the Power of the Stars to Earth

The FES program contributes to this goal by managing a program of fundamental research into the nature of fusion plasmas and the means for confining plasma to yield energy. This program includes exploring basic issues in plasma science; developing the scientific basis and computational tools to predict the behavior of magnetically confined plasmas; using the advances in tokamak research to enable the initiation of the burning plasma physics phase of the FES program; exploring innovative confinement options that offer the potential to increase the scientific understanding and to improve the confinement of plasmas in various configurations; investigating non-neutral plasmas and high energy density physics; and developing the cutting edge technologies that enable fusion facilities to achieve their scientific goals.

These activities require operation of a set of unique and diversified experimental facilities, including smaller-scale devices at universities involving individual principal investigators, larger national facilities that require extensive collaboration among domestic institutions, and an even larger, more costly experiment that requires international collaborative efforts to share the costs and gather the scientific and engineering talents needed to undertake such an experiment. These facilities provide scientists with the means to test and extend theoretical understanding and computer models—leading ultimately to an improved predictive capability for fusion science.

The specific long term (10 year) goals for scientific advancement to which the FES program is committed and against which progress can be measured are:

- **Predictive Capability for Burning Plasmas**: Progress toward developing a predictive capability for key aspects of burning plasmas using advances in theory and simulation benchmarked against a comprehensive experimental database of stability, transport, wave-particle interaction, and edge effects.
- **Configuration Optimization**: Progress toward demonstrating enhanced fundamental understanding of magnetic confinement and improved basis for future burning plasma experiments through research on magnetic confinement configuration optimization.
- **High Energy Density Plasma Physics**: Progress toward developing the fundamental understanding and predictability of high energy density plasma physics.

Annual Performance Results and Targets

FY 2005 Results	FY 2006 Results	FY 2007 Results	FY 2008 Results	FY 2009 Targets	FY 2010 Targets
GPRA Unit Program Goal 3.1/2.49.00 (Bring the Power of the Stars to Earth)					
Science					
Conduct experiments on the major fusion facilities (DIII-D, Alcator C-Mod and NSTX) leading toward the predictive capability for burning plasmas and configuration optimization. In FY 2005, FES measured plasma behavior in Alcator C-Mod with high-Z antenna guards and input power greater than 3.5 MW. [Met Goal]	Conduct experiments on the major fusion facilities (DIII-D, Alcator C-Mod, and NSTX) leading toward the predictive capability for burning plasmas and configuration optimization. In FY 2006, FES injected 2 MW of neutral power in the counter direction on DIII-D and began physics experiments. [Met Goal]	Conduct experiments on major fusion facilities leading toward the predictive capability for burning plasmas and configuration optimization. In FY 2007, FES measured and identified magnetic modes on NSTX that were driven by energetic ions traveling faster than the speed of magnetic perturbations (Alfvén speed); such modes are expected in burning plasmas such as ITER. [Met Goal]	Conduct experiments on major fusion facilities leading toward the predictive capability for burning plasmas and configuration optimization. In FY 2008, FES evaluated the generation of plasma rotation and momentum transport, and assessed the impact of plasma rotation on stability and confinement. Alcator C-Mod investigated rotation without external momentum input, NSTX examined very high rotation speeds, and DIII-D varied rotation speeds with neutral beams. The results achieved at the major facilities provided important new data for estimating the magnitude of and assessing the impact of rotation on ITER plasmas. [Met Goal]	Conduct experiments on major fusion facilities to develop understanding of particle control and hydrogenic fuel retention in tokamaks. In FY 2009, FES will identify the fundamental processes governing particle balance by systematically investigating a combination of divertor geometries, particle exhaust capabilities, and wall materials. Alcator C-Mod operates with high-Z metal walls, NSTX is pursuing the use of lithium surfaces in the divertor, and DIII-D continues operating with all graphite walls. Edge diagnostics measuring the heat and particle flux to walls and divertor surfaces, coupled with plasma profile data and material surface analysis, will provide input for validating simulation codes. The results achieved will be used to improve extrapolations to planned ITER operation.	Conduct experiments on major fusion facilities to improve understanding of the heat transport in the tokamak scrape-off layer (SOL) plasma, strengthening the basis for projecting divertor conditions in ITER. The divertor heat flux profiles and plasma characteristics in the tokamak SOL will be measured in multiple devices to investigate the underlying thermal transport processes. The unique characteristics of C-Mod, DIII-D, and NSTX will enable collection of data over a broad range of SOL and divertor parameters (e.g., collisionality, beta, parallel heat flux, and divertor geometry). Coordinated experiments using common analysis methods will generate data that will be compared with theory and simulation.

FY 2005 Results	FY 2006 Results	FY 2007 Results	FY 2008 Results	FY 2009 Targets	FY 2010 Targets
Increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2005, FES simulated nonlinear plasma edge phenomena using extended MHD codes with a resolution of 20 toroidal modes. [Met Goal]	Increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2006, FES simulated nonlinear plasma edge phenomena using extended MHD codes with a resolution of 40 toroidal modes. [Met Goal]	Increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2007, FES improved the simulation resolution of linear stability properties of Toroidal Alfvén Eigenmodes driven by energetic particles and neutral beams in ITER by increasing the number of toroidal modes used to 15. [Met Goal]	Increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2008, the simulation resolution of ITER-relevant modeling of lower hybrid current drive experiments on Alcator C-Mod was improved by increasing the number of poloidal modes used to 2,000 and the number of radial elements used to 1,000 using the leadership class computers at ORNL. [Met Goal]	Continue to increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2009, gyrokinetic edge electrostatic turbulence simulations will be carried out across the divertor separatrix with enhanced resolution down to the ion gyroradius scale.	Optimizing confinement and predicting the behavior of burning plasmas require improved simulations of toroidal momentum transport, since it influences plasma rotation which plays a critical role in reducing the loss of heat from the plasma and in stabilizing macroscopic instabilities. In FY 2010, gyrokinetic simulations of turbulent transport of toroidal momentum with Boltzmann and with kinetic electrons will be carried out. These simulations will explore the Ion Temperature Gradient (ITG) and the Collisionless Trapped Electron Mode (CTEM) regimes.
Facility Operations					
Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%.[Met Goal]	Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%. [Met Goal]	Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%. [Met Goal]	Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%. [Met Goal]	Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%.	Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%.
Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. [Met Goal]	Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. [Met Goal]	Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. The NCSX team has concluded that the project cannot be completed within the cost and schedule baseline. [Goal Not Met]	Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. The NCSX project was cancelled. [Goal Not Met]	Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%.	Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%.

Science

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Science			
Tokamak Experimental Research	51,622	50,522	51,441
Alternative Concept Experimental Research	57,003	65,566	65,595
Theory	24,505	24,176	24,283
Advanced Fusion Simulations	7,081	9,188	11,212
General Plasma Science	14,821	14,869	14,869
SBIR/STTR	—	8,066	8,667
Total, Science	155,032	172,387	176,067

Description

Plasmas are electrically charged gases that are influenced by the long range interactions between the ions and electrons and by magnetic fields, either externally applied or generated by currents within the plasma. Thus, the Science subprogram focuses on two key questions: What are the physical processes that govern the behavior of a plasma, especially a high temperature plasma? How do you create, confine, heat, and control a burning plasma to make fusion power a reality? These two questions are inherently linked, since a profound understanding of plasma science will be needed to learn how to bring the power of the stars to earth. This linkage is captured in a major goal of the Science subprogram which is to develop a predictive understanding of high temperature fusion burning plasmas in a range of confinement configurations.

The Science subprogram is supporting the preparation for the eventual exploration of burning plasmas by addressing the question of how high temperature plasmas behave in a tokamak based magnetic configuration. The Science subprogram is focused on advancing understanding of plasmas and the fusion environment through an integrated program of experiments, theory, and simulation as outlined in the FESAC report, *Scientific Challenges, Opportunities and Priorities for the Fusion Energy Sciences Program*. This research program aims to yield new methods for sustaining and controlling high temperature, high-density plasmas, which will have a major impact on ITER operation. Research on ITER is expected to provide sufficient information on the complex science of burning plasmas to make a definitive assessment of the scientific feasibility of fusion power.

In parallel with supporting the eventual burning plasma program of ITER, the Science subprogram is pursuing the development of advanced computational simulation tools, capable of taking advantage of the emerging petascale computing resources, needed to address and predict in an integrated manner the questions of how a burning plasma will behave—the Fusion Simulation Program (FSP). This effort will yield the computational tools needed to fully utilize ITER as a science tool. It should also keep the U.S. science community in the lead in using high performance computers to advance understanding of the plasma state.

Addressing the scientific questions associated with the behavior of high temperature plasmas requires a close collaboration between theorists, computational scientists, and experimentalists. In an effort to make this a close and effective collaboration, the Science subprogram is initiating an integrated national science campaign. This science campaign will create a team of scientists from the three major FES facilities, working with theorists and computational scientists to understand the properties of the tokamak edge plasma. Understanding the plasma edge will be a major advance for the fusion program since the edge appears to determine many of the properties of a tokamak plasma. In particular the performance of ITER will likely be determined by the properties of the edge plasma.

The majority of the plasma science questions being addressed within the Science subprogram are closely linked with addressing the question of how to bring the power of the stars to the laboratory. However, there are a number of plasma science questions that do not have this linkage, and these questions are addressed in the General Plasma Science and the Alternative Concepts Experimental Research parts of the Science subprogram. Examples of the plasmas that are being explored are low temperature plasmas used in industrial processing, HEDLP for national security, plasmas for space propulsion, and astrophysics plasmas. An additional objective of the Science subprogram is to broaden the intellectual and institutional base in fundamental plasma science and HEDLP. Two activities, a National Science Foundation (NSF)/DOE partnership in plasma physics and engineering, and the Plasma Physics Junior Faculty Development Program for early career university faculty members, will continue to contribute to this objective. The ongoing Plasma Science Centers (PSCs), funded under General Plasma Science, will also foster fundamental understanding and connections to these related sciences.

Selected FY 2008 Accomplishments

- *World's first gyrokinetic turbulence simulation in realistic edge plasma:* Researchers at the Scientific Discovery through Advanced Computing (SciDAC) Center for Plasma Edge Simulation carried out simulations of plasma turbulence in the edge of the DIII-D tokamak. These simulations showed the existence of ion temperature gradient (ITG) turbulence, in the entire edge region of the plasma—even where the local conditions for the existence of the ITG turbulence were not satisfied. This unexpected result established for the first time the non-local nature of this turbulence mode. The ion thermal transport calculated in the ITG turbulence simulation agreed with the experimentally observed value.
- *Coordinated research effort to examine rotation physics:* A coordinated research campaign was conducted through the three major FES facilities to explore multiple aspects of plasma rotation on turbulence, transport, and stability in tokamaks. Alcator C-Mod investigated active rotation drive using radio waves. DIII-D used magnetic perturbations to increase the rotation of a tokamak plasma for the first time, and NSTX utilized various combinations of magnetic perturbations and modulated neutral beam injection to study momentum sources and sinks in the plasma. Additional experiments at the three facilities provided important data on intrinsic plasma rotation (the rotation observed in plasmas with no external source of momentum input), validating a theory toroidal plasma viscosity, and understanding the role of rotational shear on energy transport. Since rotation generally has favorable effects on turbulence, transport, and stability, these results have important implications for ITER.
- *Mode conversion flow drive:* Experiments on Alcator C-Mod demonstrated that significant toroidal and poloidal plasma flow can be driven by radio frequency (RF) waves. This was an unexpected result, but one of significant importance, since plasma flows are important for achieving good plasma confinement and stability. This result has important implications for ITER, since it may be possible to affect energy transport in a burning plasma using RF flow drive
- *Highest magnetic field achieved in dense plasma in the laboratory at the OMEGA Laser Facility:* Magnetic flux in dense plasmas has been compressed to generate a field of more than 30 million gauss using lasers at the University of Rochester's OMEGA facility. Such high fields are expected to have a significant effect on the properties of a plasma, but the behavior of dense plasmas in high

magnetic fields is a relatively unexplored regime of high energy density plasma physics. This accomplishment paves the way for studying the behavior of dense plasmas in high magnetic fields and developing potentially attractive schemes for inertial fusion energy.

Detailed Justification

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Tokamak Experimental Research	**51,622**	**50,522**	**51,441**

The tokamak magnetic confinement concept has to date been the most effective approach for confining high-temperature plasmas in a laboratory environment. Many of the important issues in fusion science are being studied in tokamaks, including the two major U.S. tokamak facilities: DIII-D and Alcator C-Mod. In association with the International Tokamak Physics Activity (ITPA), the U.S. tokamaks continue to give high priority to joint experiments with tokamak facilities in Europe and Japan to resolve ITER-relevant physics issues. Through the ITER project, the tokamak will, for the first time, offer fusion scientists the opportunity to create, control, and probe a burning plasma.

Today, tokamak experimental research is marked by plasma measurements of unprecedented detail and accuracy, excellent plasma control, and strong connections to theory and simulation efforts. Both DIII-D and Alcator C-Mod use flexible plasma shaping and dynamic control capabilities to attain good confinement and stability. They control the distribution of current in the plasma with electromagnetic wave heating and current drive. The interface between the plasma edge and the material walls of the confinement vessel is managed by means of a magnetic "divertor" and magnetic coils for fine control. Through tokamak research, the science of plasma confinement, plasma control, plasma responses to heating and fueling sources, and plasma-wall interactions has matured sufficiently to establish the physics basis for ITER and continues to advance rapidly. In FY 2010, U.S. tokamak researchers will continue to expand the frontiers of fusion science, both to address outstanding ITER issues and to develop the basis for practical fusion power plants.

Both DIII-D and Alcator C-Mod are operated as national collaborative science facilities with research programs established through public research forums, program advisory committee recommendations, and peer review. As the new superconducting tokamak programs in China (Experimental Advanced Superconducting Tokamak, EAST) and Korea (Korean Superconducting Tokamak Advanced Research, KSTAR) advance their research operations, increases in international collaborations are planned to address steady state physics and technology issues that are not currently being addressed on U.S. facilities.

▪ **DIII-D Research**	**27,451**	**26,488**	**26,604**

The DIII-D tokamak is the largest magnetic fusion facility in the U.S. DIII-D provides for considerable experimental flexibility and has extensive diagnostic instrumentation to measure the properties of high temperature plasmas. It also has unique capabilities to shape the plasma and provide feedback control of error fields that, in turn, affect particle transport and plasma stability. DIII-D has been a major contributor to the world fusion program over the past decade in the areas of plasma turbulence, energy and particle transport, electron-cyclotron plasma heating and current drive, plasma stability, and boundary layer physics using a "magnetic divertor" to control the magnetic field configuration at the edge of the plasma. The divertor is produced by magnet coils that bend the magnetic field at the edge of the tokamak out into a region where plasma particles following the field are neutralized and pumped away.

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010

The primary goal of the DIII-D program is to establish the scientific basis for the optimization of the tokamak approach to fusion energy. This is being accomplished by advancing basic scientific understanding across a broad front of fusion plasma topical areas including transport, stability, plasma-wave physics, and interactions with physical boundaries. These topics are integral parts of six physics groups in the DIII-D Experimental Science Division structure, which are: Steady State Integration, Integrated Modeling, ITER Physics, Plasma Control and Operations, Fusion Science, and Plasma Boundary Interfaces. In addition, three cross-cutting task groups focus on rapid shutdown schemes for ITER, the physics of non-axisymmetric field effects for ITER, and transport model validation. Over the past few years, the investigation of ITER-relevant discharge scenarios, including the development of advanced enhanced performance scenarios, has gained emphasis in the DIII-D experimental program.

The FY 2010 experimental program on DIII-D will commence in mid-October 2009, after a short maintenance period following FY 2009 operations. The objective will be to complete a 14 week research campaign by mid-June and then begin a major hardware modification effort (primarily involving re-orientation of one of the neutral beam lines for off-axis current drive capability) which is planned to take 11 months to finish. The FY 2010 experimental program will continue to focus on experiments to provide solutions to key ITER issues and build a firm physics basis for ITER program planning. The DIII-D program will also be able to accommodate a number of ITPA joint experiments in collaboration with the international community.

▪ **Alcator C-Mod Research**	**9,502**	**9,027**	**9,030**

Alcator C-Mod is a unique, compact tokamak facility that uses intense magnetic fields to confine high-temperature, high-density plasmas in a small volume. It is the only tokamak in the world operating at and above the ITER design magnetic field and plasma densities, and it produces the highest pressure tokamak plasma in the world, approaching pressures expected in ITER. It is also unique in the use of all-metal walls to accommodate high power densities. By virtue of these characteristics, Alcator C-Mod is particularly well suited to operate in plasma regimes that are relevant to ITER. The facility has made significant contributions to the world’s fusion program in the areas of plasma heating, stability, confinement, non-inductive current drive and rotational flows in high field tokamaks, all of which are important integrating issues for burning plasmas.

In FY 2010, Alcator C-Mod will continue a strong research program primarily in support of ITER. Experiments will continue to elucidate the physics of electron runaway dynamics during tokamak discharge disruptions and characterization of small edge-localized modes. Both of these topics are of vital importance to ITER performance: runaway electrons generated during disruptions can damage tokamak walls and controlling the size of the edge-localized modes impacts both the transport properties of the discharge and protection of the tokamak divertor and plasma facing components.

Other ITER-relevant topics that the Alcator C-Mod team will continue to focus on in FY 2010 include plasma surface interaction with all-metal walls (especially in the divertor area), measuring the effects of and mitigating disruptions in the plasma, understanding the physics of the plasma edge in the presence of large heat flows, controlling the current density profile for better stability, and helping to build international cross-machine databases using dimensionless parameter techniques. The main effort will shift to developing accurate models of the fuel retention process in first-wall tiles, an activity important both to ITER and to DEMO-like future machines. C-Mod

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010

will continue participation in many joint experiments organized by the ITPA involving all seven ITER members.

▪ **International Research**	**5,014**	**4,897**	**4,900**

In addition to their work on domestic experiments, scientists from the FES program participate in leading edge scientific experiments on fusion facilities abroad in Europe, Japan, China, South Korea, the Russian Federation, and India—the ITER members—and conduct comparative studies to enhance the understanding of underlying physics of fusion plasmas. The FES program, in return, hosts visiting scientists from the international community for participation in U.S. experiments. The FES program has a long-standing policy of seeking international collaboration. This allows U.S. scientists to have access to the unique capabilities of fusion facilities that exist abroad. These include the world's highest performance tokamak—the Joint European Torus in England, a stellarator—the Large Helical Device in Japan, a superconducting tokamak—Tore Supra in France, AxiSymmetric Divertor Experiment Upgrade and Tokamak Experiment for Technology Oriented Research in Germany, and several smaller devices. In addition, the U.S. is collaborating with China and South Korea on EAST and KSTAR respectively, which have become operational in the past two years. The U.S. collaborations on these two new superconducting tokamaks were instrumental in achieving their first plasmas in September 2006 and June 2008, respectively. These collaborations provide a valuable link with the 80% of the world's fusion research that is conducted outside the U.S. and provide a firm foundation to support ITER activities.

The U.S. is a major participant in the ITPA, which identifies experimental and computational studies to resolve high-priority ITER physics needs and assists in implementation through collaborative experiments among the major international tokamaks, and analysis and interpretation of experiments for extrapolation to ITER.

In FY 2010, the United States will continue to participate in high priority research activities in support of ITER. These include joint ITPA experiments and other joint ITER-relevant experiments in the areas of plasma wall interactions, plasma instabilities, and first wall design considerations for ITER.

▪ **Diagnostics**	**4,141**	**3,962**	**3,912**

Support for the development of unique measurement capabilities (diagnostic instruments) will continue. Diagnostic instruments serve two important functions: to provide a link between theory/computation and experiments, thereby increasing the understanding of the complex behavior of the plasma in fusion research devices; and to provide sensory tools for feedback control of plasma properties in order to enhance device operation.

In FY 2010, research will include the development of diagnostics for fundamental plasma parameter measurements, state-of-the-art measurement techniques, and R&D for ITER-relevant diagnostic systems. Diagnostic systems will be installed and operated on current experiments in the U.S. and on non-U.S. fusion devices, where appropriate, through collaborative programs.

A competitive peer review of the diagnostics development program will be conducted in FY 2010 for funding that begins in FY 2011.

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
▪ **Other**	**5,514**	**6,148**	**6,995**

Funding in this category supports educational activities such as research at historically black colleges and universities, graduate and postgraduate fellowships in fusion science and technology, and summer internships for undergraduates. In addition, funding in this category supports outreach efforts related to fusion science and enabling R&D, operations of the U.S. Burning Plasma Organization and the Fusion Energy Sciences Advisory Committee.

Alternative Concept Experimental Research	**57,003**	**65,566**	**65,595**

This program element broadens the fusion program by exploring the science of confinement optimization in the extended fusion parameter space, with plasma densities spanning twelve orders of magnitude, by seeking physics pathways to improve confinement, stability, and reactor configurations. Through this scientific diversity, the program element adds strength and robustness to the overall fusion program by lowering overall programmatic risks in the quest for practical fusion power in the long term, for which economic and environmental factors are important. At present, two alternate concepts are being pursued at the larger-scale, proof-of-principle level. A number of concepts are also being pursued at a concept-exploration level, as well as research in establishing a knowledge base for high energy density plasmas. The smaller scale experiments and the cutting-edge research have proven to be effective in attracting students and strongly contribute to fusion workforce development and the intellectual base of the fusion program. The research has also resulted in new ideas for the larger toroidal devices, including ITER.

▪ **NSTX Research**	**16,293**	**17,387**	**17,399**

The National Spherical Torus Experiment (NSTX) is one of two large experiments in the world that are exploring the spherical torus (ST) confinement configuration; the other is the MegaAmp Spherical Tokamak (MAST) in the United Kingdom. The spherical torus is an innovative confinement configuration that produces a plasma that is shaped like a sphere with a cylindrical hole through its center. The properties of a ST plasma are different from a conventional tokamak plasma, which is shaped like a donut with a large hole through the center. Results to date indicate that a ST uses applied magnetic fields more efficiently than conventional tokamaks and could, therefore, lead to a cost-effective facility for carrying out the nuclear engineering science research needed to design the power extraction and tritium breeding systems for a fusion energy system.

In FY 2010 the NSTX team will continue a research program designed to provide the physics basis for future ST-based research facilities, contribute to the physics basis for ITER, and advance the fundamental understanding of magnetically confined plasmas. Using new diagnostic capabilities, the NSTX team will perform unique and critical experiments to understand the relation between electron energy confinement and fluctuations in the plasma density and electron temperature. This is an area of critical importance to fusion science and NSTX offers unique capabilities to investigate this topic. Continued study of macroscopic instabilities such as the resistive wall mode and neoclassical tearing mode will focus on developing passive and active control techniques to stabilize these modes. Following the installation of a liquid lithium divertor, boundary physics studies will focus on how reduced recycling affects the properties of the plasma edge. Plasma-wave studies will concentrate on developing a predictive understanding of the redistribution/loss of fast-ions due to energetic particle modes. Research on energetic particle modes will also lead to increased knowledge of how the plasma current density is modified by

	(dollars in thousands)	
FY 2008	FY 2009	FY 2010

energetic ion driven instabilities and how this will affect the ability to sustain the plasma with currents driven by injected high energy particle beams. Finally, there will be a considerable effort on demonstrating solenoid-free start-up and current ramp-up capabilities that will be needed by future ST devices.

	FY 2008	FY 2009	FY 2010
▪ **Experimental Plasma Research**	**17,026**	**16,780**	**16,745**

Experimental Plasma Research was started to explore Innovative Confinement Concepts (ICC). In the ICC program, a number of small concept-exploration level facilities have been constructed, an ICC-centric theory center has been formed and several small topic-specific investigations have been supported. The facilities built include stellarators, spheromaks, field-reversed configurations, a levitated dipole, a flow-stabilized z-pinch, centrifugally confined magnetic mirrors, and electrostatic confinement. In general, these cover emerging concepts for plasma confinement and stability. These studies have intrinsic value to the plasma science and fusion energy missions of the FES program since they provide unique tests and extensions of our understanding of confined plasmas. In that sense, these programs complement the larger tokamak programs to help establish the predictive understanding of fusion plasma behavior. The program will undergo a peer review in FY 2010, the goal of which is to select a portfolio of concepts to generate sufficient experimental data to elucidate the underlying physics principles upon which these concepts are based and, as needed, to develop computational models of promising concepts to a sufficient degree of scientific fidelity to allow an assessment of the relevance of those concepts to future fusion energy systems.

In FY 2010, experimental plasma research will continue to examine novel three-dimensional confinement systems that address potential deficiencies in the tokamak, and support development of instability mitigation techniques for ITER. Despite the cancellation of the National Compact Stellarator Experiment (NCSX), stellarators remain a top alternative confinement concept that can mitigate several of the potential deficiencies of the tokamak configuration. Research on the stellarator concept will be continued within this program.

	FY 2008	FY 2009	FY 2010
▪ **High Energy Density Laboratory Plasmas**	**16,021**	**24,534**	**24,536**

High energy density laboratory plasma physics is the study of ionized matter at extremely high density and temperature. According to the 2007 National Academies Press report on *Plasma Science—Advancing Knowledge in the National Interest*, high energy density (HED) physics begins when matter is heated or compressed (or both) to a point that the stored energy in the matter reaches approximately 10 billion Joules per cubic meter. This corresponds to a pressure of approximately 100,000 atmospheres. HED conditions exist in the interior of the Sun where hydrogen has been fused to produce energy. Supernovae, gamma ray bursts, accretion disks around black holes, pulsars, and astrophysical jets are examples of HED astrophysical phenomena. On Earth, HED conditions can only be created transiently in the laboratory by using intense pulses of lasers, particle beams (electrons or ions), plasma jets, magnetic pinches, or their combinations. Because of its potentially immense impact on energy security, the National Academies report recommended that SC provide stewardship of HED plasma science related to inertial fusion including the use of magnetized targets.

In FY 2010, the proposed budget will maintain the research at approximately the same level as FY 2009. On-going research include studies of warm dense matter driven by heavy ion beams, fast

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010

ignition, magnetized high energy density plasmas, and high mach number and high density plasma jets. Funding awards will be determined by competitive peer-review and recommendations from workshops and conferences.

To enhance the study of the field of high energy density matter, FES is building a Matter in Extreme Conditions (MEC) Instrument project at the Stanford Linear Accelerator Laboratory (SLAC) Linac Coherent Light Source (LCLS). LCLS will be the world's state-of-the-art x-ray laser and the MEC project will enable high energy density matter to be probed and controlled by this advanced coherent x-ray source with unprecedented resolution in time and space. Recovery Act funding will be used to completely build the MEC instrument.

▪ **Madison Symmetrical Torus**	**6,910**	**6,865**	**6,915**

The goals of the Madison Symmetrical Torus (MST) at the University of Wisconsin-Madison are to obtain a fundamental understanding of the physics of reversed field pinches (RFPs), particularly magnetic fluctuations and their macroscopic consequences, and to use this understanding to develop the RFP fusion configuration. The RFP is geometrically similar to a tokamak, but with a much weaker externally applied magnetic field that reverses direction near the edge of the plasma. Research in the RFP's self-organization properties has astrophysical applications and may lead to a more cost-effective fusion system. The plasma dynamics that limit the energy confinement and plasma pressure, as well as novel means to the sustainment of the plasma current, are being investigated in this experiment. MST is one of the four leading RFP experiments in the world and is unique in that it pioneered the reduction of magnetic fluctuations by current density profile control. In recent years, this approach has led to a ten-fold increase in energy confinement time.

In FY 2010, the major plans of the MST program are to begin high power (approximately 1 MW) neutral beam injection experiments and further investigations of electron temperature fluctuations using high rep-rate Thomson scattering. The neutral beam injection will provide key new capability in the investigations of the RFP beta limit, momentum transport, and the confinement and stability of energetic ions.

▪ **NCSX Research**	**753**	**—**	**—**

Due to the cancellation of the National Compact Stellarator Experiment (NCSX) in May 2008, the NCSX research portion of the program was concluded in FY 2008.

Theory	**24,505**	**24,176**	**24,283**

The Theory program provides the conceptual scientific underpinning of the magnetic fusion energy sciences program by supporting three thrust areas: burning plasmas, fundamental understanding, and configuration improvement. Theory efforts describe the complex multiphysics, multiscale, non-linear plasma systems at the most fundamental level and, in doing so, generate world-class science. These descriptions—ranging from analytic theory to highly sophisticated computer simulation codes—are used to interpret results from current experiments, plan new experiments on existing facilities, design future experimental facilities, and assess projections of facility performance. The program focuses on both tokamaks and alternate concepts. Work on tokamaks is aimed at developing a predictive understanding of advanced tokamak operating modes and burning plasmas—both of which are important to ITER—while the emphasis on alternate concepts is on understanding the fundamental processes determining equilibrium, stability, and confinement for each concept. The theory program also provides the input needed in the FES large-scale simulation efforts that are part of the SciDAC

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010

portfolio and, together with SciDAC, is expected to lead to a predictive understanding of how fusion plasmas can be sustained and controlled.

The Theory program is a broad-based program with researchers located at six national and federal laboratories, over thirty universities, and several private companies. Theorists in larger groups, located mainly at national laboratories and private industry, generally support major experiments, work on large problems requiring a team effort, or tackle complex issues requiring multidisciplinary teams. Those at universities tend to support smaller, innovative experiments or work on more fundamental problems in plasma physics while training the next generation of fusion plasma scientists.

In FY 2010 the Theory Program will focus particular attention on the turbulent transport of toroidal and poloidal momentum in tokamak plasmas and the understanding of spontaneous toroidal rotation; progress toward a predictive understanding of particle and electron transport; the physics of the edge pedestal and the transition from low to the high confinement modes in tokamaks; the formation of edge and internal transport barriers; the first-principles formulation of moment closures in extended magnetohydrodynamics models; the calculation of atomic and molecular collision processes of importance in fusion reactors; the study of how to improve the stellarator concept and find configurations that are less prone to the formation of islands; the study of other innovative confinement concepts; the understanding of fast magnetic reconnection in high temperature fusion plasmas; and the development of predictive integrated computational models for tokamak plasmas.

Advanced Fusion Simulations	**7,081**	**9,188**	**11,212**

The FES Advanced Fusion Simulations program includes projects funded under the auspices of the SC Scientific Discovery through Advanced Computing (SciDAC) program as well as a new computational activity focused on integrated modeling, the Fusion Simulation Program (FSP). These two program elements are described in more detail below.

▪ **SciDAC**	**7,081**	**7,212**	**7,212**

The SciDAC program is a set of coordinated research efforts across all SC programs overseen by the Advanced Scientific Computing Research (ASCR) program with the goal of achieving breakthrough scientific advances through computer simulation that are otherwise impossible using theoretical or laboratory studies alone. By taking advantage of the exponential advances in computing and information technologies as tools for discovery, SciDAC encourages and enables a new model of multi-disciplinary collaboration among physical scientists, mathematicians, computer scientists, and computational scientists. The product of this collaborative approach is a new generation of scientific simulation codes that can fully exploit the emerging capabilities of terascale and petascale computing.

The current FES SciDAC portfolio includes eight projects spanning 29 institutions with 44% of the funding going to national laboratories, 38% going to universities, and 18% going to private industry. Of these, five are focused on single-issue topical science areas, such as macroscopic stability, the simulation of electromagnetic wave-plasma interaction, the study of turbulent transport in burning plasmas, and the physics of energetic particles. In FY 2010, these projects will continue to focus their efforts on grand challenge scientific questions of importance to burning plasmas and ITER emphasizing validation of simulation codes with experimental results.

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010

The remaining three projects are known as Fusion Simulation Prototype Centers or proto-FSPs and focus on code integration and computational framework development in the areas of edge plasma transport, interaction of RF waves with MHD, and the coupling of the edge and core regions of tokamak plasmas. In FY 2010, the proto-FSP Centers will continue to focus their efforts on issues important to burning plasmas and ITER such as advancing our understanding of the effects of RF waves on macroscopic instabilities, the development of a first-principles predictive edge pedestal model for ITER, and the development of advanced computational frameworks for integrated fusion simulations.

▪ **Fusion Simulation Program**	**—**	**1,976**	**4,000**

The Fusion Simulation Program (FSP) is a computational initiative led by FES with collaborative support from ASCR. It is aimed at the development of a world-leading, experimentally validated, predictive simulation capability for fusion plasmas in the regimes and geometries relevant for practical fusion energy. The FSP will take advantage of the emergence of SC petascale computing capabilities and the scientific knowledge enabled by the FES and ASCR research programs, in particular those under the auspices of the SciDAC program. The FSP will contribute significantly toward the FES mission of establishing the scientific basis for fusion energy, as well as its long term goal of developing a predictive capability for burning plasmas. It will also help the U.S. sustain and strengthen its leadership in advanced fusion computations.

In 2007, a national research needs workshop was held to refine the long term vision of the FSP and develop a detailed roadmap. The workshop report was reviewed by the FESAC, which suggested that FES proceed with a detailed planning study for this research program.

In FY 2009, following a successful peer review, FES selected a multi-institutional interdisciplinary team of six national laboratories, nine universities, and two private companies to carry out a two-year detailed planning study for the FSP. The FSP planning team, led by the Princeton Plasma Physics Laboratory, includes scientists with a broad range of expertise in computational, theoretical and experimental plasma science, applied mathematics, computer and computational science, and software engineering. The increase in funding for FY 2010 will enhance the efforts of the FSP planning team, allowing it to complete the detailed planning study of the program by the end of 2010. The results of this study will help FES and ASCR proceed with the full FSP in FY 2011, subject to the results of an independent review at the end of the planning period.

General Plasma Science	**14,821**	**14,869**	**14,869**

The General Plasma Science program is directed toward basic plasma science and engineering research. This research strengthens the fundamental underpinnings of the discipline of plasma physics that makes contributions in many basic and applied physics areas. Principal investigators at universities, laboratories, and private industry carry out the research. A critically important element is the education of plasma physicists. Continuing elements of this program are the NSF/DOE Partnership in Basic Plasma Science and Engineering, the Plasma Science Centers (PSCs), the Plasma Physics Junior Faculty Award Program, the General Plasma Science program carried out at the DOE laboratories, and basic plasma physics user facilities at laboratories and universities (sharing costs with NSF where appropriate). The PSCs perform plasma science research in areas of such wide scope and complexity that it would not be feasible for individual investigators or small groups to make

	FY 2008	FY 2009	FY 2010
	(dollars in thousands)		

progress. Atomic and molecular data for fusion will continue to be generated and distributed through openly available databases. FES will continue to share the cost with NSF of the multi-institutional plasma physics Frontier Science Center started in FY 2003 and renewed by NSF for five years in FY 2008.

In 2004, two PSCs were established for a period of 5 years at the cost of $11,900,000. These two PSCs are up for renewal in FY 2009. The program is now in the final stage of a competitive peer review of seven applications for centers that would start in FY 2009. The final funding decisions will be made after presentations to a peer review panel in FY 2009. In FY 2010, the second year of funding is provided for the two new PSCs selected through this peer review process.

	FY 2008	FY 2009	FY 2010
SBIR/STTR	**—**	**8,066**	**8,667**

In FY 2008, $6,353,000 and $762,000 were transferred to the congressionally mandated Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, respectively. The FY 2009 and FY 2010 amounts are the estimated requirements for the continuation of these programs.

	FY 2008	FY 2009	FY 2010
Total, Science	**155,032**	**172,387**	**176,067**

Explanation of Funding Changes

	FY 2010 vs FY 2009 ($000)
Tokamak Experimental Research	
▪ **DIII-D Research**	
Increase to DIII-D Research will maintain enhanced data analysis capability for continued code validation coupled to increased operating time.	+116
▪ **Alcator C-Mod Research**	
Small increase to C-Mod Research will maintain research effort at approximately the same level as FY 2009.	+3
▪ **International Research**	
Small increase to International Research will maintain research effort at approximately the same level as FY 2009.	+3
▪ **Diagnostics**	
The decrease in funding will result in a reduced level of effort in one program.	-50
▪ **Other**	
Small increases to a variety of activities for educational/outreach programs and administrative activities in support of the U.S. Burning Plasma Organization.	+847
Total, Tokamak Experimental Research	**+919**

	FY 2010 vs FY 2009 ($000)
Alternative Concept Experimental Research	
▪ **NSTX Research**	
Small increase to NSTX Research will maintain research effort at approximately the same level as FY 2009.	+12
▪ **Experimental Plasma Research**	
Small decrease to Experimental Plasma Research will maintain research effort at approximately the same level as FY 2009.	-35
▪ **High Energy Density Laboratory Plasmas (HEDLP)**	
Small increase to HEDLP will maintain research effort at approximately the same level as FY 2009.	+2
▪ **Madison Symmetrical Torus (MST)**	
Small increase to MST will maintain research effort at approximately the same level as FY 2009.	+50
Total, Alternative Concept Experimental Research	**+29**
Theory	
Small increase to fund the purchase of computer clusters for the theory program.	+107
Advanced Fusion Simulations	
The increase will accelerate the Fusion Simulation Program planning study initiated in FY 2009 and allow FES to begin the full program in FY 2011 as scheduled.	+2,024
SBIR/STTR	
Support for SBIR/STTR is funded at the mandated level.	+601
Total Funding Change, Science	**+3,680**

Facility Operations

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Facility Operations			
DIII-D	34,452	36,141	38,330
Alcator C-Mod	15,695	15,934	17,434
NSTX	22,274	22,975	23,400
NSTX Upgrade (MIE)	—	5,575	5,000
NCSX	15,900	—[a]	—
GPP/GPE/Other	2,577	2,628	2,578
U.S. Contributions to ITER (MIE TPC)	26,070[b]	124,000	135,000
Total, Facility Operations	116,968	207,253	221,742

Description

The mission of the Facility Operations subprogram is to provide for the operation, maintenance, and enhancements of the major fusion research facilities—Alcator C-Mod, DIII-D, and NSTX—to meet the needs of the scientific collaborators using the facilities. Periodic facility reviews are used to ensure that the facilities are operated efficiently and in a safe and environmentally sound manner. The major FES facilities enable U.S. scientists from universities, laboratories, and industry, as well as visiting foreign scientists, to conduct world-class research that is funded through the Science and Enabling R&D subprograms. In addition, this subprogram is responsible for the execution of new projects and upgrades of major fusion facilities, such as installation of new diagnostics, in accordance with the highest project management standards and with minimum deviation from approved cost and schedule baselines.

The *DIII-D* tokamak at General Atomics in San Diego, California is the largest magnetic fusion facility in the United States. DIII-D provides for considerable experimental flexibility and has extensive diagnostic instrumentation to measure the properties of high temperature plasmas. It also has unique capabilities to shape the plasma and provide feedback control of error fields that, in turn, affect particle transport and the stability of the plasma.

Alcator C-Mod at the MIT is the only tokamak in the world operating at and above the ITER design magnetic field and plasma densities, and it produces the highest pressure tokamak plasma in the world, approaching pressures expected in ITER. It is also unique in the use of all-metal walls to accommodate high power densities. Because of these characteristics, C-Mod is particularly well suited to examine plasma regimes that are highly relevant to ITER.

NSTX is an innovative magnetic fusion device at the PPPL using the spherical torus confinement configuration. A major advantage of this configuration is the ability to confine a higher plasma pressure

[a]Due to cancellation of the NCSX project in May 2008, closeout costs were provided for in FY 2008, and the FY 2009 funding has been reallocated to provide increases in facilities operations and upgrades and experimental plasma research on smaller-scale stellarators.
[b] Starting in FY 2009, the U.S. Contributions to ITER project TEC and OPC funds are consolidated and requested in this subprogram. FY 2008 funding displayed here reflects this change. The FY 2008 budget reflected the FY 2008 OPC costs of $10,626,000 under the Enabling R&D subprogram.

for a given magnetic field strength, which could enable the development of smaller, more economical fusion research facilities.

ITER is a critical step between today's facilities designed to study plasma physics and a demonstration fusion power plant. An unprecedented international collaboration of scientists and engineers led to the design of this burning plasma physics experiment. Project partners are China, the European Union (EU), India, Japan, Russia, South Korea, and the United States. ITER is presently under construction in Cadarache, France, with experimental operations planned to begin in approximately 10 years.

As a result of the FY 2009 Appropriations, DIII-D, Alcator C-Mod, and NSTX plan to operate less in FY 2009 than in FY 2008. Recovery Act funding is provided to enhance and increase the facility operations, allowing each facility to conduct a larger number of high priority science experiments. The funding requested in FY 2010 will support operations at 50-60% of the maximum level and provide research time for about 500 scientists from universities, laboratories, and industry.

The *U.S. Contributions to the ITER Project* continues into its fifth year. The FY 2010 Request of $135,000,000 will provide for operation of the U.S. ITER Project Office (USIPO) at Oak Ridge National Laboratory; engineering design, R&D, and long-lead procurements for U.S. hardware components; U.S. personnel seconded to the ITER Organization (IO); and funds to the IO for its common needs such as directly employed IO staff and infrastructure. The scope and schedule of work planned for FY 2010 will also depend on the IO's schedule needs and priorities.

Funding is also included in this subprogram for general plant projects (GPP) and general purpose equipment (GPE) at PPPL. GPP and GPE support essential facility renovations and other necessary capital alterations and additions to buildings and utility systems.

Selected FY 2008 Accomplishments

- *Facility operation reviews completed:* In FY 2008 a series of coordinated reviews of the operational efficiency and effectiveness of all three major facilities was conducted. Operational review panels evaluated data, toured the facilities, and received presentations from the facility management. Charged with answering a set of questions pertaining to the cost effectiveness and efficiency of operations at each of the facilities, the panels found that all three are generally well run and provide an excellent set of tools to the U.S. fusion research community.
- *DIII-D:* As a result of FY 2008 activities, the installation of a new high voltage transformer was completed in FY 2009. This upgrade to the site power capability will permit simultaneous operation of all auxiliary heating and current drive systems at full power for the typical DIII-D pulse length.
- *Alcator C-Mod:* A major inspection, which is carried out every five years, was conducted on the Alcator C-Mod facility. The Alcator C-Mod tokamak was disassembled and inspected, and the magnet joints were cleaned and refurbished.
- *NSTX:* Successful operation of dual Lithium evaporators to provide complete toroidal coverage of lithium to the lower divertor structure was accomplished. Plasma performance was improved over the previous experience with one Lithium evaporator, and high-performance operation with no between-shot helium glow discharge cleaning was demonstrated, thus increasing the achievable shot-rate by more than 10%.

Detailed Justification

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
DIII-D	**34,452**	**36,141**	**38,330**

To carry out the science identified in the previous section, support is provided for operation, maintenance, and improvement of the DIII-D facility and its auxiliary systems. In FY 2010, 14 weeks of single shift plasma operation will be conducted, during which time essential scientific research will be performed as described in the Science subprogram. Operations will continue to support experiments addressing ITER design and operations issues and developing the advanced tokamak concept for fusion energy. Experiments in FY 2010 will take advantage of the recently completed facility power system upgrade, adding the ability to operate all eight neutral beam sources, six high power microwave tubes, and three fast wave heating systems simultaneously if required. After operations are completed in FY 2010 an extended vent period is planned in order to modify one of the neutral beam lines for off-axis injection and add a set of additional inner wall coils to the inside of the DIII-D vessel.

Achieved Operating Hours	758	N/A	N/A
Planned Operating Hours	758	520	560
Optimal Hours	1,000	1,000	1,000
Percent of Optimal Hours	75.8%	52.0%	56.0%
Unscheduled Downtime	12.3%	N/A	N/A
Number of Users	240	220	235

Alcator C-Mod	**15,695**	**15,934**	**17,434**

Support is provided for operation, maintenance, minor upgrades, and improvement of the Alcator C-Mod facility and its auxiliary systems, including completing and installing a second advanced 4-strap ion cyclotron radio frequency antenna, returning to full system capability (8 MW source, at least 6 MW coupled), continued planning for a second advanced lower hybrid launcher (FY 2011 installation), and the design of a DEMO-like high temperature tungsten divertor (FY 2011 installation). In FY 2010, Alcator C-Mod will be operated for 16 weeks, focusing on ITER design and operations issues and addressing high field and density issues.

Achieved Operating Hours	502	N/A	N/A
Planned Operating Hours	502	192	512
Optimal Hours	800	800	800
Percent of Optimal Hours	62.8%	24.0%	64.0%
Unscheduled Downtime	5.0%	N/A	N/A
Number of Users	193	182	200

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
NSTX	**22,274**	**22,975**	**23,400**

Support is provided for operation, maintenance, and a few facility and diagnostic upgrades on NSTX, including an edge ultra-soft x-ray array, a divertor spectrometer, beam emission spectroscopy for measuring ion-scale turbulence, and an ion flow measurement diagnostic. In FY 2010, there is funding for 15 weeks of operation to explore issues of sustained spherical torus (ST) operation and study ST confinement at high fields relevant to evaluating the science base for high-heat flux and plasma nuclear science initiatives. In FY 2010, NSTX will fully exploit new capabilities added in FY 2009 such as the liquid lithium divertor and the upgraded high harmonic fast wave (HHFW) antenna.

	FY 2008	FY 2009	FY 2010
Achieved Operating Hours	665	N/A	N/A
Planned Operating Hours	665	440	640
Optimal Hours	1,000	1,000	1,000
Percent of Optimal Hours	66.5%	44.0%	64.0%
Unscheduled Downtime	7.3%	N/A	N/A
Number of Users	150	140	145

	FY 2008	FY 2009	FY 2010
NSTX Upgrade (MIE)	**—**	**5,575**	**5,000**

Support is provided to begin conceptual design work for a major upgrade of NSTX to keep its world-leading status. A new centerstack magnet assembly that will double the magnetic field and a second neutral beam (NB) line that will double the NB power into heating the plasma are both being considered. The proposed funding and Critical Decision (CD) schedule for these activities will be refined in FY 2010. A final decision as to which upgrades to proceed with will be made at CD-2.

	FY 2008	FY 2009	FY 2010
NCSX	**15,900**	**—**	**—**

This project was initiated in FY 2003 and consisted of the design and fabrication of a compact stellarator proof-of-principle class experiment and was terminated in May 2008. There was no funding required in FY 2009; all closeout activities were funded using the FY 2008 appropriation for NCSX. The FY 2009 funding for the NCSX MIE and NCSX Research was redistributed within the FES program to the operations and upgrades of DIII-D, C-Mod, and NSTX ($16,823,000), and for other smaller stellarator research efforts ($3,429,000).

	FY 2008	FY 2009	FY 2010
GPP/GPE/Other	**2,577**	**2,628**	**2,578**

These funds are provided primarily for general infrastructure repairs and upgrades for the PPPL site based upon quantitative analysis of safety requirements, equipment reliability, and research needs.

	FY 2008	FY 2009	FY 2010
U.S. Contributions to ITER Project	**26,070**	**124,000**	**135,000**

Background: The U.S. ITER Project is the U.S. share of a seven-member international collaboration to design and build a first-of-a-kind international research facility in Cadarache, France to demonstrate the scientific feasibility of fusion energy. The U.S. ITER Project scope consists of delivering hardware components, personnel, and funds to the ITER Organization (IO). The legal framework for construction, operation, deactivation, and decommissioning is contained in the *Agreement on the Establishment of the ITER International Fusion Energy Organization for the Joint Implementation of the ITER Project* (or the JIA), which entered into force in October 2007 for a period of 35 years.

While significant technical progress has been made with large fusion experiments around the world, most of which were constructed in the 1980s, it has long been obvious that a larger and more powerful magnetic confinement device would be needed to create the physical conditions expected in a fusion power plant (i.e., a sustained “burning plasma” comprised of hot ionized deuterium and tritium gas) and to demonstrate its feasibility. The idea to cooperatively design and build such a device originated from a Geneva superpower summit in November 1985 where Soviet Premier Gorbachev proposed to President Reagan that an international project be set up to develop fusion energy for peaceful purposes. The U.S. participated in the initial design activity, and after a hiatus, the U.S. joined the ITER negotiations in early 2003.

U.S. membership in ITER complies with provisions of the Energy Policy Act of 2005 (EPAct 2005), Section 972(c)(5)(C) which required that DOE provide Congress with three reports: a “Plan for U.S. Scientific Participation in ITER”, a report describing the management structure of ITER and estimate of the cost of U.S. participation, and a report describing how U.S. participation in ITER will be funded without a funding reduction in other SC programs. The National Research Council also reviewed (and endorsed) the Plan for Scientific Participation in ITER, as required by EPAct.

International ITER Project Status: The IO, located at Cadarache, has been established as an independent international legal entity comprised of personnel from all of the Members. The IO is led by a Director General who is appointed by the ITER Council, which serves as ITER’s executive governing board. The Council is comprised of representatives from all the Members. Like all non-host Members, the U.S. share for ITER’s construction is 1/11 (9.09%) of the total value estimate—roughly 80% will be in-kind components manufactured by U.S. industry—and beyond that, the U. S. has agreed to fund 13% of the cost for operation, deactivation, and decommissioning. As the Host, the EU is obligated to provide 5/11 (45.45%) of ITER’s construction value. The JIA identifies the hardware procurement allocations among the seven Members based on this cost sharing arrangement. Starting from literally a “green field” site in 2006, the ITER enterprise at Cadarache had staffed up to roughly half of its full complement of 700 personnel by the end of 2008.

An international design review in 2007 recommended several important ITER design improvements and identified some missing items of scope, such as certain test facilities and a number of spare parts. In 2008, the first bottoms-up Integrated Project Schedule was developed for the Construction Phase. Although the JIA included a goal for construction completion and first plasma to be achieved in 2016, this appears certain to slip. Together with other factors, these developments have served to drive up the estimate for ITER’s construction cost. Indeed, the IO’s most urgent tasks at present are to complete work on the overall ITER design and systems engineering and establish realistic schedule and cost baselines. While the ITER Council has asked the IO to accomplish these efforts by late 2009 and has commissioned an independent cost review panel to evaluate the IO’s cost estimates, it appears that this milestone will not be met. The U. S. will continue to emphasize the importance of completing these efforts and provide support as needed.

At its June 2008 meeting, the ITER Council established the Export Control Working Group (ECWG) to provide advice on the establishment of ITER policies and procedures for export control, peaceful uses, and non-proliferation. These administrative processes must be consistent with the primacy of each Member’s export control regulations, and at the same time prevent export-control-driven delivery delays of hardware and technology. To date, policies and strategies for implementation have been drafted by the ECWG for presentation at the June 2009 ITER Council Meeting.

The U. S. has consistently insisted on project management excellence in all aspects of ITER in order to minimize cost and schedule risk.

U.S. ITER Project Status: The main cost risk to the U.S. ITER Project is the slow rate of progress by the IO in specifying design requirements and in design integration, which in turn is hindering design completion and extending the schedule. Next, there remains some ambiguity in the impact of EU/French nuclear regulatory requirements on U.S. hardware designs. Development of a realistic ITER baseline schedule and cost estimate is ongoing. Once the baseline has been established and approved by the Council, the USIPO will be able to develop schedule and cost baselines for the U.S. ITER Project scope in preparation for CD-2, Approve Performance Baselines. CD-2 is currently projected to occur in late FY 2010 or FY 2011.

Research activities in the domestic fusion program continue to enhance the physics basis and technology support for ITER. While these activities are of general interest to developing the underlying knowledge base for fusion energy, they synergistically support the move to science research on ITER in the future by:

- Providing R&D on ITER physics and technology issues and exploring new modes of operation to enhance ITER performance;
- Developing safe and environmentally attractive technologies relevant to ITER;
- Advancing fusion simulation as a tool to examine the complex behavior of burning plasmas in tokamaks, which will impact the planning and conduct of experimental operations in ITER;
- Conducting experiments on domestic science facilities to develop diagnostics and plasma control techniques that can be extrapolated to ITER; and
- Integrating all that is learned into a forward-looking approach to future fusion applications.

Estimated ITER TPC Range: The TPC range approved at CD-1 represents the magnitude of the cost risks that remained at the time it was developed in late 2007. It preceded, and thus did not account for, the impact of the FY 2008 Energy and Water Development and Related Agencies Appropriations Act. The sources of potential cost growth can be categorized as follows: U.S. funding shortfalls actions taken by the ITER Council and the IO external factors outside of DOE's control and design maturity.

Among the aspects under the IO’s purview, the principal cost drivers are the overall project schedule, design changes and other actions affecting hardware scope and manufacturing costs, as well as French and EU licensing/regulatory requirements. The IO is continuing to develop an integrated baseline schedule for the Construction Phase that includes detailed inputs from the seven Members. Likewise, there are several changes to the reference design to be implemented in 2009, some of which may increase the U.S. ITER TPC.

External factors include changes in Dollar/Euro exchanges rates, escalation rates, commodity prices, and market conditions for hardware procurement. The JIA requires funding contributions from the Members to be made in Euros, which has already increased U.S. ITER Project costs due to increases in the Dollar-Euro exchange rates. Prices for raw materials used in manufacturing U.S. supplied hardware have also been steadily increasing. Although prices have moderated in recent months, this remains a significant concern.

Finally, the reference design for ITER is not complete in certain areas such as the first wall and shield system, for which the U.S. has some manufacturing responsibility. This means that there could be adverse cost impacts as the design is finalized prior to fabrication. A Test Blanket Module (TBM) program has been envisioned as a means to demonstrate a key element of fusion technology, namely the breeding of tritium for a closed fuel cycle in a fusion power plant. While not part of the construction scope of ITER it will have near-term financial implications since certain modifications to the currently designed ITER civil infrastructure must be made to accommodate TBMs. The U.S. share of these modifications is expected to be modest (under $10,000,000) and will be funded by the U.S. ITER Project.

All of these risks were previously evaluated to develop a TPC range for CD-1. It was determined that the bottom of the range should be set at $1.45 billion, which included a reasonable contingency amount (equal to 27 percent of the hardware cost). The difference between $1.45 billion and the top end of the TPC range, $2.2 billion, essentially provides additional contingency for known risks in the above categories as well as an amount for unidentified risks.

ITER Financial Schedule

Total Project Cost (TPC)[a]

(budget authority in thousands)

Fiscal Year	Total Estimated Cost	Other Project Costs	Total Project Costs
2006	15,866	3,449	19,315
2007	42,000	18,000	60,000
2008	22,500	3,570	26,070
2009	109,000	15,000	124,000
2010	105,000	30,000	135,000
Outyears	TBD	TBD	TBD

In FY 2009, the $124,000,000 appropriation will be used to resume the full range of U.S. responsibilities in ITER. U.S. activities will focus on material bonding R&D for first wall components; design and analysis of the central solenoid magnet structure, first wall and shield, port limiters, tokamak cooling water system, fueling pellet injector, tokamak exhaust processing system, ion and electron cyclotron heating transmission lines, and diagnostics; and initiating long-lead procurements of toroidal field magnet conductor materials, tokamak cooling water system components, and first articles of the first wall and shield modules. In addition, the funds will be used to support the USIPO, provide U.S. secondees to the IO, and provide funding contributions to the IO per the terms of the JIA.

In FY 2010, the $135,000,000 requested will be used to continue the R&D and design activities described above. Funds will also be used to support the USIPO and U.S. secondees at the IO, as well as provide funding contributions to the IO per the terms of the JIA.

[a]A complete baseline funding profile, including the outyears, will be established at CD-2, which is anticipated to be in late FY 2010 or FY 2011.

	FY 2008	FY 2009	FY 2010
	(dollars in thousands)		

ITER Related Annual Funding Requirements: The current estimate in the table below incorporates the terms of the JIA on cost sharing during operations, deactivation and decommissioning. Specifically, it considers the procedure for converting currencies into Euros and the 20-year period of annual contributions to the decommissioning fund in conjunction with ITER operations.

(dollars in thousands)

	Current Estimate	Previous Estimate
FY 2015–FY 2034[a]		
U.S. share of annual facility operating costs including commissioning, maintenance, repair, utilities, power, fuel, improvements, and annual contribution to decommissioning fund for the period 2015 to 2034. Estimate is in year 2015 dollars.	80,000	80,000
FY 2035–FY 2039		
U.S. share of the annual cost of deactivation of ITER facility for the period 2035–2039. Estimate is in year 2037 dollars.	25,000	25,000

	FY 2008	FY 2009	FY 2010
Total, Facility Operations	**116,968**	**207,253**	**221,742**

Explanation of Funding Changes

	FY 2010 vs. FY 2009 ($000)
DIII-D	
The increase in funding for FY 2010 will allow for an increase in the weeks of operation from 13 in FY 2009 to 14 in FY 2010. It will also support the initiation of the modification of one beam line for off-axis injection and installation of a new inner coil set.	+2,189
Alcator C-Mod	
The increase in funding for FY 2010, along with the completion of major maintenance activities which limited operations in FY 2009, will allow an increase in the weeks of operation from 6 in FY 2009 to 16 in FY 2010.	+1,500
NSTX	
The increase in funding for FY 2010 will allow for an increase in the weeks of operation from 11 in FY 2009 to 16 in FY 2010. It will also support several diagnostic upgrades and full exploitation of the new liquid lithium divertor.	+425

[a] These estimates will be updated to reflect a more realistic start date for the ITER Operations Phase once the ITER Council has approved a baseline schedule for the Construction Phase.

	FY 2010 vs. FY 2009 ($000)
NSTX Upgrade (MIE) A small decrease in funding for FY 2010 will maintain the effort at approximately the same level as FY 2009.	-575
GPP/GPE/Other A small decrease in funding for FY 2010 will maintain the effort at approximately the same level as FY 2009.	-50
U.S. Contributions to ITER Project This funding change provides for the fifth year of project funding. Activities in FY 2010 will mainly focus on advancing and/or completing various U.S. hardware component designs and supporting R&D activities, as well as long-lead procurements for major U.S. components.	+11,000
Total Funding Change, Facility Operations	**+14,489**

Enabling R&D

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Enabling R&D			
Engineering Research	17,183	18,119	17,974
Materials Research	5,750	4,791	5,217
Total, Enabling R&D	22,933	22,910	23,191

Description

The Enabling R&D subprogram helps the Science subprogram address its scientific challenges by developing, and continually improving, the hardware, materials, and technology that are incorporated into existing fusion research facilities, thereby enabling these facilities to achieve higher levels of performance within their inherent capability. Enabling R&D efforts provide both evolutionary development advances in present day capabilities that make it possible to enter new plasma experimental regimes, such as burning plasmas, and nearer-term technology advancements enabling international technology collaborations that allow the U.S. to access plasma experimental conditions not available domestically. In addition, the Enabling R&D subprogram supports the development of new hardware, materials and technology that are incorporated into the design of next generation facilities, thereby increasing confidence that the predicted performance of these new facilities will be achieved.

The Engineering Research element addresses the breadth and diversity of domestic interests in enabling R&D for magnetic fusion systems as well as international collaborations with emphasis on plasma heating, fueling, and surface protection technologies. While much of the effort is focused on current devices, a significant and increasing amount of the research is oriented toward the technology needs or issues that will be faced in future experiments, including ITER. An example would be to understand scientifically what is occurring in a burning plasma with material erosion and redeposition within the fusion chamber caused by this harsh environment and what effect it can have on the plasma and ITER operation. In addition to providing the tools that help accomplish the experimental research, a part of this element also conducts system studies of the most scientifically challenging concepts for fusion research facilities that may be needed in the future as well as identifying critical scientific issues and missions for the next stage in the FES program. Finally, analysis and studies of critical scientific and technological issues are supported, the results of which will provide guidance for optimizing future experimental approaches and for understanding the implications of fusion research on applications of fusion.

The Materials Research element focuses on the key science issues of materials for practical and environmentally attractive uses in fusion research and future facilities. This element uses both experimental and modeling activities, which makes it more effective at using and leveraging the substantial work on nanosystems and computational materials science being funded by other programs, as well as making it more capable of contributing to broader research in niche areas of materials science. The long-term goal of this element is to develop experimentally validated predictive and analytical tools that can lead the way to nanoscale design of advanced fusion materials with superior performance and lifetime.

In FY 2010, research efforts will continue supporting the development of enabling technologies that enhance plasma performance and address fusion engineering science issues for both current and planned domestic and international machines. Resources will be used to continue to develop a scientifically-validated database for materials that can be used in future facilities and to address potential issues that may occur during ITER operation. In addition, a small, but joint materials initiative will begin with the Offices of Basic Energy Sciences (BES) and Advanced Scientific and Computing Research (ASCR) to address the significant challenges of materials under extreme environments like those posed by fusion.

Selected FY 2008 Accomplishments

- *Discovery of a New Atomic Diffusion Mechanism in Materials:* Materials science research has uncovered a new atomic diffusion mechanism in materials. All crystalline materials contain point defects such as vacant lattice sites (vacancies) and atoms that are misplaced off normal lattice sites (interstitials). Much higher than normal concentrations of these defects are created during irradiation, and they typically migrate by a random process. Researchers' observation of a material during testing discovered that nanometer-sized clusters of lattice vacancies exhibited fast migration. Harnessing this migration mode may permit new control of defects which in turn will allow the development of better materials for many different commercial applications.
- *Deployment of a High Power Density ITER-Like Ion Cyclotron Heating Antenna:* A high power prototype of an ITER-Like Antenna (ILA) was built and successfully tested in the U.S. prior to installation on JET. During the testing, the ILA prototype exceeded its performance requirements. In addition, the ILA has been designed to withstand disruptive events that can occur near the plasma edge and still provide the required heating for the plasma. In an upcoming experimental campaign, the ILA will be installed on JET as a demonstration of its full capability and as a test for a future system on ITER.
- *Understanding Tritium Co-Deposition in Plasma Facilities:* Tritium retention in ITER and future fusion devices, which is an important operational and safety issue, will likely be dominated by tritium trapped in co-depositing material. Because of the intensity of the burning plasma in ITER, material inside the plasma chamber can erode from its original place of origin and deposit in other places inside the chamber. After a series of experiments on U.S. facilities, a better understanding of the situation has been developed and it is now possible to make much more accurate predictions of tritium accumulation rates at various locations throughout the ITER vessel.

Detailed Justification

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Engineering Research	**17,183**	**18,119**	**17,974**
▪ **Plasma Technology**	**14,540**	**13,851**	**13,651**

Plasma Technology efforts will focus resources on developing enabling technologies for current and future machines, both domestically and internationally, and on addressing potential ITER operational issues in the area of safety and plasma materials interactions. In addition, we will continue our collaborative program with Japan (Tritium Irradiation Thermofluid American-Japanese Network, TITAN) on plasma facing and blanket materials for use in future experiments.

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010

In FY 2010, the following specific activities will be supported:

- Continue the experimental studies and modeling activities of tungsten-carbon-beryllium mixed materials layer formation and redeposition in the University of California at San Diego PISCES facility and in the Tritium Plasma Experiment at Idaho National Laboratory (INL). Results will be applied to evaluate tritium accumulation in plasma facing components that will occur during ITER operation.
- Continue a series of material science experiments under the TITAN cost-sharing collaboration with Japan in the Safety and Tritium Applied Research Facility at INL to resolve key issues of tritium behavior in materials proposed for use in fusion systems.

Besides the above activities, research will be conducted on plasma facing components, heating technologies, and blanket concepts that could be tested in ITER. In addition, this category funds research in safety and plasma-surface interaction and modeling that support addressing potential issues that could be encountered during operation of ITER or future devices.

	FY 2008	FY 2009	FY 2010
▪ **Advanced Design**	**2,643**	**4,268**	**4,323**

In FY 2010 this effort will continue to focus on system studies by a team of individuals drawn from throughout the fusion research community that have a wealth of experience in fusion science, technology, and facilities. The team is known for its objective approach and its ability to develop highly innovative solutions. In the past the team has conducted studies of various types of fusion devices to help the program identify the R&D necessary to move the program forward.

Using this existing team and other resources, the FES program will initiate a series of strategic planning/scoping studies as follow-on to its June 2009 Research Needs Workshop on the Magnetic Fusion Energy Sciences part of the program. These studies will help identify possible approaches for the next stage in the U.S. fusion research program in the ITER era. The long-term objective is to identify potential initiatives and facilities that may be pursued at the pre-conceptual level.

	FY 2008	FY 2009	FY 2010
Materials Research	**5,750**	**4,791**	**5,217**

Materials Research remains the key element in establishing the scientific foundations for safe and environmentally attractive uses of fusion as well as providing solutions for materials issues faced by other parts of the FES program. The FY 2010 request will maintain a Materials Research program that addresses material needs for nearer and longer term fusion devices. The funding will be used for both modeling and experimental activities aimed at the science of materials behavior in fusion environments, including research on candidate materials for the structural elements of fusion chambers. Through a variety of cost-shared international collaborations, this element conducts irradiation testing of candidate fusion materials in the simulated fusion environments of fission reactors to provide data for validating and guiding the development of models for the effects of neutron bombardment on the microstructural evolution, damage accumulation, and property changes of fusion materials.

	FY 2008	FY 2009	FY 2010
Total, Enabling R&D	**22,933**	**22,910**	**23,191**

Explanation of Funding Changes

	FY 2010 vs. FY 2009 ($000)
Engineering Research	
▪ **Plasma Technology**	
The decrease will reduce activities on high temperature superconducting magnet technology.	-200
▪ **Advanced Design**	
The increase will support a series of strategic planning/scoping studies.	+55
Total, Engineering Research	-145
Materials Research	
The increase is the FES part of a joint initiative with ASCR and BES on materials under extreme environments such as fusion.	+426
Total Funding Change, Enabling R&D	**+281**

Supporting Information

Operating Expenses, Capital Equipment and Construction Summary

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Operating Expenses	247,767	286,023	309,503
Capital Equipment	45,289	114,559	109,529
General Plant Projects	1,877	1,968	1,968
Total, Fusion Energy Sciences	294,933	402,550	421,000

Funding Summary

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
Research			
National Laboratories	76,709	77,022	77,176
Universities	69,732	69,775	69,344
Industrial	28,837	27,671	27,081
Other	2,687	12,763	16,990
SBIR and STTR	—	8,066	8,667
Total Research	177,965	195,297	199,258
Scientific User Facilities Operations	72,421	75,050	79,164
Major Items of Equipment	41,970	129,575	140,000
Other (GPP, GPE and Infrastructure)	2,577	2,628	2,578
Total, Fusion Energy Sciences	294,933	402,550	421,000

Scientific User Facilities Operations and Research

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
DIII-D			
Operations	34,452	36,141	38,330
Facility Research	27,451	26,488	26,604
Total DIII-D	61,903	62,629	64,934
Alcator C-Mod			
Operations	15,695	15,934	17,434
Facility Research	9,502	9,027	9,030
Total Alcator C-Mod	25,197	24,961	26,464

	(dollars in thousands)		
	FY 2008	FY 2009	FY 2010
NSTX			
Operations	22,274	22,975	23,400
Facility Research	16,293	17,387	17,399
Total NSTX	38,567	40,362	40,799
Scientific User Facilities Operations and Research			
Operations	72,421	75,050	79,164
Facility Research	53,246	52,902	53,033
Total Scientific User Facilities Operations and Research	125,667	127,952	132,197

Facility Users and Hours

	FY 2008	FY 2009	FY 2010
DIII-D National Fusion Facility			
Achieved Operating Hours	758	N/A	N/A
Planned Operating Hours	758	520	560
Optimal Hours	1,000	1,000	1,000
Percent of Optimal Hours	75.8%	52.0%	56.0%
Unscheduled Downtime	12.3%	N/A	N/A
Number of Users	240	220	235
Alcator C-Mod			
Achieved Operating Hours	502	N/A	N/A
Planned Operating Hours	502	192	512
Optimal Hours	800	800	800
Percent of Optimal Hours	62.8%	24.0%	64.0%
Unscheduled Downtime	5.0%	N/A	N/A
Number of Users	193	182	200
National Spherical Torus Experiment			
Achieved Operating Hours	665	N/A	N/A
Planned Operating Hours	665	440	640
Optimal Hours	1,000	1,000	1,000
Percent of Optimal Hours	66.5%	44.0%	64.0%
Unscheduled Downtime	7.3%	N/A	N/A
Number of Users	150	140	145

Summary Major Items of Equipment

	(dollars in thousands)					
	Prior Years	FY 2008	FY 2009	FY 2010	Out Years	Total
MIEs						
NCSX						
TEC	74,159	15,900	—	—	—	90,059
OPC	9,570	—	—	—	—	9,570
TPC	83,729	15,900	—	—	—	99,629
NSTX Upgrade						
TEC	—	—	TBD	TBD	TBD	TBD
OPC	—	—	TBD	TBD	TBD	TBD
TPC	—	—	5,575	5,000	TBD	TBD
ITER						
TEC	57,866	22,500	109,000	105,000	TBD	TBD
OPC	21,449	3,570	15,000	30,000	TBD	TBD
TPC	79,315	26,070	124,000	135,000	TBD	TBD
Total MIEs						
TEC		38,400	TBD	TBD		
OPC		3,570	TBD	TBD		
TPC		41,970	129,575	140,000		

Facility Operations MIEs:

- ***National Compact Stellarator Experiment (NCSX)***

  Funding for NCSX Research ($692,000) and NCSX MIE Project ($19,560,000) was included in FY 2009. Due to cancellation of the project in May 2008, closeout costs were provided for in FY 2008, and the FY 2009 funding was redirected to provide increases in facilities operations and upgrades ($16,823,000) and experimental plasma research on smaller-scale stellarators ($3,429,000).

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

  The NSTX Upgrade Project is being initiated in FY 2009 to support major upgrades at NSTX to keep its world-leading status. The upgrade will add a new centerstack magnet assembly that will double the magnetic field, and a second neutral beam (NB) line that will double the NB power into heating the plasma. CD-0 (Approve Mission Need) was completed on February 23, 2009. The proposed funding and Critical Decision (CD) schedule for these activities will be better defined at CD-1, which is planned for the first quarter of FY 2010. A final decision on upgrades will be made at CD-2.

- ***U.S. Contributions to ITER***

  The objective of the U.S. ITER Project is to deliver the U.S. share of the hardware components, personnel, and funding contributions (in Euros) to the ITER Organization (IO) for the ITER Construction Phase per the terms of the ITER Joint Implementation Agreement that was signed in November 2006. It is being managed by the U.S. ITER Project Office (USIPO), located at Oak

Ridge National Laboratory (ORNL). ORNL serves as the prime contractor to DOE, working with its partners Princeton Plasma Physics Laboratory and Savannah River National Laboratory. Each laboratory has been assigned a well-defined portion of the project's scope that takes advantage of their respective technical strengths. DOE serves as the U.S. Domestic Agency for ITER, and under its direction, the USIPO has responsibility for planning, managing, and delivering the entire scope of the U.S. ITER Project. All U.S. ITER Project activities are being overseen by a DOE Federal Project Director at the DOE Oak Ridge Office. As the design agent and eventual operator/owner of the ITER facility, the IO is responsible for specifying top level hardware design requirements and delivery schedules.

The U.S. ITER Project was formally initiated in July 2005 when Critical Decision 0 (CD-0), Mission Need, was approved by the DOE Senior Acquisition Executive, and the first year of project funding was FY 2006. CD-1, Alternative Selection and Cost Range (including authorization for long-lead procurements), was subsequently approved in January 2008. This set the Total Project Cost (TPC) range at $1.45 to 2.2 billion (as spent). This, however, did not take into account the FY 2008 Energy and Water Development and Related Agencies Appropriations Act that reduced the President's FY 2008 Budget Request from $160,000,000 to $10,626,000. A schedule range for U.S. ITER Project completion (CD-4) was set at FY 2014–2017. Current efforts are focused on completing U.S. hardware component designs and supporting R&D, and assisting the IO with establishing a functionally mature project management organization.

Scientific Employment

	FY 2008 actual	FY 2009 estimate	FY 2010 estimate
# University Grants	246	236	246
# Laboratory Projects	167	154	167
# Permanent Ph.D's (FTEs)	722	720	723
# Postdoctoral Associates (FTEs)	113	112	113
# Graduate Students (FTEs)	326	325	327
# Ph.D.'s awarded	36	37	42