Fusion Energy Sciences

Overview

The Fusion Energy Sciences (FES) program mission is to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundation needed to develop a fusion energy source. This is accomplished through the study of plasma, the fourth state of matter, and how it interacts with its surroundings.

Understanding the scientific character of the burning plasma state, as well as establishing the science for maintaining this state for long durations, is a major objective of FES research. To achieve these research goals, FES invests in flexible U.S. experimental facilities of various scales, international partnerships leveraging U.S. expertise, large-scale numerical simulations based on experimentally validated theoretical models, the development of advanced fusion-relevant materials, and the invention of new measurement techniques.

The knowledge base being established through FES research supports U.S. goals for future scientific exploration on ITER,[a] a major international fusion facility currently under construction in Caderache, France. If successful, ITER will be the world's first magnetic-confinement burning plasma experiment aimed at demonstrating the scientific and technical feasibility of fusion as a future energy source. Execution and oversight of the U.S. contribution to the ITER project are carried out within FES.

FES also supports discovery plasma science, including research in plasma astrophysics, small-scale magnetic confinement experimental platforms, and high energy density laboratory plasmas. Some of this work is jointly supported with the National Science Foundation.

Highlights of the FY 2015 Budget Request

The most notable changes in the FY 2015 budget include:

- *Increased support for collaboration in the DIII-D and NSTX-U national research programs*—Research funding is increased to make it possible for more scientists, graduate students, and post docs from universities and national laboratories to collaborate in the scientific programs at the DIII-D and NSTX-U user facilities. Areas of emphasis, all critically important for ITER operation, include boundary and pedestal physics, radio-frequency current drive and heating techniques, magneto-hydrodynamic stability and disruption studies, core transport physics, and advanced diagnostic systems.
- *Increase for NSTX-U research and operations*—With the completion of the upgrade project and the resumption of experimental operations in early FY 2015, funding for NSTX-U operations is increased to support 18 weeks of run time and to begin design and fabrication of two important facility enhancements—a divertor cryo-pump for better control of plasma density and a set of magnetic control coils to improve stable, high-performance operation. NSTX-U research funding is also increased to restore the number of PPPL researchers to pre-upgrade levels (since some resources had been shifted from research to the upgrade project).
- *Progress in hardware contributions for U.S. ITER Project*—Funding provided for critical path items will ensure that U.S. in-kind contributions maintain U.S. commitment to FY 2015 project needs. Funding is provided for ITER Project Office operations; the U.S. cash contribution; and continued progress on in-kind contributions, including industrial procurements of central solenoid magnet modules and structures, toroidal field magnet conductor fabrication, diagnostics, and tokomak cooling water system procurement.

[a] The name ITER is adapted from an acronym for International Thermonuclear Experimental Reactor, which was used for an earlier version of the project.

Fusion Energy Sciences
Funding ($K)

	FY 2013 Current	FY 2014 Enacted	FY 2014 Current	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
Fusion Energy Sciences					
DIII-D Research	32,617	30,998	30,998	32,038	+1,040
Alcator C-Mod Research	8,021	7,890	7,890	6,145	-1,745
International Research	10,132	9,954	9,954	8,545	-1,409
Diagnostics	3,539	3,500	3,500	3,575	+75
Other	4,408	11,562	11,562	2,508	-9,054
NSTX Research	18,316	22,056	22,056	26,000	+3,944
Experimental Plasma Research	10,480	10,500	10,500	10,750	+250
High Energy Density Laboratory Plasmas	17,295	17,315	17,315	6,700	-10,615
Madison Symmetric Torus	5,750	5,700	5,700	5,900	+200
Theory	23,051	24,029	24,029	21,170	-2,859
SciDAC	6,556	9,375	9,375	7,000	-2,375
General Plasma Science	13,456	15,000	15,000	15,500	+500
SBIR/STTR	0	8,797	8,797	8,490	-307
Subtotal, Fusion Energy Sciences	**153,621**	**176,676**	**176,676**	**154,321**	**-22,355**
Facility Operations					
DIII-D	31,461	43,960	43,960	37,385	-6,575
Alcator C-Mod	8,656	14,050	14,050	11,855	-2,195
NSTX	35,093	40,300	40,300	37,354	-2,946
Other, General Purpose Equipment (GPE), and General Plant Projects (GPP)	1,525	5,900	5,900	3,125	-2,775
MIE: U.S. Contributions to ITER Project	124,000	0	0	0	0
Total, Facility Operations	**200,735**	**104,210**	**104,210**	**89,719**	**-14,491**
Enabling R&D					
Plasma Technology	10,686	12,922	12,922	11,910	-1,012
Advanced Design	1,231	1,400	1,400	1,500	+100
Materials Research	11,503	9,969	9,969	8,550	-1,419
Total, Enabling R&D	**23,420**	**24,291**	**24,291**	**21,960**	**-2,331**

	FY 2013 Current	FY 2014 Enacted	FY 2014 Current	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
Construction					
14-SC-60 ITER	0	199,500	199,500	150,000	-49,500
Total, Fusion Energy Sciences	**377,776**	**504,677**	**504,677**	**416,000**	**-88,677**

SBIR/STTR:

- FY 2013 transferred: SBIR: $6,516,000; STTR: $845,000
- FY 2014 projected: SBIR $7,697,000 and STTR $1,100,000
- FY 2015 Request: SBIR: $7,461,000; STTR: $1,029,000

Fusion Energy Sciences
Explanation of Major Changes ($K)

	FY 2015 vs. FY 2014 Enacted
Science: Research funding is increased for NSTX-U and DIII-D, including more support for outside university and national laboratory collaborations on these facilities.	-22,355
Facility Operations: Facility operations funding is increased for NSTX-U; this increase is offset by a reduction in MIE funding.	-14,491
Enabling R&D: No major changes.	-2,331
Construction: Funding provided for critical path items will ensure that U.S. in-kind contributions to ITER maintain U.S. commitment to FY 2015 project needs.	-49,500
Total Funding Change, Fusion Energy Sciences	**-88,677**

Basic and Applied R&D Coordination

FES carries out a discovery-driven plasma science research program in concert with the National Science Foundation (NSF), with research extending to a wide range of natural phenomena, including the origin of magnetic fields in the universe and the heating of the solar corona. FES also operates a joint program with the National Nuclear Security Administration (NNSA) in High Energy Density Laboratory Plasma (HEDLP) physics. Both programs involve coordination of solicitations, peer reviews, and workshops. The Fusion Energy Sciences Advisory Committee (FESAC) provides technical and programmatic advice to FES and NNSA for the joint HEDLP program.

Program Accomplishments

ITER component production underway; first major deliveries made—The U.S. ITER Project completed production of all superconducting strands for the toroidal field magnets and made the first deliveries of the vacuum auxiliary system to the ITER Organization. On-going fabrication of the massive, nuclear facility-grade tokamak cooling water system drain tanks is on schedule consistent with installing components within the tokamak building in 2014.

Advanced method to accelerate data-intensive fusion applications wins a 2013 R&D 100 Award—A research team led by an Oak Ridge National Laboratory (ORNL) scientist jointly supported by FES and Advanced Scientific Computing Research (ASCR) developed the *Adaptable Input/Output System* (ADIOS), which significantly increases the performance of massively parallel codes. The ADIOS software improved the performance of fusion codes by more than an order of magnitude on the Office of Science leadership computing resources.

New measurement techniques allow two-dimensional plasma imaging—Standard methods for measuring plasma temperature and density and their fluctuations have long relied on a single line of sight, providing only a one-dimensional profile. Several newly developed techniques are now able to image the temperature and density variations over a two-dimensional (2-D) plasma cross-section. The 2-D imaging measurements enhance our understanding of how plasma transport due to fluctuations and turbulence can affect particle and energy confinement in fusion plasmas.

Birth of turbulent blobs at the edge of tokamak plasma—Understanding the turbulence at the plasma edge is critical since it controls how well particles and heat are confined across the last closed magnetic surfaces in fusion plasmas. Marking a significant advance over earlier fluid-model descriptions, new large-scale simulations with a gyrokinetic code that follows behavior in five-dimensional position and velocity space have been able to analyze how experimentally observed “blobs,” large-amplitude near-coherent structures that move radially outward at the edge, are born and propagate.

Catch and suppress capability demonstrated for plasma instabilities—Localized current driven by electron cyclotron frequency waves applied to a plasma can suppress the formation of the Neoclassical Tearing Mode, a plasma instability that, if it grows unabated, can eventually trigger a full-scale disruption. Recently this capability was greatly enhanced through development of an advanced real-time feedback control system that can rapidly aim the current at exactly the right spot to shrink the modes.

Fusion Energy Sciences
Science

Description

The Science subprogram advances the predictive understanding of plasma confinement, dynamics, and interactions with surrounding materials. The greatest emphasis is on understanding magnetically confined fusion-grade plasmas; however, FES also stewards discovery-oriented research in the broader plasma sciences. Among the activities supported by this subprogram are:

- Research at major experimental facilities aimed at resolving fundamental fusion plasma science issues, including developing the predictive understanding needed for ITER operations, and providing solutions to high-priority ITER concerns.
- Research on small- and medium-scale magnetic confinement experiments to elucidate physics principles underlying toroidal confinement and to validate theoretical models and simulation codes.
- Research performed at a new generation of international fusion research facilities to exploit their unique capabilities and characteristics, especially in areas to accelerate progress at these experiments.
- Theoretical work on the fundamental description of magnetically confined plasmas and the development of advanced simulation codes on current and emerging high-performance computers.
- Development of unique measurement capabilities and diagnostic instruments to enable experimental validation and provide tools for feedback control of fusion devices.
- Research addressing fundamental scientific questions on high energy density laboratory plasmas, through experimental, theoretical, and modeling efforts.
- Research advancing basic understanding of the broad, multidisciplinary field of general plasma science, which has far-reaching impacts, from developing new products through low-temperature plasmas to understanding exotic phenomena in the cosmos.

DIII-D Research

The DIII-D research program is carried out on the DIII-D tokamak at General Atomics in San Diego, California—the largest magnetic fusion facility in the U.S.

The DIII-D research goal is to establish the scientific basis to optimize the tokamak approach to magnetic confinement fusion. Much of this research concentrates on developing the advanced tokamak concept, in which active control techniques are used to manipulate and optimize the plasma to obtain conditions scalable to robust operating points and high fusion gain for ITER and future fusion reactors. Near-term targeted efforts address scientific issues important to the ITER design. Longer-term research focuses on advanced scenarios to maximize ITER performance. Another high-priority DIII-D research area is foundational fusion science, pursuing a basic scientific understanding across all fusion plasma topical areas.

Alcator C-Mod Research

The Alcator C-Mod tokamak is a compact device employing intense magnetic fields to confine high-temperature, high-density plasmas in a small volume. Housed at the Massachusetts Institute of Technology, the program is operated as a national scientific user facility. Key research areas are disruption mitigation, radio-frequency heating and current drive science, plasma edge physics, and plasma-material interactions. C-Mod research is organized around integrated operating scenarios at plasma conditions relevant to fusion energy production.

International Research

In addition to their work on domestic facilities, U.S. researchers participate in experiments at international facilities that leverage U.S. strengths. Such participation enables U.S. researchers to pursue fusion science not accessible in the U.S. Examples are collaborations on facilities in China (Experimental Advanced Superconducting Tokamak [EAST]), Korea (Korean Superconducting Tokamak Advanced Research [KSTAR]), United Kingdom (Joint European Torus), Germany (Wendelstein 7-X), and Japan (Large Helical Device).

Diagnostics

Diagnostics, the scientific instruments used to make detailed measurements of the behavior of plasmas, are key to advancing our ability to predict and control the behavior of fusion plasmas. Diagnostics are also an excellent vehicle to involve the university and industrial communities in fusion research on major facilities and international collaboration as the FES program advances into the burning plasma era. This program activity focuses on the development of new and innovative diagnostic techniques; the implementation of mature diagnostics systems is supported via the research programs at the major facilities.

Other

Funding in this category supports activities including research at Historically Black Colleges and Universities (HBCUs), the U.S. Burning Plasma Organization (a national organization that coordinates research in burning plasma science), peer reviews for solicitations across the program, and the Fusion Energy Sciences Advisory Committee (FESAC).

NSTX Research

The National Spherical Torus Experiment Upgrade (NSTX-U) is a national scientific user facility designed to explore the physics of plasmas confined in a spherical torus (ST) configuration. Research on this configuration could lead to the development of smaller and more economical future fusion research facilities. The ST configuration, with its very strong magnetic curvature, has different confinement and stability properties from those of conventional tokamaks. A major upgrade, currently in progress, will increase the plasma current and magnetic field capabilities of the facility by a factor of two and increase its pulse length from 1 second to 5 seconds.

Experimental Plasma Research

Experimental Plasma Research (EPR) provides data in regimes of relevance to the FES mainline magnetic confinement and materials science efforts and helps confirm theoretical models and simulation codes in support of the FES goal to develop an experimentally-validated predictive capability for magnetically confined fusion plasmas. Consisting of small-scale experiments primarily at universities, the EPR activity emphasizes plasma physics studies in a wide range of magnetic configurations. Recent investments have supported the operation of a variety of experimental facilities and a center providing theory and computational support to EPR experiments.

High Energy Density Laboratory Plasmas

High Energy Density (HED) physics is the study of ionized matter at extremely high density and temperature, specifically, matter that is heated and compressed to a point that the stored energy reaches approximately 100 billion Joules per cubic meter. Such extreme environments will be common in all future inertial fusion energy applications independent of the driver, and are also prominent in many astrophysical phenomena such as supernovae, relativistic jets, and planetary cores. The Matter at Extreme Conditions (MEC) end station of the Linac Coherent Light Source (LCLS) user facility at the SLAC National Accelerator Laboratory provides scientific users with access to HED regimes uniquely coupled with a high-brightness x-ray source, enabling experiments capable of addressing key questions in high energy density physics, laboratory astrophysics, laser-particle acceleration, and nonlinear optical science. In addition, the Office of Science (SC) works closely with the NNSA to steward a growing university community in HED science through the NNSA/FES Joint Program in high energy density laboratory plasma (HEDLP) science, and to leverage DOE-NNSA investments in defense facilities for broader scientific investigations.

Madison Symmetric Torus

The Madison Symmetric Torus (MST) experiment at the University of Wisconsin-Madison focuses on increasing the fundamental understanding of the physics of the reversed field pinch (RFP) magnetic configuration, expanding validated predictive capability of toroidal magnetic confinement, and advancing discovery science and its links to plasma astrophysics.

Theory

The Theory activity is focused on advancing the scientific understanding of the fundamental physical processes governing the behavior of magnetically confined plasmas. The efforts supported by this activity range from small single-investigator grants mainly at universities to large coordinated teams at national laboratories, universities, and private industry, while the supported research ranges from fundamental analytic theory to mid- and large-scale computational work using high-performance computing resources. In addition to its scientific discovery mission, the Theory activity provides the scientific grounding for the physics models implemented in the advanced simulation codes developed under the Scientific Discovery through Advanced Computing (SciDAC) activity and supports validation efforts at major experiments.

SciDAC

The FES Scientific Discovery Through Advanced Computing (SciDAC) activity, a component of the SC-wide SciDAC program, is aimed at advancing scientific discovery in fusion plasma science by exploiting leadership-class computing resources and associated advances in computational science. The FES SciDAC portfolio contributes to the FES goal of advancing the fundamental science of magnetically confined plasmas to develop the predictive capability required for a sustainable fusion energy source. The seven centers in the FES SciDAC portfolios address challenges in magnetic confinement science and computational fusion materials studies and are well-aligned with the needs of ITER. Two of these centers are set up as partnerships between FES and ASCR.

General Plasma Science

The General Plasma Science (GPS) activity addresses questions related to fundamental plasma properties and processes through discovery-based investigations in basic and low-temperature plasma science. Major components of the GPS activity include basic plasma science research at DOE national laboratories, low-temperature plasma science research through multi-institutional collaborations, small- to medium-scale plasma experimental platforms, and the NSF/DOE Partnership in Basic Plasma Science and Engineering, which supports exploratory single-investigator research at universities and industries.

Activities and Explanation of Changes ($K)

FY 2014 Enacted	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
DIII-D Research		
Research is conducted in three program areas, with DIII-D staff and collaborator support for diagnostics and data analysis to exploit the additional DIII-D operations in FY 2014:	Research will be conducted in the same three general program areas as in FY 2014:	The DIII-D research program is enhanced by increased collaboration of university researchers, exploiting expertise and knowledge developed in university research programs and allowing for increased student involvement on the DIII-D experiment.
▪ Dynamics and control studies to prepare for burning plasmas in ITER and develop viable steady-state options for fusion energy production.	▪ Dynamics and control studies to test transport models, evaluate plasma performance in ITER-like conditions, and begin exploring methods of active control to avoid disruptions and operate near stability boundaries under steady-state conditions.	
▪ Boundary and pedestal research to improve the understanding of Edge Localized Mode control and particle and energy transport in the edge plasma.	▪ Boundary and pedestal research to assess the benefits of divertor geometry in dissipating heat flux, investigate fueling and Edge Localized Mode control at higher density, and develop compatible core-edge solutions for high performance plasmas.	
▪ Burning plasma physics to advance the predictive capabilities to simulate future devices.	▪ Burning plasma physics research to explore and suppress energetic particle instabilities and to understand and control transport barrier formation and confinement transitions.	
Studies of 3D field effects utilize a new enhanced set of magnetic sensors. Disruption mitigation studies focus on providing a firm physics basis for the ITER disruption mitigation system.	Disruption studies will continue to be emphasized in order to guide the design of the ITER disruption mitigation system.	

FY 2014 Enacted	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
Alcator C-Mod Research		
C-Mod research focuses on resolving high-priority issues of ITER-relevant boundary and divertor physics. Research areas include disruption mitigation studies, exploration of the I-mode operating regime, radio-frequency heating physics, and plasma edge/material interaction experiments.	C-Mod research will continue to focus on resolving high-priority issues of ITER-relevant boundary and divertor physics, with the goal of completing specific high priority research tasks relevant to ITER for which C-Mod is uniquely suited. Research areas will be similar to those for FY 2014. C-Mod scientists will initiate enhanced research collaborations on other experimental facilities.	C-Mod research staff will become increasingly involved in collaborative activities on other U.S. and international experiments as the C-Mod facility transitions to closure in late FY 2016.
International Research		
Two research teams continue their research collaborations on heating and control of long-pulse plasmas on EAST (China) and KSTAR (Korea). FES is supporting the work to fabricate and deliver the power supplies for the Wendelstein 7-X (W7-X) stellarator trim coils. FES also supports the effort to design and construct an x-ray imaging crystal spectrometer for the W7-X stellarator to measure the plasma temperature (electron and ion) and plasma flow velocity.	FES will continue to support the two teams working on EAST and KSTAR. FES will also support the work to complete the design of the scraper element for the W7-X steady-state divertor, a tool that will permit early experimental investigation of the edge magnetic configuration in the first full W7-X research campaign. One or two new university collaborations on international facilities may be initiated.	Scientific collaborations on a new generation of international fusion research facilities, including the EAST (China) and KSTAR (Korea) superconducting tokamaks and the Wendelstein 7-X (Germany) superconducting stellarator, will continue at a reduced level of effort.
Diagnostics		
The Diagnostics activity continues to develop innovative measurement techniques to address current and emerging needs in the FES research program.	Efforts will continue on developing innovative techniques to address current and emerging measurement needs in the FES program. A community-informed planning activity will be undertaken to assess the need for long pulse, plasma control, disruption, and burning plasma diagnostics.	Research on advanced diagnostics will continue at approximately the same level of effort.

FY 2014 Enacted	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
Other		
Funding supports all the elements in this category, including the U.S. Burning Plasma Organization (USBPO) activities, HBCUs, peer reviews for solicitations, and FESAC. In addition, funding that supported increased computational and advanced measurement capabilities for validated fusion simulation development was placed in this category until decisions on its distribution could be implemented.	Funding will continue to support USBPO activities, HBCUs, peer reviews for solicitations, and FESAC.	Funding for many of the elements in this category will be eliminated, reduced, or absorbed by other parts of the FES program. The additional funding in FY 2014 for support of increased computational and advanced measurement capabilities for validated fusion simulation development is not continued in FY 2015. There is no funding for support of increased computational and advanced measurement capabilities for validated fusion simulation development.
NSTX Research		
The NSTX research staff complete development of advanced control algorithms for NSTX-U, and work on the design of the next generation of divertor plates, control coils, heating system upgrades, and diagnostics to be implemented during the following five-year research campaign.	The NSTX-U research staff will begin research on the enhanced facility. Initial experiments will concentrate on developing operating scenarios for high-performance plasmas, assessing transport and stability at higher plasma current and magnetic field, developing advanced divertor configurations, advancing techniques for non-inductive start-up, and assessing neutral-beam injection for current ramp-up and sustainment.	The increase in funding will support a significant expansion of the NSTX-U national research effort. The increase will restore the research team at PPPL to its pre-upgrade capability, fund increases in university and other national laboratory scientific teams, and increase the number of graduate students working on NSTX-U.
Experimental Plasma Research (EPR)		
EPR activities test the general validity of plasma physics and technology in a wider expanse of parameter regimes than those provided by current and future major magnetic confinement facilities.	Experiments will be designed to highlight and investigate individual physics principles of toroidal confinement and to validate theoretical models and simulation codes.	Research on experiments with emphasis on validation of theoretical models and simulation codes will be increased.

FY 2014 Enacted	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
High Energy Density Laboratory Plasmas (HEDLP)		
Fundamental HEDLP science is supported through academic grants as part of the SC/NNSA joint program in HEDLP science, research projects at DOE national laboratories, the establishment of a HEDLP physics research group at SLAC, and the operation of the MEC instrument at LCLS. Additionally, the program supports the advancement of heavy ion fusion science through the operation of the Neutralized Drift Compression Experiment –II (NDCX-II) at Lawrence Berkeley National Laboratory (LBNL).	Research utilizing the MEC instrument at LCLS will be emphasized, including: ▪ Continued support for the MEC beam-line science team and HEDLP research group at SLAC. ▪ Completion of phase two of the scheduled short-pulse laser upgrade to deliver 200 TW on target, and grants for external HED science users of MEC.	Contraction of the HEDLP program will result in no new academic grants for basic HEDLP research as part of the SC/NNSA joint program in HEDLP science, no new research projects in basic HEDLP science at DOE national laboratories, and the cessation of operations of the NDCX-II facility at LBNL.
Madison Symmetric Torus (MST)		
The MST activity focuses on reversed-field pinch (RFP) experiments and modeling efforts in support of toroidal research. Measurements of short-wavelength density and magnetic field fluctuations, and comparison with gyrokinetic calculations, will be made. Equilibrium reconstructions are developed for the three-dimensional helical state, and pressure-limiting mechanisms in the RFP will be assessed.	MST research will emphasize measurement of the scaling of tearing mode fluctuations with current and temperature to support the validation of nonlinear magnetohydrodynamic (MHD) codes. Physics extensions beyond MHD will be studied by measuring the Hall dynamo and comparing it to extended MHD simulations.	Diagnostic and modeling efforts will be increased.
Theory		
Continuing research activities at universities, national laboratories, and private industry are supported. For the selection of new and renewal awards via competitive merit reviews, priority is given to theoretical and computational research activities addressing issues of importance to ITER and burning plasmas.	The Theory activity will continue to support research efforts addressing high-priority issues for ITER and burning plasmas. Coordination between theory and experiment leading to model validation will be emphasized, especially in areas where the resolution of essential physics issues is urgently needed before first plasma in ITER.	Research activities on some issues will be reduced.

FY 2014 Enacted	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
SciDAC		
The research activities at most of the SciDAC centers in the FES portfolio are maintained at approximately the FY 2013 level of effort. In a few targeted areas, including the critical area of multiscale integrated modeling, the level of effort is increased.	The FES SciDAC centers continue to contribute to the FES goal of developing a predictive capability for fusion plasmas. The two FES-ASCR partnerships selected in FY 2012 will undergo a mid-term progress review. A new Funding Opportunity Announcement and companion notice to national laboratories will be issued to recompete the part of the portfolio represented by the five centers selected in FY 2011.	The FES SciDAC centers will maintain their research activities.
General Plasma Science		
Intermediate-scale facilities, the partnership with the National Science Foundation (NSF) in Basic Plasma Science and Engineering, and basic and applied plasma science research at DOE national laboratories are supported.	All core research elements of the General Plasma Science program will continue. With input from the NRC Plasma Science Committee, the program will also support: ▪ Multi-institutional teams targeting interdisciplinary connections. ▪ Intermediate-scale facilities expanding experimentally accessible parameters and providing broad access to users.	Research in General Plasma Science will continue at approximately the same level of effort.
SBIR/STTR		
SBIR/STTR funding is statutorily set at 3.2% of non-capital funding in FY 2014.	SBIR/STTR funding is statutorily set at 3.3% of non-capital funding in FY 2015.	No Change.

Description

The Facility Operations subprogram support operation, maintenance, and modifications to the research equipment and diagnostics at the major U.S. fusion user facilities, carries out major upgrades to existing facilities, and constructs new facilities to advance toward a fusion energy source.

The current major experimental user facilities in the FES program—the NSTX spherical torus at the Princeton Plasma Physics Laboratory (PPPL) in Princeton, New Jersey, the DIII-D tokamak at General Atomics in San Diego, California, and the Alcator C-Mod tokamak at the Massachusetts Institute of Technology in Cambridge, Massachusetts—provide important tools for the U.S. and international research community to explore and resolve fundamental issues for fusion plasma science. They are operated as national scientific user facilities. The funding for these facilities provides modern experimental tools such as plasma heating, fueling, and exhaust systems and supports the operating time to conduct world-class innovative research.

The NSTX upgrade project will be completed early in FY 2015, and the facility will begin full research operations later in FY 2015 as NSTX-U.

The Alcator C-Mod facility resumed operation in FY 2014 and will continue operation at a reduced level in FY 2015 to complete student research and critical experimental work before the facility ceases operations at the end of FY 2016. FES will work with MIT to develop a plan for its scientists to transition to other research activities.

<u>DIII-D</u>

The DIII-D user facility is the largest magnetic fusion research experiment in the U.S. and can magnetically confine plasmas at temperatures relevant to burning plasma conditions. Researchers from the U.S. and abroad are able to perform experiments on DIII-D for studying stability, confinement, and other properties of fusion-grade plasmas under a wide variety of conditions.

<u>Alcator C-Mod</u>

The compact size and high magnetic field of the Alcator C-Mod tokamak make it useful for dimensionless scaling studies. It can operate at and above the ITER design values for magnetic field and plasma density, and it has all-metals walls that experience heat fluxes approaching those projected for ITER. Also, it produces tokamak plasmas with very high pressure, near that expected in a burning plasma.

<u>NSTX</u>

The NSTX user facility is an innovative fusion science facility at PPPL employing a spherical torus (ST) confinement configuration. A major advantage of this configuration is the ability to confine plasma at a pressure that is high compared to the magnetic field energy density, which could lead to the development of an efficient fusion nuclear science experiment based on the ST configuration.

The NSTX Upgrade Major Item of Equipment (MIE) project is currently underway. The new center stack assembly will enable a doubling of the magnetic field and plasma current and an increase in the plasma pulse length from 1 to 5 seconds, making NSTX the world's highest-performance ST. The addition of a second neutral beam system will double the heating power, making it possible to achieve higher plasma pressure and providing improved neutral beam current drive efficiency and current profile control, which is needed for achieving fully non-inductive operation. Together, these upgrades will support a strong research program to develop the improved understanding of the ST configuration required to establish the physics basis for next-step ST facilities, broaden scientific understanding of plasma confinement, and maintain U.S. world leadership in ST research. The capability for controllable fully-non-inductive current drive will also contribute to an assessment of the ST as a potentially cost-effective path to fusion energy. The total project cost (TPC) baseline of

$94,300,000 was approved at Critical Decision-2 (CD-2) in December 2010, and CD-3 approval to start fabrication was achieved in December 2011. Project completion is anticipated by early FY 2015.

Other, General Purpose Equipment (GPE), and General Plant Projects (GPP)

Funding in this category provides support for general infrastructure repairs and upgrades for the PPPL site. This funding is based upon quantitative analysis of safety requirements, equipment reliability, research needs, and environmental monitoring needs.

Activities and Explanation of Changes ($K)

FY 2014 Enacted	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
DIII-D		
The DIII-D user facility operates for 18 weeks to support experiments. Upgrades continue to the electron cyclotron auxiliary heating system, to achieve ITER-like equal ion and electron temperatures. Refurbishment of the Thomson scattering diagnostic improves the resolution and accuracy of electron density and temperature measurements, and repair of an internal magnetic perturbation coil for plasma stabilization returns the system to full capability to support research on 3-D field effects. Additional upgrades to power supply infrastructure are initiated to increase the experimental flexibility of the facility.	The DIII-D user facility will operate for 15 weeks to support experiments. An eighth gyrotron system will be operated for additional heating and current drive to expand the advanced tokamak and steady-state operating space of DIII-D. Upgrades to the power supply systems for the field shaping and magnetic perturbation coils will continue.	Run time will be reduced, with a decrease from 18 to 15 weeks, as resources are allocated to completing the upgrade tasks begun in FY 2014. Less funding for upgrade hardware is required, due to purchases made in FY 2014.
Alcator C-Mod		
The C-Mod facility operates for 12 weeks to support experiments and complete student research. Maintenance, refurbishment, and minor upgrades of tokamak systems and diagnostics are performed, with emphasis on tasks necessary for the safe and efficient operation of C-Mod. Upgrades funded by the American Recovery and Reinvestment Act (ARRA) continue to be deployed and used to support research.	The C-Mod facility will operate for 5 weeks to support experiments and complete student research. Maintenance and refurbishment activities to support the safe and efficient operation of C-Mod will continue	Run time will be reduced, and upgrade tasks will decrease.

FY 2014 Enacted	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
NSTX		
NSTX continues its shutdown as upgrade work continues. Installation of the new center stack assembly and the second neutral beamline are completed. Operations funding supports preparation of the systems not involved in the upgrade for resumption of operation in FY 2015.	With the completion of the MIE project, the operations team will complete integrated systems testing and begin research operations, with a goal of 18 weeks of operation. Funding is shifted from the MIE project back to facility operations. The design of facility modifications, including a divertor cryopump, a set of non-axisymmetric control coils, and a 1 MW electron cyclotron heating system, will be initiated.	Funding for the MIE project decreases with the completion of the project; however, overall funding for NSTX facility operations is increased to support resumption of research operations and the design and fabrication of additional diagnostic and facility modifications. Priority is given to operating time.
Other, General Purpose Equipment (GPE), and General Plant Projects (GPP)		
At PPPL, necessary facility and utility infrastructure improvements required to ensure mission readiness and enhance reliability will be accomplished. Several small projects will be executed to modernize and/or replace aging infrastructure elements such as electrical distribution and cooling water utilities and building heating, ventilation, and air conditioning systems. Environmental monitoring needs at PPPL are supported.	Support for non-research infrastructure at PPPL will continue in order to upgrade and replace existing systems. Environmental monitoring needs at PPPL will be supported.	In consideration of the proposed SC Science Laboratories Infrastructure project at PPPL, funding that supports non-research infrastructure at PPPL will be decreased.

Enabling R&D

Description

The Enabling R&D subprogram addresses scientific challenges by developing and continually improving the hardware, materials, and technology incorporated into existing and next-generation fusion research facilities, enabling these facilities to achieve higher levels of performance and flexibility and consequently allowing the exploration of new scientific regimes. In addition, this subprogram supports conceptual studies of future fusion systems to characterize critical research gaps.

The funding changes reflect the need to maintain efforts addressing significant long-term materials challenges as fusion moves into the burning plasma era and advances toward a viable energy source.

Plasma Technology

The Plasma Technology program develops tools to heat, fuel, and confine a burning plasma; breed and process the deuterium and tritium fuel; protect the interior surface of the plasma chamber from the harsh fusion environment; and assure that fusion facilities are operated in a safe and environmentally responsible manner. This program addresses potential ITER operational issues and frequently plays a significant role in international collaboration activities.

Advanced Design

Advanced Design funding provides support for conceptual studies of potential fusion systems. These studies help to identify the various scientific challenges to fusion energy and determine how to address them. In addition, this activity supports program planning activities.

Materials Research

The Materials Research program supports the development, characterization, and modeling of structural, plasma-facing, and blanket materials used in the fusion environment, which is extremely harsh in terms of temperature, particle flux, and irradiation. Materials that can withstand this environment under the long-pulse or steady-state conditions anticipated in future fusion experiments are a prerequisite to the future of fusion research and development activities.

Activities and Explanation of Changes

FY 2014 Enacted	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
Plasma Technology		
Efforts continue to address the challenges and research gaps in this program element. A new U.S. Japan collaborative program focuses on materials characterization to evaluate improved tungsten alloys.	Increased emphasis will be placed on high-heat-flux devices and testing of materials samples under high heat conditions.	Support is decreased for all elements, including heating, fueling, and magnets.
Advanced Design		
Scoping studies are initiated to characterize significant research gaps and focus on fusion nuclear sciences programs required in order to build a fusion nuclear science facility.	Scoping studies will continue on characterizing significant research gaps in the materials and fusion nuclear sciences program required in order to build a fusion nuclear sciences facility.	The effort on scoping studies will be enhanced.
Materials Research		
Efforts increase in all activities. The focus is on the joining of Oxide Dispersion Strengthened steels and silicon carbide composites, fabrication of tungsten and corrosion resistant steels, liquid divertors and first wall technologies, and modeling/simulation of solid state and liquid materials.	Efforts will focus on elucidating the response of materials to the extreme conditions created by burning plasma. Key areas of interest will be fusion nuclear science and plasma-material interaction under reactor-relevant plasma conditions.	The experiments and modeling activity efforts focused on fusion nuclear science and plasma-material interaction will be decreased.

Description

The major international fusion project ITER, presently under construction in Cadarache, France, is designed to be the first magnetic confinement fusion facility to achieve self-heated (burning) plasmas. As ITER construction activities continue, careful and efficient management of the U.S. contributions to the international project by the U.S. ITER Project Office (USIPO) at Oak Ridge National Laboratory (ORNL) will be a high priority for FES.

ITER is designed to generate the world's first sustained (300 seconds, self-heated) burning plasma. It aims to generate fusion power 30 times the levels produced to date and to exceed the external power applied to the plasma by at least a factor of ten. ITER will be a powerful tool for discovery, capable of addressing the new challenges of the burning plasma frontier and assessing the scientific and technical feasibility of fusion energy.

The ITER Project is being designed and built by an international consortium consisting of the U.S., China, India, Japan, South Korea, the Russian Federation, and the European Union (the host). The U.S. is committed to the scientific mission of ITER and will work with ITER partners to accomplish this goal, while maintaining a balanced domestic research portfolio. Executing a fusion sciences program with well-aligned domestic and international components will sustain U.S. international leadership in fusion energy sciences. The U.S. magnetic fusion research program in experiment, theory, and computation is configured to make strong contributions to ITER's science and to bring a high level of scientific return from it. ITER joins the broader FES research portfolio in elevating plasma sciences for both practical benefit and increased understanding.

The U.S. Contributions to ITER Project activity is 9.09% of the ITER Project construction costs. The U.S. contributions, consisting of in-kind hardware components, personnel, and cash to the ITER Organization (IO) for the ITER construction phase, are established by the terms of the ITER Joint Implementation Agreement. In exchange for this contribution, the U.S. gains access to 100% of the ITER research output. ITER is similar to other modern large science projects being conducted as international collaborations that pool financial, technical, and scientific resources to achieve critical science at a scale beyond the reach of individual countries.

The U.S. contributions are managed by the USIPO, ORNL, in partnership with Princeton Plasma Physics Laboratory and Savannah River National Laboratory. The U.S. ITER Project differs from most other DOE and Office of Science (SC) projects in its in-kind hardware contribution obligations and in the risks associated with performing work that depends in large part on the execution of project responsibilities by our international partners. In the spring of 2012, in efforts to ensure a responsible budgetary approach while maintaining contributions to the project, DOE and its oversight organizations agreed to support an annual funding level of no more than $225,000,000 per year beginning in FY 2014. The present U.S. assessment of the project is that it cannot, under current conditions, meet the most recent schedule put forward by the IO. The requested level of funding for FY 2015 will ensure that U.S. in-kind contributions maintain U.S. commitment to FY 2015 project needs.

Activities and Explanation of Changes ($K)

FY 2014 Enacted	FY 2015 Request	FY 2015 vs FY 2014 Enacted
U.S. Contributions to ITER Project		
ITER contributions proceed in accordance with the two-year performance plan that was reviewed by the Office of Project Assessment and the Energy Systems Acquisition Advisory Board (ESAAB) and that was approved by the Acquisition Executive. The U.S. ITER Project Office is on track to deliver four shipments of toroidal field conductor to the European Union toroidal field magnet fabricator, drain tanks for tokamak cooling water, and hardware for the steady-state electrical network. In addition, the U.S. ITER Project Office starts fabrication of the first central solenoid module, completes various design reviews for the vacuum auxiliary system, and awards subcontracts for diagnostic design work.	Funding is provided for ITER Project Office operations; the U.S. cash contribution; and continued progress on in-kind contributions, including industrial procurements of central solenoid magnet modules and structures, toroidal field magnet conductor fabrication, diagnostics, and the tokamak cooling water system procurement.	Funding provided for critical path items will ensure that U.S. in-kind contributions maintain U.S. commitment to FY 2015 project needs.

Fusion Energy Sciences
Performance Measures

In accordance with the GPRA Modernization Act of 2010, the Department sets targets for, and tracks progress toward, achieving performance goals for each program. For more information, refer to the Department's FY 2013 Annual Performance Report. The following table shows the targets for FY 2013 through FY 2015.

	FY 2013	FY 2014	FY 2015
Performance Goal (Measure)	**FES Facility Based Experiments—Experiments conducted on major fusion facilities (DIII-D, Alcator C-Mod, NSTX) leading toward predictive capability for burning plasmas and configuration optimization**		
Target	Conduct experiments and analysis to explore enhanced confinement regimes without large edge instabilities, but with acceptable edge particle transport and a strong thermal transport barrier. Coordinated experiments, measurements, and analysis will be carried out to assess and understand the operational space for these conditions. Exploiting the complementary parameters and tools of the devices, joint teams will work to strengthen the basis for extrapolation of these regimes to ITER and other future fusion devices.	Conduct experiments and analysis to investigate and quantify plasma response to non-axisymmetric (3D) magnetic fields in tokamaks. Effects of 3D fields can be both beneficial and detrimental and research will aim to validate theoretical models in order to predict plasma performance with varying levels and types of externally imposed 3D fields. Dependence of response to multiple plasma parameters will be explored in order to gain confidence in predictive capability of the models.	Conduct experiments and analysis to quantify the impact of broadened current and pressure profiles on tokamak plasma confinement and stability. Broadened pressure profiles generally improve global stability but can also affect transport and confinement, while broadened current profiles can have both beneficial and adverse impacts on confinement and stability. This research will examine a variety of heating and current drive techniques in order to validate theoretical models of both the actuator performance and the transport and global stability response to varied heating and current drive deposition.
Result	Met	Not applicable	Not applicable
Endpoint Target	Magnetic fields are the principal means of confining the hot ionized gas of a plasma long enough to make practical fusion energy. The detailed shape of these magnetic containers leads to many variations in how the plasma pressure is sustained within the magnetic bottle and the degree of control that experimenters can exercise over the plasma stability. These factors, in turn, influence the functional and economic credibility of the eventual realization of a fusion power reactor. The key to their success is a detailed physics understanding of the confinement characteristics of the plasmas in these magnetic configurations. The major fusion facilities can produce plasmas that provide a wide range of magnetic fields, plasma currents, and plasma shapes. By using a variety of plasma control tools, appropriate materials, and having the diagnostics needed to measure critical physics parameters, scientists will be able to develop optimum scenarios for achieving high performance plasmas in ITER and, ultimately, in reactors.		

	FY 2013	FY 2014	FY 2015
Performance Goal (Measure)	**FES Facility Operations—Average achieved operation time of FES user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 90%	≥ 90%	≥ 90%
Result	Met	Not applicable	Not applicable
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically set back. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**FES Theory and Simulation—Performance of simulations with high physics fidelity codes to address and resolve critical challenges in the plasma science of magnetic confinement**		
Target	Carry out advanced simulations to address two of the most problematic consequences of major disruptions in tokamaks: the generation and subsequent loss of high-energy electrons (runaway electrons), which can damage the first wall, and the generation of large electromagnetic loads induced by disruptions, and assess the severity of these effects on ITER.	Understanding alpha particle confinement in ITER, the world's first burning plasma experiment, is a key priority for the fusion program. In FY 2014, determine linear instability trends and thresholds of energetic particle-driven shear Alfvén eigenmodes in ITER for a range of parameters and profiles using a set of complementary simulation models (gyrokinetic, hybrid, and gyrofluid). Carry out initial nonlinear simulations to assess the effects of the unstable modes on energetic particle transport.	Perform massively parallel plasma turbulence simulations to determine expected transport in ITER. Starting from best current estimates of ITER profiles, the turbulent transport of heat and particles driven by various microinstabilities (including electromagnetic dynamics) will be computed. Stabilization of turbulence by nonlinear self-generated flows is expected to improve ITER performance, and will be assessed with comprehensive electromagnetic gyrokinetic simulations.
Result	Met	Not applicable	Not applicable
Endpoint Target	Advanced simulations based on high-physics-fidelity models offer the promise of advancing scientific discovery in the plasma science of magnetic fusion by exploiting the Office of Science high-performance computing resources and associated advances in computational science. These simulations are able to address the multi-physics and multi-scale challenges of the burning plasma state and contribute to the FES goal of advancing the fundamental science of magnetically confined plasmas to develop the predictive capability needed for a sustainable fusion energy source.		

	FY 2013	FY 2014	FY 2015
Performance Goal (Measure)	**FES Construction/MIE Cost & Schedule—Cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects**		
Target	< 10%	< 10%	< 10%
Result	Met	Not applicable	Not applicable
Endpoint Target	Adhering to the cost and schedule baselines for a complex, large scale, science project is critical to meeting the scientific requirements for the project and for being good stewards of the taxpayers' investment in the project.		

Fusion Energy Sciences
Capital Summary ($K)

	Total	Prior Years	FY 2013 Current	FY 2014 Enacted	FY 2014 Current	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
Capital Operating Expenses Summary							
Capital equipment	n/a	n/a	146,773	24,371	24,371	8,739	-15,632
General plant projects (GPP)	n/a	n/a	45	5,400	5,400	2,500	-2,900
Total, Capital Operating Expenses	**n/a**	**n/a**	**146,818**	**29,771**	**29,771**	**11,239**	**-18,532**
Capital Equipment							
Major items of equipment							
ITER[a]	n/a	549,385	121,465	0	0	0	0
National Spherical Torus Experiment Upgrade (TPC $94,300)	83,665	33,695	22,800	23,700	23,700	3,470	-20,230
Total MIEs	**n/a**	**n/a**	**144,265**	**23,700**	**23,700**	**3,470**	**-20,230**
Other capital equipment projects under $2 million TEC	n/a	n/a	2,508	671	671	5,269	+4,598
Total, Capital equipment	**n/a**	**n/a**	**146,773**	**24,371**	**24,371**	**8,739**	**-15,632**
General Plant Projects							
General Plant Projects under $2 million TEC	n/a	n/a	45	5,400	5,400	2,500	-2,900

[a] Per Congressional direction, ITER became a line item in FY 2014

Major Items of Equipment Descriptions

National Spherical Torus Experiment Upgrade

This MIE project includes a new center stack to double the magnetic field and plasma current while increasing the plasma pulse length and a second neutral beam system to double the heating power, making NSTX the world's highest-performance spherical torus. Start of construction/execution (CD-3) was approved in December 2011. NSTX is shut down from FY 2012 through part of FY 2015 for the upgrade. The performance baseline for the MIE Project is $94,300,000 with completion in FY 2015.

Fusion Energy Sciences Funding Summary ($K)

	FY 2013 Current	FY 2014 Enacted	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
Research	177,041	200,967	176,281	-24,686
Scientific user facility operations	52,410	74,610	83,124	+8,514
Major items of equipment	146,800	23,700	3,470	-20,230
Other (GPP, GPE, and infrastructure)	1,525	5,900	3,125	-2,775
Construction	0	199,500	150,000	-49,500
Total, Fusion Energy Sciences	**377,776**	**504,677**	**416,000**	**-88,677**

Scientific User Facility Operations and Research ($K)

	FY 2013 Current	FY 2014 Enacted	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
DIII-D National Fusion Facility	$64,078	$74,958	$69,423	-$5,535
Achieved operating hours	528	N/A	N/A	
Planned operating hours	480	720	600	-120
Optimal hours	1,000	1,000	1,000	0
Percent of optimal hours	52.8%	72%	60%	
Unscheduled downtime hours	16	N/A	N/A	
Number of users	230	270	275	+5
Alcator C-Mod	$16,677	$21,940	$18,000	-$3,940
Achieved operating hours	0	N/A	N/A	
Planned operating hours	0	384	160	-224
Optimal hours	0	800	800	0
Percent of optimal hours	0%	48%	20%	
Unscheduled downtime hours	0	N/A	N/A	

	FY 2013 Current	FY 2014 Enacted	FY 2015 Request	FY 2015 vs. FY 2014 Enacted
Number of users	100	90	75	-15
National Spherical Torus Experiment	$30,609	$38,656	$59,884	+$21,228
Achieved operating hours	0	N/A	N/A	
Planned operating hours	0	0	720	+720
Optimal hours	0	0	1,000	+1000
Percent of optimal hours	0	N/A	72%	
Unscheduled downtime hours	0	N/A	N/A	
Number of users	0	165	250	+85
Total, Facilities users and hours	$111,364	$135,554	$147,307	+$11,753
Achieved operating hours	528	N/A	N/A	
Planned operating hours	480	1,104	1,480	+376
Optimal hours	1,000	1,800	2,800	+1000
Percent of optimal hours (funding weighted)	52.8%	61.3%	52.9%	
Unscheduled downtime hours	16	N/A	N/A	
Number of Users	330	525	600	+75

Scientific Employment

	FY 2013 Actual	FY 2014 Estimate	FY 2015 Estimate	FY 2015 vs. FY 2014
Number of laboratory projects	168	169	139	-30
Number of permanent Ph.D.'s (FTEs)	697	710	622	-88
Number of postdoctoral associates (FTEs)	94	91	66	-25
Number of graduate students (FTEs)	276	264	208	-56
Number of Ph.D.'s awarded	44	42	34	-8

14-SC-60, U.S. Contributions to ITER

1. Summary and Significant Changes

The U.S. Contributions to ITER project described in this Project Data Sheet (PDS) is a U.S. Department of Energy project to provide the U.S. share of ITER hardware and cash contributions to support ITER construction. ITER is a major fusion research facility being constructed in France by an international partnership of seven governments. Since it does not result in a facility owned by or located in the U.S., it is not a capital asset project in the typical sense. Sections of this report have also been tailored accordingly to reflect the nature of this project. This PDS does not constitute a new start.

The U.S. Contributions to ITER is managed as a DOE Office of Science (SC) project. The project began as a major item of equipment (MIE) project in FY 2006 and changed to a Congressional control point beginning in FY 2014. This does not change SC's overall management approach for the U.S. ITER Project. As with all SC projects, the principles encoded in DOE Order 413.3B will be applied including critical decision milestones and their supporting prerequisite activities. Requirements for project documentation, monitoring and reporting, change control, and regular independent peer reviews will be applied with the same degree of rigor.

The most recent DOE O 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was signed on January 25, 2008. Critical Decision 0 (CD-0) was approved in 2005 with a preliminary cost range of $1.45–$2.2 billion and projected completion date in FY 2014. Since CD-1, it has not been possible to baseline the project due to both technical challenges and continued delays in the international ITER construction schedule. Until such time as CD-2 can be approved, the U.S. contributions will be managed to address annual project needs and allow flexibility to adapt to the changing state of the project. Since the Project does not have CD-2 approval, the schedule and cost estimates contained in this PDS are TBD.

The approving official for CD-2 is the Director of the Office of Science (SC-1).

As of December 2013, design of the hardware to be supplied by the U.S. is 51% complete, with the two largest U.S. hardware contributions (by value) nearing completion of final design.

2. Critical Decision (CD) Schedule

	CD-0	CD-1	CD-2	CD-3	CD-4
FY 2006	7/5/2005	TBD	TBD	TBD	TBD
FY 2007	7/5/2005	TBD	TBD	TBD	TBD
FY 2008	7/5/2005	1/25/2008	4Q FY 2008	TBD	TBD
FY 2009	7/5/2005	1/25/2008	4Q FY 2010	TBD	TBD
FY 2010	7/5/2005	1/25/2008	4Q FY 2011	TBD	TBD
FY 2011	7/5/2005	1/25/2008	4Q FY 2011	TBD	TBD
FY 2012	7/5/2005	1/25/2008	3Q FY 2012	TBD	TBD
FY 2013	7/5/2005	1/25/2008	TBD[a]	TBD	TBD
FY 2014	7/5/2005	1/25/2008	TBD	TBD	TBD
FY 2015[b]	7/5/2005	1/25/2008	TBD	TBD	TBD

[a] The CD-2 date will be determined upon acceptable resolution of issues related to development of a high-confidence ITER Project Schedule and other international project uncertainties.
[b] This project is pre-CD-2, and the schedule and cost estimate are preliminary.

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection, Cost Range, and Start of Long-lead Procurements
CD-2 – Approve Performance Baseline
CD-3 – Approve Start of Fabrication
CD-4 – Approve Project Completion

3. Baseline and Validation Status

Since CD-1, it has not been possible to baseline the project due to both technical challenges and continued delays in the international ITER construction schedule. The factors that delayed CD-2 approval (e.g., schedule delays, design and scope changes, regulatory requirements, risk mitigations, and project management issues in the ITER Organization) have placed upward pressure on the cost range. The current best estimate of the total cost range, prior to CD-2, is $4,000,000,000-$6,500,000,000.

4. Project Description, Scope, and Justification

Introduction

ITER is an international partnership among seven Member governments (China, the European Union, India, Japan, the Republic of Korea, the Russian Federation, and the United States) aimed at demonstrating the scientific and technological feasibility of fusion energy for peaceful purposes. The *Agreement on the Establishment of the ITER International Fusion Energy Organization for the Joint Implementation of the ITER Project* (ITER Agreement), signed on November 21, 2006 provides the legal framework for the four phases of the program: construction, operation, deactivation, and decommissioning. The ITER Agreement specifies that, as the Host, the European Union will bear five-elevenths (45.45%) of the ITER facility's construction cost, while the other six Members, including the U.S., will each support one-eleventh (9.09%) of the total cost. The ITER Agreement also provides for operation, deactivation, and decommissioning of the facility to be funded through a different cost-sharing formula in which the U.S. will contribute a 13% share. Responsibility for ITER integration, management, design, licensing, installation, and operation rests with the ITER Organization (IO), which is an international legal entity located in France.

Mission Need

The February 2005 CD-0 document entitled "Mission Need Statement for a Fusion Facility for Sustained Burning Plasma Research" states the mission need and the analysis to support the mission need. The need is based on the mission of the Office of Fusion Energy Sciences to lead the national research effort to advance plasma science, fusion science, and fusion technology. From the 2005 CD-0 statement:

> There is a distinct need to investigate the fusion process in the performance region between the current scientific knowledge base and that needed for a practical fusion power. There are two parts of this need. The first part is to investigate the fusion process in the form of a "burning plasma," in which the heat generated by the fusion process exceeds that supplied from external sources by a significant amount (e.g., with a "gain factor" of at least ten). Some of this heat is used to help sustain the burning plasma while fresh fuel is being added, but the majority of this heat is captured in a blanket and used to make power available for producing electricity. The second part of this need is to sustain the burning plasma for a long duration, (e.g., several hundred to a few thousand seconds, during which time equilibrium conditions can be achieved within the plasma and adjacent structures). In the major fusion programs around the world, no fusion research facility exists or is being built in which such sustained burning plasmas can be achieved. The existing facilities have reached their limits, where the heat generated in the plasma is about equal to that supplied to the plasma from external sources, a gain of about unity. At this level of performance, the plasma behavior is dominated by external heating rather than self-heating. The duration of such experiments is only on the order of 10 seconds.

> Today, fusion research is at the threshold of exploring sustained burning plasma in which self-heating dominates the plasma behavior. Such exploration is a necessary step toward the realization of a fusion energy source; it must be done to establish the confidence in proceeding with development of a demonstration fusion power plant.
>
> Accordingly, the mission need is to establish a fusion facility for sustained burning plasma research.

There have been no material changes to the U.S. ITER Project Mission Need Statement since it was approved. The overall ITER project mission remains the same: to internationally construct a research facility that will demonstrate the scientific and technological feasibility of fusion energy.

ITER Construction Project Scope

The scope of U.S. Contributions to ITER represents 9.09% of the total international ITER construction.The U.S. ITER project includes three major elements:

- Hardware components, built under the responsibility of the U.S., then shipped to the ITER site for IO assembly, installation, and operation.
- Cash to the IO to support common expenses, including ITER research and development (R&D), IO staff and infrastructure, IO-provided hardware, on-site assembly/installation/testing of all ITER components, and IO Central Reserve, which serves as a contingency fund.
- Other costs, including R&D and conceptual design related activities.

The U.S. ITER project hardware scope is limited to design, fabrication, and delivery of mission-critical tokamak subsystems and is described below.

- **Tokamak Cooling Water System**: manages power generated during the operation of the tokamak.
- **15% of ITER Diagnostics**: provide the measurements necessary to control, evaluate, and optimize plasma performance and to further the understanding of plasma physics.
- **Disruption Mitigation Systems**: limit the impact of plasma disruptions to the tokamak vacuum vessel, blankets, and other components.
- **Electron Cyclotron Heating Transmission Lines**: bring additional power to the plasma and deposits power in specific areas of the plasma to minimize instabilities and optimize performance.
- **Tokamak Exhaust Processing System**: separates hydrogen isotopes from tokamak exhaust.
- **Fueling System (Pellet Injection)**: injects fusion fuels in the form of deuterium-tritium ice pellets into the vacuum chamber.
- **Ion Cyclotron Heating Transmission Lines**: bring additional power to the plasma.
- **Central Solenoid Magnet System**: confines, shapes and controls the plasma inside the vacuum vessel.
- **8% of Toroidal Field (TF) Conductor**: component of the TF magnet that confines, shapes, and controls the plasma.
- **75% of the Steady State Electrical Network**: supplies the electricity needed to operate the entire plant, including offices and the operational facilities.
- **Vacuum Auxiliary System**: creates low gas pressures in the vacuum vessel and connected vacuum components.
- **Roughing Pumps**: evacuate the tokamak, cryostat, and auxiliary vacuum chambers prior to and during operations.

5. Financial Schedule

(dollars in thousands)

	Appropriations	Obligations	Costs
Total Estimated Cost (TEC)			
Hardware			
FY 2006	13,754	13,754	6,169
FY 2007	34,588	34,588	24,238
FY 2008	25,500	25,500	24,122
FY 2009	85,401	85,401	26,278
FY 2010	85,266	85,266	46,052
FY 2011	63,875	63,875	84,321
FY 2012	91,716	91,716	99,264
FY 2013	107,694	107,694	110,358
FY 2014[a]	159,458	159,458	201,533
FY 2015	102,726	102,726	130,980
Subtotal	769,978	769,978	753,315
FY 2016–	TBD	TBD	TBD
Total, Hardware	TBD	TBD	TBD
Cash contributions			
FY 2006	2,112	2,112	2,112
FY 2007	7,412	7,412	7,412
FY 2008	2,644	2,644	2,644
FY 2009	23,599	23,599	23,599
FY 2010	29,734	29,734	29,734
FY 2011	3,125	3,125	3,125
FY 2012	13,214	13,214	13,214
FY 2013	13,805	13,805	13,805
FY 2014[a]	35,042	35,042	35,042
FY 2015	41,913	41,913	41,913
Subtotal	172,600	172,600	172,600
FY 2016–	TBD	TBD	TBD
Total, Cash Contributions	TBD	TBD	TBD
Total, TEC	TBD	TBD	TBD

[a] Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.

(dollars in thousands)

	Appropriations	Obligations	Costs
Other project costs (OPC)			
FY 2006	3,449	3,449	1,110
FY 2007	18,000	18,000	7,607
FY 2008	-2,074	-2,074	7,513
FY 2009	15,000	15,000	5,072
FY 2010	20,000	20,000	7,754
FY 2011	13,000	13,000	10,032
FY 2012	70	70	22,322
FY 2013	2,535	2,535	5,760
FY 2014	5,000	5,000	7,281
FY 2015	5,361	5,361	5,316
Subtotal	80,341	80,341	79,767
FY 2016–	TBD	TBD	TBD
Total, OPC	TBD	TBD	TBD
Total Project Costs (TPC)			
FY 2006	19,315	19,315	9,391
FY 2007	60,000	60,000	39,257
FY 2008	26,070	26,070	34,279
FY 2009	124,000	124,000	54,949
FY 2010	135,000	135,000	83,540
FY 2011	80,000	80,000	97,478
FY 2012	105,000	105,000	134,800
FY 2013	124,034	124,034	129,923
FY 2014[a]	199,500	199,500	243,856
FY 2015	150,000	150,000	178,209
Subtotal	1,022,919	1,022,919	1,005,682
FY 2016–	TBD	TBD	TBD
Total, TPC	TBD	TBD	TBD

6. Details of the 2014 Project Cost Estimate

The current best estimate of the total cost range, prior to CD-2, is $4,000,000,000-$6,500,000,000. This range was determined under the assumption that the annual funding level will not exceed $225,000,000 per year through first plasma;

[a] Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.

and taking into account risks associated with assembly and operations costs, the international project schedule, nuclear construction, and technical challenges in providing U.S. project hardware scope.

7. Schedule of Appropriation Requests

(dollars in thousands)

Request Year		Prior Years	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	Outyears	Total
FY 2006	TEC	738,000	151,000	120,000	29,000	0	0	0	1,038,000
	OPC	65,100	9,300	6,200	3,400	0	0	0	84,000
	TPC	803,100	160,300	126,200	32,400	0	0	0	1,122,000
FY 2007	TEC	619,366	180,785	130,000	116,900	30,000	0	0	1,077,051
	OPC	44,449	500	0	0	0	0	0	44,949
	TPC	663,815	181,285	130,000	116,900	30,000	0	0	1,122,000
FY 2008	TEC	619,366	181,964	130,000	116,900	30,000	0	0	1,078,230
	OPC	43,770	0	0	0	0	0	0	43,770
	TPC	663,136	181,964	130,000	116,900	30,000	0	0	1,122,000
FY 2009[a]	TEC	266,366	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	38,075	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	304,441	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2010	TEC	294,366	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	70,019	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	364,385	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2011	TEC	304,366	75,000	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	60,019	5,000	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	364,385	80,000	TBD	TBD	TBD	TBD	TBD	TBD
FY 2012[b]	TEC	304,366	TBD	90,000	TBD	TBD	TBD	TBD	TBD
	OPC	60,019	TBD	15,000	TBD	TBD	TBD	TBD	TBD
	TPC	364,385	TBD	105,000	TBD	TBD	TBD	TBD	TBD
FY 2013	TEC	304,366	67,000	104,930	140,965	TBD	TBD	TBD	TBD
	OPC	60,019	13,000	70	9,035	TBD	TBD	TBD	TBD
	TPC	364,385	80,000	105,000	150,000	TBD	TBD	TBD	TBD

[a] The Prior Years column for FY 2009 through FY 2012 reflects the total of appropriations and funding requests only through the year of that row. Thus, for example, in the FY 2010 row, it reflects only funding from FY 2006 to FY 2010.

[b] The FY 2012 request was submitted before a full-year appropriation for FY 2011 was in place, and so FY 2011 was TBD at that time. Hence, the Prior Years column for FY 2012 reflects appropriations for FY 2006 through FY 2010 plus the FY 2012 request.

Request Year		(dollars in thousands) Prior Years	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	Outyears	Total
FY 2014	TEC	304,366	67,000	104,930	105,572	225,000	TBD	TBD	TBD
	OPC	60,019	13,000	70	70	0	TBD	TBD	TBD
	TPC	364,385	80,000	105,000	105,642[a]	225,000	TBD	TBD	TBD
FY 2015[b]	TEC	310,010	67,000	104,930	121,499	194,500	144,639	TBD	TBD
	OPC	54,375	13,000	70	2,535	5,000	5,361	TBD	TBD
	TPC	364,385	80,000	105,000	124,034	199,500	150,000	TBD	TBD

8. Related Operations and Maintenance Funding Requirements

The U.S. Contributions to ITER operations is assumed to begin with initial commissioning activities and continue for a period of 15 to 25 years. The fiscal year in which commissioning activities begin depends on the international ITER project schedule and is therefore TBD.

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	TBD
Expected Useful Life (number of years)	15–25
Expected Future start of D&D for new construction (fiscal quarter)	TBD

9. D&D Funding Requirements

Since ITER is being constructed in France by a coalition of countries and will not be a DOE asset, the “one-for-one” requirement is not applicable to this project.

The U.S. Contributions to ITER Decommissioning are assumed to begin when operations commence and continue for a period of 20 years. The U.S. is responsible for 13 percent of the total decommissioning cost.

The U.S. Contributions to ITER Deactivation are assumed to begin 20 years after commissioning and continue for a period of 5 years. The U.S. is responsible for 13 percent of the total deactivation cost.

10. Acquisition Approach for US Hardware Contributions

The USIPO, with its two partner laboratories, will procure and deliver in-kind hardware in accordance with the Procurement Arrangements established with the IO.

The USIPO will subcontract with a variety of research and industry sources for design and fabrication of its ITER components, ensuring that designs are developed that permit fabrication, to the maximum extent possible, under fixed-price subcontracts (or fixed-price arrangement documents with the IO) based on performance specifications, or more rarely, on build-to-print designs. USIPO will use cost-reimbursement type subcontracts only when the work scope precludes accurate and reasonable cost contingencies being gauged and established beforehand.

USIPO will utilize best value, competitive source selection procedures to the maximum extent possible, including foreign firms on the tender/bid list where appropriate. Such procedures shall allow for cost and technical trade-offs during source selection.

For the large-dollar-value subcontracts (and critical path subcontracts as appropriate), USIPO will utilize unique subcontract provisions to incentivize cost control and schedule performance.

[a] The FY 2013 amount shown in the FY 2014 request reflected a short-term continuing resolution level annualized to a full year and based on the FY 2012 funding level for ITER.
[b] Prior to FY 2015, the requests were for a major item of equipment broken out by TEC, OPC, and TPC.

In addition, where it is cost effective and it reduces risk, the USIPO will participate in common procurements led by the IO, or request the IO to perform activities that are the responsibility of the U.S.