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. The interdisciplinary nature of modern fusion research is emphasized in the 2015 Quadrennial Technology Review.

The next frontier for all of the major fusion research programs around the world is the study of the burning plasma state, in which the fusion process itself provides the dominant heat source for sustaining the plasma temperature (i.e., self-heating). Production of strongly self-heated fusion plasma will allow the discovery and study of new scientific phenomena relevant to fusion energy. These include the effects of highly energetic fusion-produced alpha particles on plasma stability and confinement; the strongly nonlinear coupling that will occur among fusion alpha particles, pressure-driven self-generated current, turbulent transport, and boundary-plasma behavior; the properties of materials in the presence of high heat and particle fluxes and neutron irradiation; and the self-organized nature of plasma profiles over long time scales.

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, development of advanced fusion-relevant materials, and invention of new measurement techniques.

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

To support the program mission and its major focus, the U.S. fusion program has four elements:

- Burning Plasma Science: Foundations;
- Burning Plasma Science: Long Pulse;
- Burning Plasma Science: High Power; and
- Discovery Plasma Science.

Highlights of the FY 2017 Budget Request

Notable changes in the FY 2017 budget include:

- *No funding is provided for Alcator C-Mod operation and research*—after the final year of operation of Alcator C-Mod in FY 2016, the research staff at the MIT Plasma Science and Fusion Center will shift focus to begin full-time collaborative research activities in the DIII-D and NSTX-U national research programs; in addition, some will engage in collaborations with international laboratories.
- *Increased support for DIII-D and National Spherical Torus Experiment-Upgrade (NSTX-U) research*—Funding for the DIII-D and NSTX-U research programs is increased to address the high priority fusion science issues identified by the community research needs workshops held in FY 2015 and to support enhanced collaborations with MIT researchers.
- *Continued support to the U.S. Contributions to ITER Project*—Funding will support continued progress on in-kind hardware contributions, including central solenoid superconducting magnet modules and structures, toroidal field magnet conductor, steady-state electrical network components, and tokamak cooling water system. Funding is also provided toward the FY 2017 monetary contribution to the ITER Organization, which supports ITER Project common expenses.
- In the FY 2017 Budget Request, most funding for the Working Capital Fund (WCF) is transferred to Program Direction to establish a consolidated source of funding for goods and services provided by the WCF. CyberOne is still funded through program dollars in the SC Safeguards and Security program. In FY 2016 and prior years, WCF costs were shared by SC research programs and Program Direction.

Fusion Energy Sciences
Funding ($K)

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs. FY 2016
Fusion Energy Sciences					
Burning Plasma Science: Foundations					
Advanced Tokamak	105,348	107,675	101,255	84,238	-17,017
Spherical Tokamak	72,919	71,169	74,000	73,199	-801
Theory & Simulation	34,670	35,006	33,500	33,170	-330
GPE/GPP/Infrastructure	3,125	3,600	6,000	5,000	-1,000
Total, Burning Plasma Science: Foundations	**216,062**	**217,450**	**214,755**	**195,607**	**-19,148**
Burning Plasma Science: Long Pulse					
Long Pulse: Tokamak	7,695	7,895	8,500	6,045	-2,455
Long Pulse: Stellarators	6,419	8,010	7,269	5,084	-2,185
Materials & Fusion Nuclear Science	24,842	23,033	25,252	20,226	-5,026
Total, Burning Plasma Science: Long Pulse	**38,956**	**38,938**	**41,021**	**31,355**	**-9,666**
Discovery Plasma Science					
Plasma Science Frontiers	46,024	44,643	46,784	31,916	-14,868
Measurement Innovation	3,575	3,575	6,700	4,000	-2,700
SBIR/STTR & Other	12,883	2,760	13,740	10,300	-3,440
Total, Discovery Plasma Science	**62,482**	**50,978**	**67,224**	**46,216**	**-21,008**
Subtotal, Fusion Energy Sciences	**317,500**	**307,366**	**323,000**	**273,178**	**-49,822**
Construction					
14-SC-60 International Thermonuclear Experimental Reactor (ITER)	150,000	150,000	115,000	125,000	+10,000
Total, Fusion Energy Sciences	**467,500**	**457,366**	**438,000**	**398,178**	**-39,822**

SBIR/STTR:

- FY 2015 Transferred: SBIR $8,906,000 and STTR $1,228,000
- FY 2016 Projected: SBIR: $9,333,000; STTR: $1,400,000
- FY 2017 Request: SBIR $8,436,000 and STTR $1,186,000

[a] Reflects the transfer of Small Business Innovation/Technology Transfer Research (SBIR/STTR) funds within the Office of Science.
[b] A transfer of $861,000 to Science Program Direction to consolidate all Working Capital Funds in one program.

Fusion Energy Sciences
Explanation of Major Changes ($K)

	FY 2017 vs FY 2016
Burning Plasma Science: Foundations: Overall funding for advanced tokamak research is decreased, as operation of Alcator C-Mod ceases. Funding for DIII-D and NSTX-U research is increased to support the enhanced collaboration by MIT research staff in those programs. Funding for Theory & Simulation is increased to accelerate progress toward whole-device modeling. Decreased funding for DIII-D and NSTX-U operations results in deferment of some facility enhancements and a slight reduction to operating weeks.	**-19,148**
Burning Plasma Science: Long Pulse: Overall funding is decreased for U.S. research collaborative activities on overseas long-pulse tokamaks and stellarators and on research and experimental capabilities that address the plasma-materials interface scientific challenge.	**-9,666**
Discovery Plasma Science: Overall funding is decreased, as the High Energy Density Laboratory Plasma science activity contracts to focus on supporting research utilizing the Matter in Extreme Conditions instrument of the Linac Coherent Light Source at the SLAC National Accelerator Laboratory. Decreases in Measurement Innovation and General Plasma Science activities result from the completion of targeted research enhancements fully funded in FY 2016.	**-21,008**
Construction: Funding is provided toward the FY 2017 monetary contribution (total $44M) to the ITER Organization.	**+10,000**
Total Funding Change, Fusion Energy Sciences	**-39,822**

Basic and Applied R&D Coordination
FES coordinates within DOE and with other federal agencies on science and technology issues related to fusion and plasma science. Within SC, FES operates the Matter in Extreme Conditions (MEC) instrument at the Linac Coherent Light Source (LCLS) user facility operated by Basic Energy Sciences (BES). In addition, FES carries out a discovery-driven plasma science research program in partnership 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. Also, FES 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
Completion of the NSTX Upgrade project—the research capabilities of the NSTX user facility have been enhanced by doubling its maximum toroidal field and plasma current, lengthening the pulse length, and adding a second set of neutral beam sources for off-axis heating and current drive. These improvements make the NSTX-U experiment the highest performing spherical tokamak in the world and will allow NSTX-U researchers to explore unique spherical tokamak parameter regimes to advance predictive understanding of magnetically confined plasmas.

ITER component production and major deliveries—The U.S. ITER Project began the challenging task of winding the first 100-ton module for the ITER central solenoid, which, when completed, will be the most powerful pulsed superconducting electromagnet ever produced. U.S. vendors also successfully delivered one 100-meter superconducting length and two 800-meter production lengths of active conductor to the European Union's Toroidal Field Coil fabricator in Italy, and four lots of high-voltage substation transformers, which are part of the steady state electric network, to the ITER site. The U.S. ITER Project also completed fabrication and delivery of all five nuclear-grade tokamak cooling water system drain tanks.

First fully remote operation of an overseas tokamak—the first-ever fully remote operation of the Experimental Advanced Superconducting Tokamak (EAST) tokamak in China was carried out by U.S. scientists from a purpose-built remote collaboration room at General Atomics. The integrated China/U.S. experimental team studied axisymmetric controllability and vertical displacement disruption events over six-hour periods on two consecutive days. Operating EAST remotely during the nighttime in China but during the U.S. working daytime is a key milestone in the DOE Scenarios and Control International Collaboration that involves several U.S. institutions. This approach is expected to enable EAST to achieve 24-hour utilization and effectively offer use of a full campaign of experimental time to U.S. scientists during its operating periods. Further remote operation sessions are being planned for next year.

Shining a light on the composition of the Sun—A discrepancy exists between theoretical models (based on spectroscopic observations) that describe the relative abundances of elements in the Sun and measurements of the solar interior that are made with acoustic wave observations. Scientists with the Z facility at Sandia National Laboratories discovered that the wavelength-dependent radiation absorption (opacity) of iron, heated to 2.2 million degrees Kelvin, is 30–400 percent higher than theoretically predicted. These new measurements suggest that the true opacity of solar matter is higher than previously believed, altering theoretical models of the sun in a direction that brings them closer to the helio-seismological observations. These results have impacted our understanding of the life cycle of the Sun and stellar evolution.

Chirping radio signals from space recreated in the laboratory—Researchers at the University of California, Los Angeles, successfully excited elusive plasma waves, known as whistler-mode chorus waves, in the Basic Plasma Science Facility's Large Plasma Device. Previously these waves had only been studied in the Earth's near-space environment. They were accidentally discovered during World War I by radio operators, who dubbed them "dawn chorus" since the radio signal of the waves sounded like the chirping of birds. These waves, which occur naturally in the Earth's magnetosphere, accelerate electrons to extremely high energies and are responsible for the creation of the Van Allen radiation belt encircling the Earth, which pose a threat to satellites in orbit. These new experiments allowed researchers, for the first time, to test under controlled laboratory conditions the current understanding of nonlinear excitation of whistler waves.

Fine-tuning tokamak magnetic fields to mitigate damaging energy bursts—Plasma confined by magnetic fields in a tokamak device is subject to intense heat bursts, called Edge Localized Modes (ELMs), which can damage the walls of the confining vessel. It had been known that ELMs could be suppressed by the application of small three-dimensional (3-D) magnetic fields at the edge of the tokamak plasma; unfortunately, doing so often destabilized the central core of the plasma. Utilizing a newly enhanced magnetic diagnostic system on DIII-D, a multi-institutional team of scientists found that application of a 3-D perturbative magnetic field that encircles the tokamak twice will mitigate the ELMs without adversely affecting the core plasma. The new results suggest further possibilities for tuning the magnetic fields to make ELM control easier. These findings point the way to overcoming a persistent barrier to sustained fusion reactions.

Multi-scale simulations of tokamak plasma confinement—High temperature plasmas are a soup of positively charged ions and negatively charged electrons. While faithful computer simulations of ion transport and confinement in high-temperature tokamak plasmas are now fairly standard, accurate simultaneous simulation of the electrons has proven very difficult due to their factor-of-2000 mass difference with ions. Recently, gyrokinetic simulations of both ion and electron transport dynamics, involving widely disparate time and space scales, have been successfully performed for the first time with a realistic ion/electron mass ratio. The simulations used 100 million CPU hours, mostly on the Edison supercomputer at the National Energy Research Scientific Computing Center (NERSC) user facility. The results demonstrated that such multi-scale simulations are required to match with the experimentally measured ion and electron thermal fluxes and profiles and thus resolved a longstanding mystery of electron heat conduction in tokamaks.

Helium bubble formation in fusion materials—it has been known for some time that neutrons from fusion reactions can cause bubbles of helium to form within plasma-facing materials, such as tungsten, which will be used in the ITER tokamak. These bubbles grow and can burst violently when they migrate to the surface, resulting in releases of debris that are detrimental to the plasma. This process of bubble formation, which is important for predicting large-scale material response to the extreme fusion environment, has been studied with atom-based simulations using resources at NERSC and the Oak Ridge Leadership Computing Facility. The results show how the growth rate can affect the bubble size, shape, pressure, and surface damage. This information is critically important to accurately predict how a tokamak divertor component made of tungsten behaves under fusion conditions.

Fusion Energy Sciences
Burning Plasma Science: Foundations

Description

The Burning Plasma Science: Foundations subprogram advances the predictive understanding of plasma confinement, dynamics, and interactions with surrounding materials. Among the activities supported by this subprogram are:

- Research at major experimental facilities aimed at resolving fundamental advanced tokamak and spherical torus science issues, including developing the predictive understanding needed for ITER operations and providing solutions to high-priority ITER concerns.
- Research on small-scale magnetic confinement experiments to elucidate physics principles underlying toroidal confinement and to validate theoretical models and simulation codes.
- Theoretical work on the fundamental description of magnetically confined plasmas and the development of advanced simulation codes on current and emerging high-performance computers.
- Research on technologies needed to support the continued improvement of the experimental program and facilities.
- Support for infrastructure improvements at Office of Science laboratories conducting fusion research.

Research in the Burning Plasma Science: Foundations area in FY 2017 will focus on high-priority challenges and opportunities in the areas of transients in tokamaks, plasma-material interactions, and integrated modeling, as identified by the community research needs workshops held in FY 2015.

Advanced Tokamak

The DIII-D user facility at General Atomics in San Diego, California, 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 perform experiments on DIII-D for studying stability, confinement, and other properties of fusion-grade plasmas under a wide variety of conditions. 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.

The Alcator C-Mod facility at the Massachusetts Institute of Technology continued operation in FY 2016 to complete student research and experimental work. The facility will cease operations by the end of FY 2016.

The Enabling Research and Development (R&D) element develops the technology to enhance the capabilities for existing and next-generation fusion research facilities, enabling these facilities to achieve higher levels of performance and flexibility needed to explore new science regimes.

Small-scale tokamak plasma research projects provide data in regimes of relevance to the FES mainline tokamak magnetic confinement efforts and help confirm theoretical models and simulation codes in support of the FES goal to develop an experimentally validated predictive capability for magnetically confined fusion plasmas. This activity consists of small-scale focused experiments.

Spherical Tokamak

The NSTX-U user facility at Princeton Plasma Physics Laboratory (PPPL) is designed to explore the physics of plasmas confined in a spherical torus (ST) 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 more compact and economical future fusion research facilities based on the ST concept. The ST configuration, with its very strong magnetic curvature, has different confinement and stability properties from those of conventional tokamaks.

The NSTX-U Major Item of Equipment (MIE) project was completed in FY 2015. The upgrade of the center stack assembly enables a doubling of the magnetic field and plasma current and an increase in the plasma pulse length from 1 to 5 seconds, making NSTX-U the world's highest-performance ST. The addition of a second neutral beam system doubles the available heating power and makes it possible to achieve higher plasma pressure and improve its current drive efficiency and profile control to achieve fully non-inductive operation. Together, these upgrades 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 and broaden scientific understanding of plasma confinement. 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.

During its first year of research operations in FY 2016, NSTX-U will achieve magnetic fields and plasma currents about one and a half times higher than those prior to the upgrade project. During FY 2017, NSTX-U will achieve the design values for the magnetic field and plasma current, which are twice those achieved in NSTX.

Small-scale spherical torus plasma research projects doing focused experiments provide data in regimes of relevance to the FES spherical torus magnetic confinement program. This effort 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. It also involves high-risk, but high-payoff, experimental efforts useful to advancing spherical torus science.

<u>Theory and Simulation</u>

The Theory and Simulation element contributes to the FES goal of developing the predictive capability needed for a sustainable fusion energy source. This element includes two main interrelated but distinct activities: the Theory activity and the Scientific Discovery through Advanced Computing (SciDAC) activity.

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 SciDAC activity described below and supports validation efforts at major experiments.

The FES 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. Massively parallel computing, grounded in experimentally validated theoretical models, will be hugely valuable for enabling whole-device modeling that can integrate simulations of physics phenomena across a wide range of disparate time and space scales. The eight multi-institutional and interdisciplinary centers in the FES SciDAC portfolio address challenges in magnetic confinement science and computational fusion materials science and are well-aligned with the needs and priorities of ITER and burning plasmas. Three of these centers are set up as partnerships between FES and Advanced Scientific Computing Research (ASCR).

<u>GPE/GPP/Infrastructure</u>

Funding in this category provides support for general infrastructure improvements at the PPPL site consistent with the PPPL Campus Modernization Plan. This funding is based upon an analysis of safety requirements, equipment reliability, facility improvements, and research-related infrastructure needs.

Fusion Energy Sciences
Burning Plasma Science: Foundations

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
Advanced Tokamak $101,255,000	**$84,238,000**	**-$17,017,000**
DIII-D Research ($35,000,000) *DIII-D Operations ($45,000,000)* Operations funding supports fifteen weeks of research operations at the DIII-D facility, with experiments focusing on high-priority advanced tokamak issues and research needs as identified by the FY 2015 community workshops. Areas of research include studies of transport and radiative processes in detached divertor conditions, disruption physics and mitigation systems, and stability control strategies for robust high performance operation. Targeted enhancements to the facility involve installation of a set of high-Z coated tile rings in the divertor region to study impurity generation and transport installation of a new magnet power supply for the 3D and shaping coils, and a low power helicon antenna.	*DIII-D Research ($37,000,000)* *DIII-D Operations ($44,100,000)* Operations funding supports fourteen weeks of research operations at the DIII-D facility. Research will be conducted to prepare for burning plasmas in ITER, determine the optimal path to steady-state tokamak plasmas, and develop the plasma material interaction boundary solutions necessary for future devices. Specific research goals will involve testing the predictive models of fast ion transport by multiple Alfven eigenmodes, studying the physical processes that determine the edge pedestal density structure, and examining the impurity generation and transport from the high-Z coated tiles. Targeted enhancements to the facility will involve completion and commissioning of an additional high-power microwave heating system, as well as continued work on improving the neutral beam heating control system and designing the modifications necessary for a second off-axis and co-/counter-directed neutral beam.	*DIII-D Research (+$2,000,000)* *DIII-D Operations (-$900,000)* Increases in research funding will support the enhanced collaboration in the DIII-D national research program by the MIT scientific staff, while decreases in operations funding will delay some planned facility enhancements and require a reduction of operating weeks.

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
C-Mod Research ($6,145,000) *C-Mod Operations ($11,855,000)* Operations funding supports five weeks of research operations at the Alcator C-Mod facility in its final year of operation in FY 2016. Research is focused on research needs as identified by the FY 2015 community workshops. Experiments are conducted to study disruption physics and mitigation techniques, develop the database for the critical interactions between the plasma and material components under ITER and reactor-relevant conditions, explore robust high-performance stationary regimes free of Edge Localized Modes, and advance radiofrequency heating and current drive technology and physics understanding. The facility will be closed after final operations. The scientific staff will complete analysis of existing C-Mod data and begin making a transition to collaborative research activities on other research facilities.	*C-Mod Research ($0)* *C-Mod Operations ($0)* Operation of Alcator C-Mod ceases. No funding is requested for this element.	*C-Mod Research (-$6,145,000)* *C-Mod Operations (-$11,855,000)* Support for Alcator C-Mod operation and research ends in FY 2016, and the MIT research staff will begin collaborative research activities at other national and international facilities.
Enabling R&D ($2,165,000) Support continues to be provided for research in superconducting magnet technology and fueling and plasma heating technologies to enhance the performance for existing and future magnetic confinement fusion devices.	*Enabling R&D ($2,165,000)* Support will continue to be provided for research in superconducting magnet technology and fueling and plasma heating technologies to enhance the performance for existing and future magnetic confinement fusion devices.	*Enabling R&D ($0)* Research efforts are maintained at the FY 2016 Enacted level.
Small-scale Experimental Research ($1,090,000) Small-scale tokamak plasma research provides experimental data in regimes of relevance to the mainline advanced tokamak magnetic confinement efforts and helps confirm theoretical models and simulation codes in support of the goal to develop an experimentally validated predictive capability for magnetically confined fusion plasmas.	*Small-scale Experimental Research ($973,000)* Research will continue to provide experimental data in regimes relevant to mainline tokamak confinement and experimental validation of models and codes.	*Small-scale Experimental Research: (-$117,000)* Experimental research and modeling efforts are reduced.

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
Spherical Tokamak $74,000,000	**$73,199,000**	**-$801,000**
NSTX-U Research ($30,000,000) *NSTX-U Operations ($41,000,000)* NSTX-U begins operations after successful completion of the upgrade. Machine performance is extended to higher field and current and longer pulse lengths than what had been achievable prior to the upgrade, with results being benchmarked with prior data. Current drive and fast ion instabilities resulting from the new neutral beam line are studied. The NSTX-U team also conducts experiments on disruption physics and on high-priority research needs as identified by the FY 2015 community workshops. In mid-FY 2016, a machine vent is scheduled to install a row of molybdenum tiles in the lower divertor region. A total of 18 weeks of operation is planned in FY 2016.	*NSTX-U Research ($31,410,000)* *NSTX-U Operations ($39,090,000)* The NSTX-U team will extend performance to full field and current (1 Tesla, 2 mega Amps—which is double what had been achieved prior to the upgrade). Experiments will address divertor heat flux mitigation and plasma confinement at full parameters, assess the performance and impact of the molybdenum divertor tiles, and continue experiments on high-priority research needs as identified by the FY 2015 community workshops. Also, the team will begin experiments on fully non-inductive current drive and sustainment. Finally, the team will begin to develop scenarios for achieving and controlling high-performance discharges. A total of 16 weeks of operation is planned in FY 2017.	*NSTX-U Research (+$1,410,000)* *NSTX-U Operations (-$1,910,000)* Increases in research funding will support the enhanced collaboration in the NSTX-U national program by the MIT research staff, while decreases in operations funding will delay some planned facility enhancements and require a reduction of operating weeks.
Small-scale Experimental Research ($3,000,000) Small-scale spherical torus plasma research provides experimental data in regimes of relevance to the mainline spherical torus magnetic confinement efforts and helps confirm theoretical models and simulation codes in support of the goal to develop an experimentally validated predictive capability for magnetically confined fusion plasmas.	*Small-scale Experimental Research ($2,699,000)* Research will continue to provide experimental data in regimes relevant to mainline spherical torus confinement and experimental validation of models and codes.	*Small-scale Experimental Research (-$301,000)* Experimental research and modeling efforts are reduced.
Theory & Simulation $33,500,000	**$33,170,000**	**-$330,000**
Theory ($24,000,000) The Theory activity continues to advance the scientific understanding of the fundamental physical processes governing the behavior of magnetically confined plasmas. Emphasis on addressing ITER priorities continues to guide the selection of new and renewal awards via competitive merit reviews.	*Theory ($21,170,000)* Theoretical research at universities, private industry and national laboratories will continue to address fundamental questions of magnetic confinement science. The selection of new awards via competitive merit reviews will place emphasis on closing gaps in burning plasma science as identified by the community workshops held in FY 2015 and on addressing high priority needs of integrated simulation efforts.	*Theory (-$2,830,000)* The reduction will result in approximately six fewer awards being made to universities and private industry, relative to FY 2016, under the annual Theory Funding Opportunity Announcement. Efforts at the national laboratories will be held flat with the FY 2016 Enacted level.

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
SciDAC ($9,500,000) The five SciDAC centers, pending a positive outcome of the merit review held in FY 2015, enter the final year of their research activities, while the three FES–ASCR SciDAC-3 partnerships continue their efforts in the areas of boundary physics, materials science, and multiscale integrated modeling. FES and ASCR develop a plan emphasizing integration for the science areas represented by the entire FES SciDAC portfolio and initiate preparations for a competitive merit review.	*SciDAC ($12,000,000)* The new SciDAC centers, selected via a competitive merit review and set up as partnerships with ASCR, will start their research activities. The new portfolio will have a strong emphasis on integration and whole-device modeling, focusing on the highest-priority research directions as identified by the community workshops held in FY 2015. This area supports Clean Energy.	*SciDAC (+$2,500,000)* The increased funding will strengthen integration efforts and accelerate progress toward whole-device modeling.
GPE/GPP/Infrastructure $6,000,000	**$5,000,000**	**-$1,000,000**
Continued support of NSTX-U operations, as well as enhanced International Collaborations, is provided through improvements to the Princeton Plasma Physics Laboratory Computer Center (PPPLCC) and establishment of remote collaboration room configurations. Environmental monitoring needs at PPPL will continue to be supported.	Funding will provide support for general infrastructure improvements for the PPPL site consistent with the PPPL Campus Modernization Plan, based upon an analysis of safety requirements, equipment reliability, and research-related infrastructure needs.	Funding maintains infrastructure repairs and maintenance, as well as, modernization of laboratory infrastructure, consistent with the PPPL Campus Modernization Plan, although the reduction slows the pace of the campus modernization efforts.

Fusion Energy Sciences
Burning Plasma Science: Long Pulse

Description

The Burning Plasma Science: Long Pulse subprogram explores new and unique scientific regimes that can be achieved with long-duration superconducting international machines and addresses the development of the materials required to withstand the extreme conditions in a burning plasma environment. The key objectives of this area are to utilize these new capabilities to accelerate our scientific understanding of how to control and operate a burning plasma, as well as to develop the basis for a future fusion nuclear science facility. This subprogram includes long-pulse international tokamak and stellarator research and fusion nuclear science and materials research.

Long Pulse: Tokamak

Multi-institutional U.S. research teams will be supported to continue their successful work on the long-pulse international tokamaks that came on-line in the last few years. These collaborative teams are building on the experience gained from U.S. fusion facilities to conduct high-impact long-pulse research on the international tokamaks either onsite or via remote operation. Long plasma pulse research will enable the exploration of new plasma physics regimes and allow the U.S. fusion program to gain the knowledge needed to operate long plasma discharges in ITER and other fusion energy devices.

Long Pulse: Stellarator

Stellarators offer steady-state confinement regimes eliminating transient events such as harmful disruptions. The 3-D shaping of the plasma in a stellarator provides for a broader range in design flexibility than is achievable in a 2-D system. The participation of U.S. researchers on Wendelstein 7-X (W7-X) in Germany provides an opportunity to develop and assess 3D divertor configurations for long-pulse, high-performance stellarators. The U.S. plans to develop control schemes to maintain plasmas with stable operational boundaries, including the challenges of control with superconducting coils and issues of the diagnosis-control cycle in long-pulse conditions. U.S. researchers will play key roles in developing the operational scenarios and hardware configuration for high-power, steady-state operation, an accomplishment that will advance the performance/pulse length frontier for fusion. The U.S. contributions, during the W7-X construction phase, have earned the U.S. formal partnership status, with opportunities for full U.S. participation in W7-X research and access to data.

The U.S. domestic stellarator program is focused on optimization of the stellarator concept through quasi-symmetric shaping of the toroidal magnetic field. A conventional stellarator lacks axial symmetry, resulting in reduced confinement of energetic ions, which are needed to heat the plasma. Quasi-symmetric shaping, invented in the U.S., provides an improved solution for stable, well confined, steady-state stellarator plasma confinement.

Materials and Fusion Nuclear Science

The fusion environment is extremely harsh in terms of temperature, particle flux, and neutron irradiation. The Materials and Fusion Nuclear Science element supports the development, characterization, and modeling of structural, plasma-facing, and blanket materials used in the fusion environment. 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. Studies that help identify the various scientific challenges to fusion energy deployment and that determine how to address them in a safe and environmentally responsible manner are a key component of the Materials and Fusion Nuclear Science element.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
Long Pulse: Tokamak $8,500,000	**$6,045,000**	**-$2,455,000**
U.S. scientists will develop, install, and commission improved plasma control feedback systems for China's Experimental Advanced Superconducting Tokamak (EAST) and Korea's Superconducting Tokamak Advanced Research (KSTAR). ITER operating scenarios will be explored and evaluated on EAST and KSTAR. Radio-frequency heating and current drive and neutral beam injection actuator models for EAST and KSTAR will be developed and validated.	Multi-institutional U.S. research teams will continue to conduct high-impact research on the international superconducting long-pulse tokamaks, taking advantage of their upgraded capabilities.	The program will reduce the overall level of effort and will defer some scheduled research tasks. There will be additional limitations to the on-site presence of U.S. researchers, which will shift emphasis to remote operations.
Long Pulse: Stellarators $7,269,000	**$5,084,000**	**-$2,185,000**
Superconducting Stellarator Research ($4,200,000) U.S. scientists are participating in the first plasma operating campaign of W7-X. The U.S. team will be involved with characterizing the 3-D magnetic configuration and performing the first tests of U.S.-supplied equipment during plasma operation. The team will also prepare the Test Divertor Unit (TDU) scraper element for the second operating campaign.	*Superconducting Stellarator Research ($2,515,000)* U.S. scientists will participate in W7-X research on topics important for understanding the physics of long-pulse plasma confinement in 3-D magnetic configurations. Topics include error fields, magnetic island physics, energetic-particle transport, impurity studies, plasma-material interactions, core plasma transport, and plasma control. The U.S. team will collaborate in the preparation of equipment and plasma scenarios for long-pulse operation.	*Superconducting Stellarator Research (-$1,685,000)* The program will reduce participation by U.S. researchers in the second plasma operating campaign of the W7-X experimental activities.

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
Compact Stellarator Research ($3,069,000) Compact stellarator research provides experimental data in regimes of relevance to the mainline stellarator magnetic confinement efforts and helps confirm theoretical models and simulation codes in support of the goal to develop an experimentally validated predictive capability for magnetically confined fusion plasmas.	*Compact Stellarator Research ($2,569,000)* Research will continue on experiments that are providing data in regimes relevant to mainline stellarator confinement and experimental validation of models and codes	*Compact Stellarator Research (-$500,000)* Experimental research and modeling efforts will be reduced.
Materials & Fusion Nuclear Science $25,252,000	**$20,226,000**	**-$5,026,000**
Fusion Nuclear Science ($11,252,000) The focus remains the utilization of existing experimental capabilities to conduct research in the areas of plasma-facing materials and plasma-material interactions consistent with the high-priority research needs identified by the FY 2015 community workshops. Research toward understanding tritium retention and permeation, neutronics, and material-corrosion issues for blankets continues. Scoping studies continue on characterizing significant research gaps in the materials and fusion nuclear sciences program.	*Fusion Nuclear Science ($10,000,000)* Utilization of existing experimental capabilities and development of new ones to conduct research in the areas of plasma-facing materials and plasma-material interactions will be a key emphasis. In addition, research on understanding tritium retention, permeation and processing, neutronics, and material-corrosion issues for blankets and scoping studies on future fusion facilities will continue.	*Fusion Nuclear Science (-$1,252,000)* The program will reduce research efforts across this program element.
Materials Research ($14,000,000) The focus remains the utilization of existing experimental capabilities to conduct research in the area of material response to simulated fusion neutron irradiation consistent with the high-priority research needs identified by the FY 2015 community workshops. Research toward structural materials that can withstand high levels of damage, increasing the ductility of tungsten, and modeling of helium damage in numerous materials continues.	*Materials Research ($10,226,000)* The program will emphasize the utilization of existing experimental capabilities and development of new ones to conduct research in the area of material response to simulated fusion neutron irradiation. There will be a continued focus on research toward structural materials that can withstand high levels of damage, increasing the ductility of tungsten, and modeling of helium damage in numerous materials.	*Materials Research (-$3,774,000)* The program will decrease research efforts across this program element.

Description

The Discovery Plasma Science subprogram supports research that explores the fundamental properties and complex behavior of matter in the plasma state to improve the understanding required to control and manipulate plasmas for a broad range of applications. Plasma science is not only fundamental to understanding the nature of visible matter throughout the universe, but also to achieving the eventual production and control of fusion energy. Discoveries in plasma science are leading to an ever-increasing array of practical applications, ranging from energy efficient lighting to atmospheric pressure plasma for medical applications.

This subprogram supports a portfolio of research projects and small- and mid-scale experimental user facilities for exploring the diverse frontiers of plasma science. The activities of this subprogram are carried out through inter- and intra-agency partnerships at academic institutions, industry research groups, and national laboratories across the country.

The Discovery Plasma Science subprogram is organized into two principal activities: Plasma Science Frontiers and Measurement Innovation.

<u>Plasma Science Frontiers</u>

The Plasma Science Frontiers activities involve research in largely unexplored areas of plasma science, with a combination of theory, computer modeling, and experimentation. These frontiers are often, but not limited to, the extremes of the plasma state, ranging from the very small (several atom systems) to the extremely large (plasma structure spanning light years in length), from the very fast (attosecond processes) to the very slow (hours), from the diffuse (interstellar medium) to the extremely dense (diamond compressed to tens of gigabar pressures), and from the ultracold (tens of micro kelvin) to the extremely hot (stellar core). Advancing the science of these unexplored areas creates opportunities for new and unexpected discoveries with potential to translate into practical applications.

The Plasma Science Frontiers portfolio includes coordinated research activities in the following three areas:

- *General Plasma Science* – Research in frontier areas of basic and low temperature plasma science and engineering, including advancing our understanding of the behavior of non-neutral and single-component plasmas, ultra-cold neutral plasmas, dusty plasmas, and micro-plasmas, as well as the study of dynamical processes in classical plasmas including turbulence, thermal, radiative and particle transport, waves, structures, flows and their interactions.
- *High Energy Density Laboratory Plasmas* – Structural and dynamical studies of ionized matter at extreme densities and temperatures.
- *Exploratory Magnetized Plasma* – Basic and applied research directed at developing the understanding of magnetized-plasma behavior necessary to advance innovative solutions and capabilities for the creation, control, and manipulation of magnetically confined plasmas for terrestrial and space applications.

This subprogram maintains a leadership role in the national stewardship of plasma science by partnering with the National Science Foundation (NSF) and the National Nuclear Security Administration (NNSA) and by leveraging access to best-in-class experimental facilities as well as stewarding and operating world-class plasma science user facilities at small and intermediate scales. Along with facilitating discovery, intermediate-scale platforms are also providing critical data for the verification and validation of plasma science codes.

<u>Measurement Innovation</u>

The Measurement Innovation activity supports the development of novel and innovative diagnostic techniques and their application to new, unexplored, or unfamiliar plasma regimes or scenarios. The challenge is to develop diagnostics with the spatial, spectral, and temporal resolution necessary to validate plasma physics models used to predict the behavior of fusion plasmas. Advanced diagnostic capabilities successfully developed through this activity are migrated to domestic and international facilities, as part of the Burning Plasma Science: Foundations and Burning Plasma: Long Pulse subprograms. The implementation of mature diagnostics systems is supported via the research programs at FES user facilities.

SBIR/STTR & Other

Funding for SBIR/STTR is included in this subprogram. Other activities that are supported include research at Historically Black Colleges and Universities (HBCUs); the U.S. Burning Plasma Organization (USBPO), 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).

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
Plasma Science Frontiers $46,784,000	**$31,916,000**	**-$14,868,000**
General Plasma Science ($16,125,000) Research continues in fundamental science areas of plasma turbulence and transport, interactions of plasmas and waves, statistical mechanics of plasmas, and self-organization and reconnection. Research on major FES user facilities is enhanced.	*General Plasma Science ($15,500,000)* Core research elements of this activity will continue.	*General Plasma Science (-$625,000)* The program will reduce support for user research on major FES user facilities.
High Energy Density Laboratory Plasmas ($20,250,000) Research emphasizes utilizing the Matter in Extreme Conditions (MEC) instrument at the Linac Coherent Light Source facility, including continued operational support for the MEC instrument and the HEDLP research group at SLAC as well as grants for external HED science users of MEC. Fundamental HEDLP science is supported through new research grants as part of the SC/NNSA Joint Program in HEDLP and the NSF/DOE Partnership in Basic Plasma Science and Engineering, as well as operation of the Neutralized Drift Compression Experiment-II (NDCX-II).	*High Energy Density Laboratory Plasmas ($7,000,000)* Research will emphasize utilizing the MEC at LCLS, including continued support for the MEC beam-line science team, the HEDLP research group at SLAC, and enhanced support of external HED science users of the MEC instrument.	*High Energy Density Laboratory Plasmas (-$13,250,000)* Contraction of the HEDLP program will result in no new research activities at either universities or DOE national laboratories and the cessation of operations and research at the NDCX-II.
Exploratory Magnetized Plasma ($10,409,000) This portfolio will be evaluated through a competitive peer-review process.	*Exploratory Magnetized Plasma ($9,416,000)* Research direction and emphasis will be informed by the high-priority research as identified by the plasma science frontiers workshops held in FY 2015.	*Exploratory Magnetized Plasma (-$993,000)* The program will reduce research efforts and/or scope, taking into consideration the outcomes of the plasma science frontiers workshops held in FY 2015.

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
Measurement Innovation $6,700,000	**$4,000,000**	**-$2,700,000**
Core research elements of the Measurement Innovation activity continue with enhanced effort on diagnostic development important to addressing the scientific issues identified in the community workshops held in FY 2015.	Measurement Innovation research activities will continue, with special emphasis on diagnostics for plasma transient instabilities, plasma-materials interactions, modeling validation, and basic plasma science.	The program will reduce funding to address scientific issues identified in the FY 2015 community workshops.
SBIR/STTR & Other $13,740,000	**$10,300,000**	**-$3,440,000**
Funding continues to support USBPO activities, HBCUs, peer reviews for solicitations, and FESAC. SBIR/STTR funding is statutorily set at 3.45 percent of noncapital funding in FY 2016.	Funding will continue to support USBPO activities, HBCUs, peer reviews for solicitations, and FESAC. SBIR/STTR funding is statutorily set at 3.45 percent of noncapital funding in FY 2017.	The decrease is due to consolidation of funding for the Working Capital Fund under Program Direction and reduction in the required SBIR/STTR funding.

Fusion Energy Sciences
Construction

Description
The exploration of high-power burning (self-heated) plasmas is the next critical area of scientific research for fusion. Previously the U.S. and European fusion programs had investigated burning plasmas at low power (10 megawatt level). The ITER facility, currently under construction in St. Paul-lez-Durance, France, will provide access to burning plasmas with fusion power output approaching reactor levels of hundreds of megawatts, for hundreds of seconds. ITER will thus be the first-ever facility capable of assessing the scientific and technical feasibility of fusion energy. As a collaborator in the ITER project, which was established though an international agreement (the "ITER Joint Implementing Agreement"), the U.S. contributes in-kind-hardware components, personnel, and direct monetary funding to the ITER Organization (IO) for the ITER construction phase, as established by the terms of the ITER Joint Implementing Agreement. The key objective of these efforts is the completion of all activities associated with the U.S. Contributions to ITER (USITER) project.

U.S. Contributions to ITER Project
The ITER international fusion project is designed to be the first magnetic confinement fusion facility to achieve a self-sustained burning plasma. 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) continue to be a high priority for FES.

ITER is designed to generate the world's first sustained (300-second discharge, 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 central project execution authority is the ITER Organization (IO). 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 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 USITER project consists primarily of in-kind hardware components, with additional contributions of personnel and cash to the IO for the ITER construction phase, which are established by the terms of the ITER Joint Implementing Agreement. In exchange for the U.S. share of the ITER project, the U.S. gains access to 100 percent of the ITER research output, and U.S. scientists may conduct their own research experiments. The U.S. contributions are managed by the USIPO at ORNL, in partnership with PPPL and Savannah River National Laboratory (SRNL). The U.S. ITER Project is unique among major DOE projects in that U.S. in-kind hardware contributions are delivered to the IO, which is outside direct DOE oversight and management control. The risks associated with performing the installation, assembly, and commissioning work depend on the execution of project responsibilities by the IO.

The 2013 Management Assessment of ITER found a significant number of challenges and deficiencies in the organization. The installation of a new Director-General in April 2015 and his efforts to improve the organization's culture and lead the development of a revised project resource-loaded long-term schedule demonstrate a positive shift in the IO. An independent review of the updated schedule is underway, with expected delivery of the report in mid-April 2016. This will present an opportunity to review and gauge the international commitment to the ITER project in light of significant delays and increased costs.

The 2016 Omnibus Appropriations directed, "*Not later than May 2, 2016, the Secretary of Energy shall submit to the Committees on Appropriations of both Houses of Congress a report recommending either that the United States remain a partner in the ITER project after October 2017 or terminate participation, which shall include, as applicable, an estimate of either the full cost, by fiscal year, of all future Federal funding requirements for construction, operation, and maintenance of*

ITER or the cost of termination." There are numerous activities (e.g., 2013 Management Assessment Corrective Action Plan performance; 2015 Management Assessment conclusions and recommendations; independent schedule review conclusions and recommendations; ITER Council-approved milestone performance) that will factor into the decision by the Secretary of Energy. The $125 million requested in FY 2017 will allow the most critical USITER activities to make progress, as well as provide cash funds for ITER Organization operations and the Director General's Reserve Fund.The requested level of funding for FY 2017 supports U.S. in-kind hardware contributions; funds the USIPO staff and support contractors at ORNL, PPPL, and SRNL; and provides funding toward the FY 2017 monetary contribution to the IO.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
U.S. Contributions to ITER Project $115,000,000 Funding supports continued progress on in-kind hardware contributions, including: central solenoid superconducting magnet modules and structures, toroidal field magnet conductor, steady-state electrical network components, and tokamak cooling water system components.	**$125,000,000** Funding will support continued progress on critical in-kind hardware contributions, including central solenoid superconducting magnet modules and structures, toroidal field magnet conductor, steady-state electrical network components, diagnostics development, tokamak cooling water system, and vacuum system. Funding is also provided toward the FY 2017 cash contribution for ITER Organization operations and Director General's Reserve Fund.	**+$10,000,000** The increase provides funding toward the cash contribution for ITER Organization operations and the Director General's Reserve Fund.

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. The following table shows the targets for FY 2015 through FY 2017. Details on the Annual Performance Report can be found at http://energy.gov/cfo/reports/annual-performance-reports.

	FY 2015	FY 2016	FY 2017
Performance Goal (Measure)	**FES Facility Based Experiments—Experiments conducted on major fusion facilities (DIII-D, Alcator C-Mod, NSTX-U) leading toward predictive capability for burning plasmas and configuration optimization**		
Target	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.	Conduct research to detect and minimize the consequences of disruptions in present and future tokamaks, including ITER. Coordinated research will deploy a disruption prediction/warning algorithm on existing tokamaks, assess approaches to avoid disruptions, and quantify plasma and radiation asymmetries resulting from disruption mitigation measures, including both pre-existing and resulting MHD activity, as well as the localized nature of the disruption mitigation system. The research will employ new disruption mitigation systems, control algorithms, and hardware to help avoid disruptions, along with measurements to detect disruption precursors and quantify the effects of disruptions.	Conduct research to examine the effect of configuration on operating space for dissipative divertors. Handling plasma power and particle exhaust in the divertor region is a critical issue for future burning plasma devices, including ITER. The very narrow edge power exhaust channel projected for tokamak devices that operate at high poloidal magnetic field is of particular concern. Increased and controlled divertor radiation, coupled with optimization of the divertor configuration, are envisioned as the leading approaches to reducing peak heat flux on the divertor targets and increasing the operating window for dissipative divertors. Data obtained from DIII-D and NSTX-U and archived from Alcator C-Mod will be used to assess the impact of edge magnetic configurations and divertor geometries on dissipative regimes, as well as their effect on the width of the power exhaust channel, thus providing essential data to test and validate leading boundary plasma models.
Result	Met	TBD	TBD

	FY 2015	FY 2016	FY 2017
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 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.		
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	Not Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the SC 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	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 micro-instabilities (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.	Predicting the magnitude and scaling of the divertor heat load width in magnetically confined burning plasmas is a high priority for the fusion program and ITER. One of the key unresolved physics issues is what sets the heat flux width at the entrance to the divertor region. Perform massively parallel simulations using 3D edge kinetic and fluid codes to determine the parameter dependence of the heat load width at the divertor entrance and compute the divertor plate heat flux applicable to moderate particle recycling conditions. Comparisons will be made with data from DIII-D, NSTX-U, and C-Mod.	Lower hybrid current drive (LHCD) will be indispensable for driving off-axis current during long-pulse operation of future burning plasma experiments including ITER, since it offers important leverage for controlling damaging transients caused by magnetohydrodynamic instabilities. However, the experimentally demonstrated high efficiency of LHCD is incompletely understood. In FY 2017, massively parallel, high-resolution simulations with 480 radial elements and 4095 poloidal modes will be performed using full-wave radiofrequency field solvers and particle Fokker-Planck codes to elucidate the roles of toroidicity and full-wave effects. The simulation predictions will be compared with experimental data from the superconducting EAST tokamak.

	FY 2015	FY 2016	FY 2017
Result	Met	TBD	TBD
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 SC 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.		

Fusion Energy Sciences
Capital Summary ($K)

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Capital Operating Expenses Summary							
Capital equipment	n/a	n/a	7,798	11,388	6,899	5,229	-1,670
General plant projects (GPP)	n/a	n/a	2,500	2,500	5,000	4,321	-679
Accelerator Improvement Projects (AIP) (<$5M)							
Total, Capital Operating Expenses	**n/a**	**n/a**	**10,298**	**13,888**	**11,899**	**9,550**	**-2,349**
Capital Equipment							
Major items of equipment[a]							
National Spherical Torus Experiment Upgrade (TPC $94,300)	83,665	80,195	3,470	3,470	0	0	0
U.S. Contributions to ITER (TPC TBD)	TBD	673,385	0	0		0	0
Total MIEs	**n/a**	**729,880**	**3,470**	**3,470**	**0**	**0**	**0**
Total Non-MIE Capital Equipment	n/a	n/a	4,328	7,918	6,899	5,229	-1,670
Total, Capital equipment	**n/a**	**n/a**	**7,798**	**11,388**	**6,899**	**5,229**	**-1,670**
General Plant Projects[b]							
General Plant Projects under $2 million TEC	n/a	n/a	2,500	2,500	5,000	4,321	-679

[a] Each MIE located at a DOE facility Total Estimated Cost (TEC) >$5M and each MIE not located at a DOE facility TEC > $2M.

[b] Each Plant Project (GPP/GPE) Total Estimated Cost (TEC) > $5M

Fusion Energy Sciences
Construction Projects Summary ($K)

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
14-SC-60, U.S. Contributions to ITER Project							
Total Estimated Cost (TEC)	TBD	797,905	144,639	144,639	115,000	125,000	+10,000
Other Project Cost (OPC)	TBD	74,980	5,361	5,361	0	0	0
Total, Project Cost (TPC), 14-SC-60	**TBD**	**872,885**	**150,000**	**150,000**	**115,000**	**125,000**	**+10,000**

Fusion Energy Sciences
Funding Summary ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
Research	216,258	205,610	219,145	184,988	-34,157
Scientific user facility operations	94,647	94,686	97,855	83,190	-14,665
Major items of equipment	3,470	3,470	0	0	0
Other (GPP, GPE, and infrastructure)	3,125	3,600	6,000	5,000	-1,000
Construction	150,000	150,000	115,000	125,000	+10,000
Total, Fusion Energy Sciences	**467,500**	**457,366**	**438,000**	**398,178**	**-39,822**

Scientific User Facility Operations and Research ($K)

The treatment of user facilities is distinguished between two types: TYPE A facilities that offer users resources dependent on a single, large-scale machine; TYPE B facilities that offer users a suite of resources that is not dependent on a single, large-scale machine.

Definitions:

Achieved Operating Hours – The amount of time (in hours) the facility was available for users.

Planned Operating Hours –

- For Past Fiscal Year (PY), the amount of time (in hours) the facility was planned to be available for users.
- For Current Fiscal Year (CY), the amount of time (in hours) the facility is planned to be available for users.
- For the Budget Fiscal Year (BY), based on the proposed budget request the amount of time (in hours) the facility is anticipated to be available for users.

Optimal Hours – The amount of time (in hours) a facility would be available to satisfy the needs of the user community if unconstrained by funding levels.

Percent of Optimal Hours – An indication of utilization effectiveness in the context of available funding; it is not a direct indication of scientific or facility productivity.

- For BY and CY, Planned Operating Hours divided by Optimal Hours expressed as a percentage.
- For PY, Achieved Operating Hours divided by Optimal Hours.

Unscheduled Downtime Hours – The amount of time (in hours) the facility was unavailable to users due to unscheduled events. NOTE: For type "A" facilities, zero Unscheduled Downtime Hours indicates Achieved Operating Hours equals Planned Operating Hours.

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request[a]	FY 2017 vs. FY 2016
TYPE A FACILITIES					
DIII-D National Fusion Facility	**$79,950**	**$83,108**	**$80,000**	**$81,100**	**+1,100**
Number of Users	579	579	579	570	-9
Achieved operating hours	600	550	N/A	N/A	N/A
Planned operating hours	600	600	600	560	-40
Optimal hours	1,000	1,000	1,000	560	-440
Percent optimal hours	60%	55%	60%	100%	+40%
Unscheduled downtime hours	50	50	N/A	N/A	N/A
Alcator C-Mod	**$22,260**	**$21,429**	**$18,000**	**0**	**-18,000**
Number of Users	170	170	140	0	-140
Achieved operating hours	0	400	N/A	N/A	N/A
Planned operating hours	384	384	160	0	-160
Optimal hours	800	800	800	0	-800
Percent optimal hours	48%	50%	20%	0	-20%
Unscheduled downtime hours	0	0	N/A	N/A	N/A

[a] For FY 2017 the number of optimal hours for DIII-D and NSTX-U is less than the typical amount due to planned enhancement activities at the facility that will preclude operation during part of the fiscal year.

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request[a]	FY 2017 vs. FY 2016
National Spherical Torus Experiment-Upgrade	**$72,919**	**$68,470**	**$71,000**	**$70,500**	**-500**
Number of Users	250	250	329	322	-7
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	480	480	720	640	0
Optimal hours	500	500	1,000	640	-280
Percent optimal hours	96%	96%	72%	100%	+28%
Unscheduled downtime hours	0	480	N/A	N/A	N/A
Total Facilities	**$168,960**	**$173,007**	**$169,000**	**151,600**	**-17,400**
Number of Users	999	999	1,048	892	-156
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	1,464	1,464	1,480	1,200	-280
Optimal hours	2,300	2,300	2,800	1,200	-1,600
Percent of optimal hours[a]	73.1%	70.6%	60.8%	100%	+39.2%
Unscheduled downtime hours	N/A	530	N/A	N/A	N/A

Scientific Employment

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
Number of permanent Ph.D.'s (FTEs)	724	724	767	625	-142
Number of postdoctoral associates (FTEs)	93	93	98	80	-18
Number of graduate students (FTEs)	268	268	293	200	-93
Other[b]	1,102	1,102	1,025	947	-78

[a] For total facilities only, this is a "funding weighted" calculation FOR ONLY TYPE A facilities: $\frac{\sum_1^n[(\%OH\ for\ facility\ n)\times(funding\ for\ facility\ n\ operations)]}{Total\ funding\ for\ all\ facility\ operations}$

[b] Includes technicians, engineers, computer professionals, and other support staff.

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

1. Significant Changes and Summary

Significant Changes
This Construction Project Data Sheet (CPDS) is an update of the FY 2016 CPDS and does not include a new start for FY 2017.

Summary
The FY 2017 Request for ITER is $125,000,000, $10,000,000 more than the FY 2016 Enacted level of $115,000,000. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on January 25, 2008 with a preliminary cost range of $1.45–$2.2 billion. Since CD-1, it has not been possible to baseline the project because of continued delays in the international ITERproject construction schedule. Until CD-2 can be approved, U.S. funding will be managed to address annual project priorities and to 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 CPDS are identified as “TBD”. A substantial increase in the overall Total Project Cost of the project is anticipated once it is ready to be baselined.

The approving official for all critical decisions is the Director of the Office of Science (SC-1).

A Federal Project Director with certification level 3 has been assigned to this project and has approved this CPDS.

ITER is a major fusion research facility being constructed in Cadarache, France by an international partnership of seven governments. Since it will not result in a facility owned by the U.S. or located in the U.S., the U.S. Contributions to ITER (USITER) project is not classified as a capital asset project. The USITER is a U.S. Department of Energy project to provide the U.S. share of in-kind hardware (e.g., subsystems, equipment, and components), as well as cash contributions to support the ITER organization in France. Sections of this CPDS have been tailored accordingly to reflect the nature of this project.

The USITER project is managed as a DOE Office of Science (SC) project. The project began as a major item of equipment (MIE) in FY 2006, and was changed to a Congressional control point beginning in FY 2014. This did not change SC’s overall program and project management approach for the USITER Project. As with all SC projects, the principles of DOE Order 413.3B are applied in the effective management of the project, including critical decision milestones and their supporting prerequisite activities. Requirements for project documentation, monitoring and reporting, change control, and regular independent project reviews are being applied with the same degree of rigor as other SC line-item projects. An approved Annual Performance Plan (APP) authorizes the work activities to be performed, as well as establishes milestones for project performance against which progress will be measured. Progress and performance against the APP is reported regularly in monthly performance metrics and project status reports.

The USITER project is making significant progress in the areas of design completion and fabrication of hardware. As of the end of December 2015, the USITER project is 29% complete overall;design of all twelve technical systems the U.S. is responsible for delivering is 58% complete; and hardare fabrication is 9% complete. Two of the largest U.S. systems, the Tokamak Cooling Water System (TCWS) and the Central Solenoid (CS) Magnets, are in or beyond the final design stage. Active fabrication is underway in four of the U.S. twelve hardware systems (TCWS, Steady State Electric Network [SSEN] Components, Toroidal Field [TF] Conductor and CS Magnets). The U.S. has completed the fabrication and delivery of five nuclear-grade cooling water drain tanks to the ITER site. These components, which are time critical for ITER construction sequencing and which are fabricated in accordance with French Nuclear regulations, are some of the first major hardware components delivered to the site in France. The U.S. has also been procuring major high-voltage electric power components (e.g., transformers, switch gear, circuit breakers, and voltage regulators). Deliveries of U.S. electric power components to the ITER site in France began in FY 2014 and are continuing. Fabrication of the TF conductor is also well underway. The purchase of superconducting strand material is complete, and cabling activities are well underway with four of the nine lengths completed through November 2015. Jacketing of three conductor lengths has been completed. The U.S. has shipped finished lengths of conductors to the European Union, one of the ITER Members responsible for TF Magnet fabrication, and fabrication of TF conductor and final delivery will be completed in early FY 2017. The U.S. has contracted with General Atomics (GA) for the fabrication of the world’s largest superconducting magnets for the ITER CS Magnet system. The GA fabrication facility is essentially complete and commissioning is complete for six of the eleven work stations needed for fabrication of each of the seven modules the U.S. is responsible for delivering. In FY 2015, the U.S. started fabrication of a mockup (non-superconducting) coil to provide assurance of manufacturing processes; and most notably, started the winding of the first production module with superconducting CS conductor provided by the Japanese Domestic Agency. Initiation of fabrication activities in the GA facility represents the culmination of several years of preparation and a major accomplishment for the USITER project. By the end of CY 2017, all modules will be in fabrication. DOE has begun to award contracts for the assembly tooling necessary for CS Magnet installation in the ITER facility with fabrication of all tooling planned for FY 2018 completion, and contracts for CS Structures has begun with deliveries beginning in FY 2017 and planned fabrication complete in FY 2019. To date the USITER project has awarded and obligated over $794 million to U.S. industry, universtities, and DOE laboratories.

FY 2016 funding supports continued in-kind contributions and related support activities. No funding is provided for cash contributions to support the ITER organization in FY 2016. FY 2017 funding will support ITER Project Office operations, the U.S. cash contribution to the ITER Organization, and continued progress on U.S. in-kind contributions, including: central solenoid magnet modules and structures, toroidal field magnet conductor, steady state electric network, diagnostics development, tokamak cooling water system, and vacuum system.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2006	7/5/2005		TBD	TBD		TBD	N/A	TBD
FY 2007	7/5/2005		TBD	TBD		TBD	N/A	2017
FY 2008	7/5/2005		1/25/2008	4Q FY 2008		TBD	N/A	2017
FY 2009	7/5/2005	09/30/2009[a]	1/25/2008	4Q FY 2010		TBD	N/A	2018
FY 2010	7/5/2005	07/27/2010[b]	1/25/2008	4Q FY 2011		TBD	N/A	2019
FY 2011	7/5/2005	05/30/2011[c]	1/25/2008	4Q FY 2011	04/12/2011[d]	TBD	N/A	2024
FY 2012	7/5/2005	07/10/2012[e]	1/25/2008	3Q FY 2012	05/02/2012[f]	TBD	N/A	2028
FY 2013	7/5/2005	12/11/2012[g]	1/25/2008	TBD[h]	04/10/2013[i]	TBD	N/A	2033
FY 2014	7/5/2005		1/25/2008	TBD	12/10/2013[j]	TBD	N/A	2034
FY 2015	7/5/2005		1/25/2008	TBD		TBD	N/A	2036
FY 2016[k]	7/5/2005		1/25/2008	TBD		TBD	N/A	TBD
FY 2017[l]	7/5/2005		1/25/2008	TBD		TBD	N/A	TBD

[a] Electron Cyclotron Heating (ECH) Transmission lines (TL) (06/22/2009); Tokamak Cooling Water System (07/21/2009); CS Modules, Structures, and Assembly Tooling (AT) (09/30/2009).
[b] Ion Cyclotron Heating Transmission Lines (ICH) (10/14/2009); Tokamak Exhaust Processing (TEP) (05/17/2010); Diagnostics: Residual Gas Analyzer (RGA) (07/14/2010), Upper Visible Infrared Cameras (VIR) (07/27/2010).
[c] Vacuum Auxiliary System (VAS) – Main Piping (12/13/2010); Diagnostics Low-Field-Side Reflectometer (LFS) (05/30/2011).
[d] Cooling Water Drain Tanks (04/12/2011).
[e] Diagnostics: Upper Port (10/03/2011), Electron Cyclotron Emission (ECE) (12/06/2011), Equatorial Port E-9 and Toroidal Interferometer Polarimeter (TIP) (01/02/2012), Equatorial Port E-3 (07/10/2012).
[f] Steady State Electrical Network (05/02/2012).
[g] VAS Supply (11/13/2012); Disruption Mitigation (12/11/2012); Pellet Injection (04/29/2013); Diagnostics: Motional Stark Effect Polarimeter (MSE) (05/29/2013), Core Imaging X-ray Spectrometer (CIXS) (06/01/2013).
[h] The CD-2 date will be determined upon acceptable resolution of issues related to development of a high-confidence ITER Project Schedule and establishment of an approved funding profile.
[i] RGA Divertor Sampling Tube (07/28/14); CS Assembly Tooling, Early Items (09/17/14).
[j] CS Modules and Structures (11/18/2013); VAS Main Piping B-2, L-1, L-2 (12/10/2013).
[k] CS AT Remaining Items; VAS 02 Supply; VAS Main piping (L3-L4); Pellet Injection Flight Tubes.
[l] TCWS Captive Piping; ICH Gallery: Radio Frequency (RF) Building; Port Plug Test Facility Transmission Line (PPTF TL); ECH TL System Design; RGA; Upper VIR Cameras; LFS.

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. Project Cost History

At the time of CD-1 approval in January 2008, the preliminary cost range was $1.45–$2.2 billion. Since then, however, it has not been possible to confidently baseline the project due to continued delays in the international ITER construction schedule. Various factors (e.g., schedule delays, design and scope changes, funding constraints, regulatory requirements, risk mitigations, and project management and leadership issues in the ITER Organization) have affected the project cost. DOE anticipates a substantial increase in the overall Total Project Cost of the project once the project is ready to be baselined.

4. Project Scope and Justification

<u>Introduction</u>
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. Through participation in the agreement, the European Union, as the host, 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 ITER facilities cost. Operation, deactivation, and decommissioning of the facility are to be funded through a different cost-sharing formula in which the U.S. will contribute a 13% share, which is not a part of the USITER project funding. 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.

<u>**Scope**</u>
<u>ITER Construction Project Scope</u>
The USITER 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.
- Funding 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 project costs, including R&D and conceptual design related activities.

The USITER project hardware scope is limited to design, fabrication, and delivery of mission-critical tokamak subsystems and is described below. As of December 2015, the USITER project is 28% complete.

- **Tokamak Cooling Water System (TCWS)**: manages the thermal energy generated during the operation of the tokamak. The TCWS is 24% complete.
- **15% of ITER Diagnostics**: provides the measurements necessary to control, evaluate, and optimize plasma performance and to further the understanding of plasma physics. Diagnostics are 21% complete.
- **Disruption Mitigation Systems ($20M cost cap)**: limit the impact of plasma disruptions to the tokamak vacuum vessel, blankets, and other components. The Disruption Mitigation Systems are 25% complete.
- **Electron Cyclotron Heating (ECH) Transmission Lines**: bring additional power to the plasma and deposits power in specific areas of the plasma to minimize instabilities and optimize performance. The ECH is 19% complete.
- **Tokamak Exhaust Processing (TEP) System**: separates hydrogen isotopes from tokamak exhaust. The TEP system is 11% complete.

- **Fueling System (Pellet Injection)**: injects fusion fuels in the form of deuterium-tritium ice pellets into the vacuum chamber. The Pellet Injection system is 18% complete.
- **Ion Cyclotron Heating (ICH) Transmission Lines**: bring additional power to the plasma. The ICH is 17% complete.
- **Central Solenoid** (CS) **Magnet System**: confines, shapes and controls the plasma inside the vacuum vessel. The CS Magnet modules are 56% complete; the CS structures are 26% complete; and the CS tooling is 47% complete.
- **8% of Toroidal Field (TF) Conductor**: component of the TF magnet that confines, shapes, and controls the plasma. The TF Conductor is 95% complete.
- **75% of the Steady State Electrical Network (SSEN)**: supplies the electricity needed to operate the entire plant, including offices and the operational facilities. The SSEN is 59% complete.
- **Vacuum Auxiliary System**: creates and maintains low gas densities in the vacuum vessel and connected vacuum components. The Vacuum Auxiliary System is 20% complete,
- **Roughing Pumps**: evacuate the tokamak, cryostat, and auxiliary vacuum chambers prior to and during operations. Roughing Pumps system is 15% complete.

Justification

The purpose of ITER is to investigate and conduct research in the so-called “burning plasma” regime—a performance region that exists beyond the current experimental state of the art. Creating a self-sustaining burning plasma will provide essential scientific knowledge necessary for practical fusion power. There are two parts of this need that will be achieved by ITER. 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 (i.e., self-heating). 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. ITER is the necessary next step to establish the confidence in proceeding with development of a demonstration fusion power plant.

The project is being conducted in accordance with the project management principles of DOE O 413.3B, Program and Project Management for the Acquisition of Capital Assets.

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
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[b]	91,441	91,407	99,215
FY 2013[a]	107,635	107,669	110,074
FY 2014[ac]	161,605	161,605	153,368
FY 2015	128,682	128,682	105,908
FY 2016[d]	115,000	115,000	139,984
FY 2017	85,000	85,000	143,828
Subtotal	997,747	997,747	963,557
Total, Hardware	TBD	TBD	TBD

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.
[b] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.
[c] Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.
[d] FY 2016 funding for taxes and tax support is included in the FY 2016 Hardware funding amount.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Cash Contributions[a]			
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[b]	32,895	32,895	32,895
FY 2015	15,957	15,957	15,957
FY 2016[b]	0	0	0
FY 2017	40,000	40,000	40,000
Subtotal	184,497	184,497	184,497
Total, Cash Contributions	TBD	TBD	TBD
Total, TEC	TBD	TBD	TBD
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[c]	345	345	22,336
FY 2013[a]	2,560	2,560	5,984
FY 2014[ad]	5,000	5,000	2,717
FY 2015	5,361	5,361	5,500
FY 2016	0	0	5,016
FY 2017	0	0	0
Subtotal	80,641	80,641	80,641
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[a]	105,000	104,966	134,765
FY 2013[a]	124,000	124,034	129,863
FY 2014[ab]	199,500	199,500	188,980

[a] Includes cash payments, secondees, taxes and tax support.
[b] No FY 2016 funding is provided to support the ITER organization.
[c] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.
[d] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.
[b] 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[a]
FY 2015	150,000	150,000	127,365
FY 2016	115,000	115,000	145,000
FY 2017	125,000	125,000	183,828
Subtotal	1,262,885	1,262,885	1,228,695
Total, TPC	TBD	TBD	TBD

6. Details of the 2017 Project Cost Estimate

Since CD-1, it has not been possible to baseline the project because of continued delays in the international ITER construction schedule; therefore a Total Project Cost estimate cannot be formulated at this point in time. Until such time as CD-2 can be approved, U.S. funding will be managed to address annual project priorities and to allow flexibility to adapt to the changing state of the project.

7. Schedule of Appropriation Requests

(dollars in thousands)

Request Year		Prior Years	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	Outyears	Total
FY 2006	TEC	889,000	120,000	29,000	0	0	0	0	0	1,038,000
	OPC	74,400	6,200	3,400	0	0	0	0	0	84,000
	TPC	963,400	126,200	32,400	0	0	0	0	0	1,122,000
FT 2007	TEC	800,151	130,000	116,900	30,000	0	0	0	0	1,077,051
	OPC	44,949	0	0	0	0	0	0	0	44,949
	TPC	845,100	130,000	116,900	30,000	0	0	0	0	1,122,000
FY 2008	TEC	801,330	130,000	116,900	30,000	0	0	0	0	1,078,230
	OPC	43,770	0	0	0	0	0	0	0	43,770
	TPC	845,100	130,000	116,900	30,000	0	0	0	0	1,122,000
FY 2009[a]	TEC	266,366	0	0	0	0	TBD	TBD	TBD	TBD
	OPC	38,075	0	0	0	0	TBD	TBD	TBD	TBD
	TPC	304,441	0	0	0	0	TBD	TBD	TBD	TBD
FY 2010	TEC	294,366	0	0	0	0	TBD	TBD	TBD	TBD
	OPC	70,019	0	0	0	0	TBD	TBD	TBD	TBD
	TPC	364,385	0	0	0	0	TBD	TBD	TBD	TBD
FY 2011	TEC	379,366	0	0	0	0	TBD	TBD	TBD	TBD
	OPC	65,019	0	0	0	0	TBD	TBD	TBD	TBD
	TPC	444,385	0	0	0	0	TBD	TBD	TBD	TBD
FY 2012[b]	TEC	304,566	90,000	0	0	0	TBD	TBD	TBD	TBD
	OPC	60,019	15,000	0	0	0	TBD	TBD	TBD	TBD
	TPC	364,385	105,000	0	0	0	TBD	TBD	TBD	TBD
FY 2013[c]	TEC	371,366	104,930	140,965	0	0	TBD	TBD	TBD	TBD
	OPC	73,019	70	9,035	0	0	TBD	TBD	TBD	TBD
	TPC	444,385	105,000	150,000	0	0	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.

[c] 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.

(dollars in thousands)

Request Year		Prior Years	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	Outyears	Total
FY 2014[a]	TEC	371,366	104,930	105,572	225,000	0	TBD	TBD	TBD	TBD
	OPC	73,019	70	70	0	0	TBD	TBD	TBD	TBD
	TPC	444,385	105,000	105,642	225,000	0	TBD	TBD	TBD	TBD
FY 2015	TEC	377,010	104,930	121,465	194,500	144,639	TBD	TBD	TBD	TBD
	OPC	67,375	70	2,535	5,000	5,361	TBD	TBD	TBD	TBD
	TPC	444,385	105,000	124,000	199,500	150,000	TBD	TBD	TBD	TBD
FY 2016	TEC	377,010	104,930	121,465	194,500	144,639	150,000	TBD	TBD	TBD
	OPC	67,375	70	2,535	5,000	5,361	0	TBD	TBD	TBD
	TPC	444,385	105,000	124,000	199,500	150,000	150,000	TBD	TBD	TBD
FY 2017[a]	TEC	377,010	104,930	121,499	194,500	144,639	115,000	125,000		
	OPC	67,375	70	2,535	5,000	5,361	0	0	TBD	TBD
	TPC	444,385	105,000	124,034	199,500	150,000	115,000	125,000	TBD	TBD

8. Related Operations and Maintenance Funding Requirements

The U.S. Contributions to ITER operations is assumed to begin with initial integrated 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 USITER Project Office (USIPO) at Oak Ridge National Laboratory, with its two partner laboratories (Princeton Plasma Physics Laboratory and Savannah River National Laboratory), will procure and deliver in-kind hardware in accordance with the Procurement Arrangements established with the International Organization (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.

[a] Prior to FY 2015, the requests were for a major item of equipment broken out by TEC, OPC, and TPC.

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.

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.