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 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.

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

Highlights of the FY 2018 Budget Request

Strategic choices in this Budget Request were informed by the reductions in the overall FY 2018 Office of Science Budget Request, priorities described in "The Office of Sciences' Fusion Energy Sciences Program: A Ten-Year Perspective" (submitted to Congress in 2015), and the research opportunities identified in a series of community engagement workshops held in 2015. Priorities include keeping FES user facilities world-leading, increasing investment in massively parallel computing, supporting high-impact research in fusion materials, strengthening partnerships for access to international facilities with unique capabilities, learning how to predict and control transient events in fusion plasmas, and continuing stewardship of discovery plasma science (e.g., via intermediate-scale basic facilities). Building on the workshops and the ten-year strategic perspective, FES has recently commissioned a study by the National Academies of Science about research priorities for burning plasma science. Also, SC has charged the Fusion Energy Sciences Advisory Committee (FESAC) to investigate the potential for transformative developments in fusion science and technology.

Notable changes in the FY 2018 Request include:

- *Increased support for DIII-D program*—Total funding for the DIII-D program 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 involvement of collaborating university and laboratory researchers in these programs. Funding will support 18 weeks of operation and greater involvement of the National Spherical Torus Experiment Upgrade (NSTX-U) scientists in the DIII-D program while repairs of NSTX-U are underway. It will also support increased collaborations by Massachusetts Institute of Technology (MIT) researchers following the closure of the Alcator C-Mod facility in FY 2017.
- *Continued support for NSTX-U program research and recovery activities*—The NSTX-U facility is down for recovery (assessment and repair) during FY 2017, and this will continue in FY 2018. In FY 2016, a series of deficiencies were found in the design and construction of the NSTX-U device, which prompted the Princeton Plasma Physics Laboratory (PPPL) to cease operation and carry out thorough design verification and validation reviews. The FY 2018 NSTX-U Operations budget will support high-priority activities to implement repairs and corrective actions required to obtain robust, reliable research operations. The NSTX-U Research budget will fund the continued analysis of high-impact data acquired during the FY 2016 run campaign, a focused effort on physics topics that directly support the recovery of

robust NSTX-U plasma operations, and enhanced involvement of university collaborative research at other facilities to support NSTX-U research program priorities.

- *Reduced support for ITER*—This reduction reflects the decrease in the DOE science budget and U.S. concerns about the cost and schedule of ITER.
- *Increased support for Scientific Discovery through Advanced Computing* (*SciDAC)*—Funding for SciDAC is increased to address high-priority research in tokamak disruptions and boundary physics as identified in the 2015 community workshops, and to accelerate development of a whole-device modeling capability, in partnership with the Advanced Scientific Computing Research (ASCR) program.
- *Continued support for Long Pulse Tokamak and Stellarator research*—Funding for Long Pulse Tokamak is maintained for research opportunities for U.S. scientists on superconducting tokamaks with world-leading capabilities. Funding for Long Pulse Stellarator will enable U.S. research teams to take full advantage of U.S. hardware investments on Wendelstein 7-X (W7-X) and enhance the scientific output on this device.
- *Support for Fusion Nuclear Science and Materials Research*—Funding for Fusion Nuclear Science and Materials Research is refocused on fundamental science.
- *Support for Discovery Plasma Science*—Research and operations on intermediate-scale user facilities will be emphasized to pursue opportunities identified in the 2015 community workshops.

Fusion Energy Sciences
Funding ($K)

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Fusion Energy Sciences				
Burning Plasma Science: Foundations				
Advanced Tokamak	101,754	-	86,000	-15,754
Spherical Tokamak	76,195	-	59,100	-17,095
Theory & Simulation	33,810	-	32,500	-1,310
GPE/GPP/Infrastructure	5,875	-	0	-5,875
Total, Burning Plasma Science: Foundations	**217,634**	**-**	**177,600**	**-40,034**
Burning Plasma Science: Long Pulse				
Long Pulse: Tokamak	8,944	-	8,500	-444
Long Pulse: Stellarators	7,079	-	7,000	-79
Materials & Fusion Nuclear Science	24,053	-	19,823	-4,230
Total, Burning Plasma Science: Long Pulse	**40,076**	**-**	**35,323**	**-4,753**
Discovery Plasma Science				
Plasma Science Frontiers	46,504	-	23,600	-22,904
Measurement Innovation	3,568	-	900	-2,668
SBIR/STTR & Other	15,218	-	9,517	-5,701
Total, Discovery Plasma Science	**65,290**	**-**	**34,017**	**-31,273**
Subtotal, Fusion Energy Sciences	**323,000**	**-**	**246,940**	**-76,060**
Construction				
14-SC-60 International Thermonuclear Experimental Reactor (ITER)	115,000	-	63,000	-52,000
Total, Fusion Energy Sciences	**438,000**	**-**	**309,940**	**-128,060**

SBIR/STTR:

- FY 2016 Transferred: SBIR: $9,333,000; STTR: $1,400,000
  FY 2018 Request: SBIR $XXX and STTR $XXX

[a] The FY 2016 Enacted level includes SBIR and STTR and reflects updates through the end of the fiscal year.

[b] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

Fusion Energy Sciences
Explanation of Major Changes ($K)

	FY 2018 vs FY 2016
Burning Plasma Science: Foundations: Funding for tokamak research decreases due to the shutdown of the Alcator C-Mod facility in FY 2017. DIII-D program funding increases to support the enhanced collaboration by university and laboratory personnel, including MIT and NSTX-U scientists, in the DIII-D program. Funding for SciDAC increases to accelerate progress toward whole-device modeling. Funding for the NSTX-U program will support the repair of the facility, while DIII-D funding will enable 18 weeks of operations. All GPE/GPP funding is deferred.	-$40,034
Burning Plasma Science: Long Pulse: Funding for Materials and Fusion Nuclear Science decreases with an emphasis on addressing the highest priority issues in both program elements.	-$4,753
Discovery Plasma Science: Overall funding is decreased. For General Plasma Science and Exploratory Magnetized Plasma, research and operations of intermediate-scale, scientific user facilities are emphasized. For High Energy Density Laboratory Plasma, the focus remains on supporting research utilizing the Matter in Extreme Conditions instrument of the Linac Coherent Light Source facility at the SLAC National Accelerator Laboratory at Stanford University.	-$31,273
Construction: Funding decreases for the U.S. Contributions to ITER project.	-$52,000
Total Funding Change, Fusion Energy Sciences	**-$128,060**

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 NSF, with research extending to a wide range of natural phenomena, including the origin of magnetic fields in the universe and the nature of plasma turbulence. 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 FESAC provides technical and programmatic advice to FES and NNSA for the joint HEDLP program.

Program Accomplishments
Important for fusion reactors: novel stable, efficient operating scenario with low-rotation developed—Most current-day tokamaks have plasmas with significant rotation, due to the large torque applied by neutral ion beams used for heating. However, future fusion power plants will operate with almost no rotation. The DIII-D tokamak facility at General Atomics, with its ability to balance the neutral beam torque while still heating (with up to 10 megawatts of power), has unique capabilities to study low-torque regimes. Normally, rotation is needed to suppress plasma instabilities. Recently, however, scientists on DIII-D found that fusion performance while operating in the Quiescent H-Mode scenario (which is free of dangerous edge localized mode instabilities) actually improved as the rotation was decreased. The improvement occurs because the plasma undergoes a bifurcation into a new state characterized by increased pedestal height and width, resulting in enhanced global confinement.

Towards a possible breakthrough for reactor wall materials: lithium wall contains plasma without cooling it—In large tokamaks with tungsten walls, the edge plasma must be cooled to low temperatures (a few tens of electron-volts) in order to reduce sputtering of the wall, which can lead to heavy tungsten impurities beginning to accumulate in the plasma. But lower temperatures at the edge cause the plasma to be less hot in the core, which then degrades fusion performance. The Lithium Tokamak Experiment, a medium-scale tokamak at PPPL, found that lithium-coated walls can handle edge plasma temperatures higher than 200 electron-volts, with little influx of lithium and no impact on performance. Another advantage is that the resulting temperature profile is essentially flat from the edge to the core, which potentially avoids deleterious instabilities driven by a temperature gradient.

Massively parallel computation enables essential step towards predictive capability: simulations of electrical current generation in tokamaks—The conventional understanding of how intrinsic electrical current (the so-called bootstrap current) is generated is that the current is carried by charged particles that flow around the doughnut-shaped tokamak without getting magnetically trapped at the outboard side of the confinement configuration. New massively parallel numerical simulations, performed by scientists in the SciDAC Edge Physics Simulation Center (a partnership with ASCR) have, however, shown that the bootstrap current in the boundary region of the plasma is carried predominately by the magnetically trapped particles. This new understanding will greatly improve the prediction of the properties of the boundary plasma, including the important "pedestal" region, which plays a critical role in determining the overall fusion performance of the plasma.

Extending the reach of U.S. fusion science: collaborative research during the initial operation of W7-X—The U.S. is an international partner in the new Wendelstein 7-X facility, the world's largest stellarator, which began operation in early FY 2016. U.S. scientists helped map out the magnetic field line surfaces with an electron beam, to confirm magnetic coil alignment. During the first plasma operation period, the U.S. collaboration team used the set of five trim coils it had constructed to measure intrinsic field errors, calibrate magnetic measuring instruments, and perturb the plasma. Also, the U.S. scientists used their x-ray imaging crystal spectrometer instrument to make the first measurements of time-resolved ion temperature profiles, together with high-quality electron temperature profiles. The spectrometer also measured plasma flow and core impurity transport – critical for reactor design. The U.S. participated in the March 2016 celebration event at which German Chancellor Angela Merkel officially dedicated this new fusion research facility.

Essential for developing attractive materials for fusion reactors: first-of-a-kind materials irradiation experiments—The U.S. and Japan have a five-year collaboration project to study the feasibility of using a helium-cooled divertor made out of tungsten material for future fusion devices. Recently, the collaborating scientists began a landmark series of irradiation experiments on the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL). A shielded gadolinium rod is used to absorb the high thermal-neutron flux in the water-cooled HFIR reactor and thus achieve the appropriate ratio between displacement damage and transmutation content that is expected in a fusion power plant. The tungsten material samples thus being irradiated will yield unique understanding about the effects of fusion-type neutrons on their thermo-mechanical and fuel retention properties.

U.S. Contributions to ITER First Plasma subproject more than 50% complete—The U.S. completed the fabrication and delivery of over 21,000 feet of superconductor cable, more than enough to wind one of the eighteen Toroidal Field coils. Four U.S. industrial companies produced this superconductor. Additionally, the U.S. completed the fabrication and delivery of all of its components for the Steady State Electrical Network, needed to provide power for construction activities, as well as for plasma operations at ITER. Lastly, successful winding of the first two Central Solenoid superconducting magnet modules was completed. Each Central Solenoid module is fabricated from approximately 6,000 meters of niobium-tin superconductor. After winding and assembly, each completed module will undergo heat treatment, insulation, vacuum pressure impregnation, and final testing at the cryogenic operating temperature (4 degrees Kelvin). The Central Solenoid, an enormous electromagnet that is considered the "heartbeat of the ITER device," consists of six stacked magnet modules surrounded by a support structure. When assembled, the entire Central Solenoid and associated structures will be over 42 feet tall, weigh over 1,100 U.S. tons, and produce a very strong magnetic field (13 Tesla).

Exotic solar phenomena explained in the lab: pulsating reconnection driven by three-dimensional (3D) flux-rope interactions—In high-temperature plasmas, magnetic field lines can reconnect and release stored energy as the magnetic field undergoes topological changes. Although the two-dimensional dynamics of magnetic reconnection has been extensively studied, most applications in space and astrophysical plasmas are inherently three-dimensional. In a laboratory experiment at UCLA, researchers measured the 3D electric and magnetic fields resulting from the interaction of two magnetic flux "ropes" generated between a cathode and anode. The ropes were observed to bounce and reconnect in a periodic pulsating fashion. These results provide the first direct experimental test of reconnection within a quasi-separatrix layer (where magnetic field lines separate rapidly).

Science of the interior of giant planets accessed in the lab: liquid metallic hydrogen observed for the first time—The planet Jupiter is 70% composed of hydrogen, with the outer layer made of familiar molecular hydrogen (as on Earth), but surrounding the core an exotic state of hydrogen, called liquid metallic hydrogen, that requires extremely high pressures to exist. Researchers have been trying to observe this metallic state in the laboratory ever since it was predicted 80 years ago. High-power lasers can provide the high pressures necessary to induce the insulator-to-metal transition of hydrogen. Recently, SLAC scientists and their collaborators were able to observe this transition at a pressure of 250,000 atmospheres, using one laser beam to compress deuterium (a hydrogen isotope) and another laser beam to produce very short-wavelength x-rays that can probe the hydrogenic transition. These results provide insight into the physical properties of giant planets and also into the design of inertially confined fusion experiments with deuterium as a fuel.

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.
- 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 2018 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.

<u>Advanced Tokamak</u>

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 future fusion reactors. 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 operated in FY 2016 to complete student research and experimental work and ceased operations at the end of that fiscal year. The facility was placed in a safe shutdown state in FY 2017.

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.

<u>Spherical Tokamak</u>

The NSTX-U user facility at PPPL is designed to explore the physics of plasmas confined in a spherical torus (ST) configuration. With its unusually strong magnetic curvature, powerful heating systems, and advanced diagnostics, NSTX-U will uniquely enable the detailed study of plasmas at ratios of plasma pressure to the pressure of the confining magnetic field, or plasma beta, many times higher than are accessible in the world's other tokamaks. The implications of a successful NSTX-U research program are therefore significant: high plasma pressures translate to high fusion reactivity, making the NSTX-U geometry a candidate for a future neutron source for scientific study of fusion materials and components. Also, the high beta plasmas and measurement capabilities on NSTX-U will enable first-of-a-kind detailed laboratory study of plasma processes that are relevant to extraordinary astrophysical systems, such as the turbulence in accretion discs surrounding black holes. The upgraded neutral beam heating systems will combine with the plasma properties to make NSTX-U and ideal test bed for studying interactions between plasma waves and fast fuel ions that are relevant to burning plasma science. The liquid metal divertor research program planned for NSTX-U also will enable assessment of a potential break-out path for fusion heat and particle exhaust handling.

Following an extensive series of reviews (e.g. design validation and verification, extent of condition) in FY 2017, NSTX-U activities will focus on recovery efforts to repair or replace essential components during FY 2018-19.

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.

Theory and Simulation

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 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 extremely 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 research needs in burning plasma science. Most of the FES SciDAC portfolio, in partnership with ASCR is up for recompetition in FY 2017. The portfolio that will emerge from this competition will address the leading-priority research directions identified in the 2015 community workshops.

GPE/GPP/Infrastructure

Funding will support repairs of critical general infrastructure (e.g., utilities, roofs, roads, facilities) at the PPPL site. This funding level will assure appropriate maintenance of safety requirements, equipment reliability, and research-related infrastructure needs.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
Advanced Tokamak $101,754,000	**$86,000,000**	**-$15,754,000**
DIII-D Research ($34,643,000) *DIII-D Operations ($44,764,000)* Operations funding supported seventeen 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 2015 community workshops. Areas of research included 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 involved 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 ($38,000,000)* *DIII-D Operations ($45,000,000)* Operations funding will support eighteen weeks of research at the DIII-D facility. Research will focus on determining the optimal path to steady-state tokamak plasmas, exploring techniques to avoid and mitigate transients in tokamaks, and developing the plasma material interaction boundary solutions necessary for future devices. Experiments will continue to exploit a new upper divertor configuration and explore plasma wall coupling and dissipative divertor physics. Specific research goals will involve examining the processes that determine the edge pedestal density structure, assessing models of runaway electron evolution during disruptions, and utilizing new diagnostics to probe the divertor and edge region to challenge and validate theoretical models.	*+$3,357,000* *+$236,000* Funding will allow for greater involvement of university and laboratory collaborators in the DIII-D national program, including the MIT staff previously involved in Alcator C-Mod research, as well as NSTX-U scientists.

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
C-Mod Research ($9,374,000) *C-Mod Operations ($8,675,000)* Operations funding supported over seventeen weeks of research operations at the Alcator C-Mod facility in its final year of operation in FY 2016. Research was focused on research needs as identified by the FY 2015 community workshops. Experiments were 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 was closed after final operations. The scientific staff worked on completing analysis of existing C-Mod data and began making a transition to collaborative research activities on other research facilities.	*C-Mod Research ($0)* *C-Mod Operations ($0)* This facility was closed in FY 2016.	*-$9,374,000* *-$8,675,000*
Enabling R&D ($3,165,000) Support continued 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 ($2,000,000)* Support will continue to be provided for research in superconducting magnet technology and plasma fueling and heating technologies required to enhance the performance for existing and future magnetic confinement fusion devices.	*-$1,165,000* Research efforts will be focused on the highest-priority enabling R&D issues.
Small-scale Experimental Research ($1,133,000) Small-scale tokamak plasma research provided experimental data in regimes of relevance to the mainline advanced tokamak magnetic confinement efforts and helped 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 ($1,000,000)* Support will continue to be provided for research on experimental data in regimes relevant to mainline tokamak confinement and experimental validation of models and codes.	*-$133,000* Experimental research and modeling efforts will be continued.

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
Spherical Tokamak $76,195,000	**$59,100,000**	**-$17,095,000**
NSTX-U Research ($27,860,000) *NSTX-U Operations ($44,708,000)* NSTX-U began operations after completion of the upgrade. Machine performance was 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 were studied. The machine operated for 10 weeks in FY 2016 before experiencing a coil failure.	*NSTX-U Research ($20,000,000)* *NSTX-U Operations ($35,600,000)* Operations funding will support the repair of the NSTX-U facility. Research will be focused on the study of ST confinement improvements observed during the FY 2016 experimental run campaign. Modeling and new measurements will allow elucidation of the detailed physical mechanisms responsible for these confinement improvements. In the absence of plasma operations at the NSTX-U facility, researchers will carry out experiments on both domestic and international spherical tokamaks, and continue analysis and publication of data obtained in FY 2016.	*-$7,860,000* *-$9,108,000* The NSTX-U Research funds will support continued analysis of high-impact data acquired during the FY 2016 run campaign and a focused effort on physics topics that directly support the recovery of robust NSTX-U plasma operations. Researchers will also collaborate on other spherical tokamak facilities to advance high-priority research needs that were identified by the 2015 community workshops. The NSTX-U Operations budget supports high-priority activities to implement repairs and corrective actions required to obtain robust, reliable research operations. While consumable expenditures are reduced due to the non-operation of NSTX-U in FY 2018, the additional anticipated costs associated with the repair and replacement of components (e.g., material procurements) offset these savings.
Small-scale Experimental Research ($3,627,000) Small-scale spherical torus plasma research provided experimental data in regimes of relevance to the mainline spherical torus magnetic confinement efforts and helped 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 ($3,500,000)* Experimental studies of plasmas surrounded by liquid lithium material surfaces, which was identified as a priority research direction in the 2015 plasma materials interactions workshop, will be conducted. Developing techniques to operate STs without the use of a central solenoid will be experimentally tested. If successful, these small-scale, high-risk lines of research may provide underlying scientific insights for future devices.	*-$127,000* Funding will support experimental research efforts on small scale spherical tokamak facilities in support of NSTX-U program priorities.
Theory & Simulation $33,810,000	**$32,500,000**	**-$1,310,000**
Theory ($24,439,000) The program continued to advance the scientific understanding of the fundamental physical processes governing the behavior of magnetically confined plasmas. Emphasis on addressing ITER priorities	*Theory ($15,500,000)* The program will continue to support theoretical and computational research addressing fundamental questions of magnetic confinement science. Emphasis will be placed on projects maximizing synergy with the FES SciDAC portfolio and addressing the	*-$8,939,000* The program will be refocused to emphasize SciDAC activities.

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
continued to guide the selection of new and renewal awards via competitive merit reviews.	recommendations from the 2015 community workshops.	
SciDAC ($9,371,000) The five SciDAC centers entered the final year of their research activities, while the three FES–ASCR SciDAC-3 partnerships continued their efforts in the areas of boundary physics, materials science, and multiscale integrated modeling. FES and ASCR developed a plan emphasizing integration for the science areas represented by the entire FES SciDAC portfolio and initiated preparations for a competitive merit review.	*SciDAC ($17,000,000)* The entire FES SciDAC portfolio will continue to focus on integrated simulations and whole device modeling, addressing the leading priority research directions identified in the 2015 community workshops. Synergy with whole-device modeling activities supported by the DOE Exascale Computing Project will be strengthened.	*+$7,629,000* Increase in funding will enable the development and implementation of additional critical computational modules, accelerating the development of the whole-device modeling capability. It will also allow the continuation and strengthening of efforts in the critical area of runaway electron avoidance and mitigation.
GPE/GPP/Infrastructure $5,875,000	**$0**	**-$5,875,000**
Continued support of NSTX-U operations, as well as enhanced International Collaborations, was provided through improvements to the Princeton Plasma Physics Laboratory Computer Center (PPPLCC) and establishment of remote collaboration room configurations. Environmental monitoring needs at PPPL continued to be supported.	All GPE/GPP funding is deferred.	All GPE/GPP funding is deferred.

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 and technologies required to withstand and sustain a burning plasma. 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 continue their successful work on advancing the physics and technology basis for long-pulse burning plasma operation via bilateral research on U.S. and international fusion facilities. Research on overseas superconducting tokamaks, conducted onsite and also via fully remote facility operation, leverages progress made in domestic devices and allows the U.S. fusion program to gain the knowledge needed to operate long-duration plasma discharges in future fusion energy devices. When advantageous, these efforts will be augmented by research into long-pulse related physics issues on overseas tokamaks and spherical tokamaks with nonsuperconducting coil systems.

Long Pulse: Stellarator

Stellarators offer the promise of steady-state confinement regimes without transient events such as harmful disruptions. The three-dimensional (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 W7-X in Germany provides an opportunity to develop and assess 3-D 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. Accordingly, the U.S. is participating fully 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 for use in future fusion devices. Materials that can withstand this environment, under the long-pulse or steady-state conditions anticipated in 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 2018 Request	Explanation of Change FY 2018 vs FY 2016
Long Pulse: Tokamak $8,944,000	**$8,500,000**	**-$444,000**
U.S. scientists have developed, installed, and commissioned improved plasma control feedback systems for China's Experimental Advanced Superconducting Tokamak (EAST) and Korea's Superconducting Tokamak Advanced Research (KSTAR). ITER operating scenarios were explored and evaluated on EAST and KSTAR. Radio-frequency heating and current drive and neutral beam injection actuator models for EAST and KSTAR were developed and validated.	Three multi-institutional collaborative teams will continue their activities on the superconducting tokamaks, EAST and KSTAR, focusing on the high-priority areas of control and extension of steady-state plasma scenarios to long-pulse, disruption physics, and control of plasma-material interfaces for long-pulse. Research efforts on international conventional tokamaks will continue to address burning plasma physics issues relevant to achieving long pulse plasma operation.	Funding will continue support for U.S. scientists on superconducting tokamaks with unique, world-leading capabilities, as well as research on international conventional tokamaks.
Long Pulse: Stellarators $7,079,000	**$7,000,000**	**-$79,000**
Superconducting Stellarator Research ($4,168,000) U.S. scientists participated in the first plasma operating campaign of W7-X. The U.S. team was involved with characterizing the 3-D magnetic configuration and performing the first tests of U.S.-supplied equipment during plasma operation. The team also prepared the Test Divertor Unit (TDU) scraper element for the second operating campaign.	*Superconducting Stellarator Research ($4,500,000)* U.S. research teams will utilize new W7-X capabilities to enhance the scientific output of the first major experimental campaign. Experiments will investigate controlling the interface between the magnetic field and plasma-facing components, provide measurements of temperature and poloidal rotation profiles, and use a stellarator- optimization code for plasma equilibrium reconstruction from experimental measurements.	*+$332,000* Funding will enable U.S. scientists to take advantage of U.S. hardware investments to investigate important physics issues in long-pulse plasma confinement, such as edge and impurity transport and pellet fueling for steady-state operation. Gas puff and phase contrast imaging studies will be extended.
Compact Stellarator Research ($2,911,000) Compact stellarator research provided experimental data in regimes of relevance to the mainline stellarator magnetic confinement efforts and helped 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 ($2,500,000)* Research will continue on experiments that are providing data in regimes relevant to mainline stellarator confinement and experimental validation of models and codes.	*-$411,000* Research efforts will be focused on the highest-priority stellarator issues.

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
Materials & Fusion Nuclear Science $24,053,000	**$19,823,000**	**-$4,230,000**
Fusion Nuclear Science ($11,271,000) The focus remained on 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 continued. Scoping studies continued on characterizing significant research gaps in the materials and fusion nuclear sciences program.	*Fusion Nuclear Science ($8,823,000)* Research will continue in the areas of plasma-facing components, safety, tritium fuel cycle, and breeder blanket technologies. The program will continue to utilize existing facilities in support of foundational science as emphasized by the 2015 community workshops and the FES strategic plan. Additionally, the program will continue to evaluate the potential for high-priority research on liquid metal plasma-facing components through a systems-level study.	*-$2,448,000* Research efforts will be focused on the highest-priority fusion nuclear science issues.
Materials Research ($12,782,000) The focus remained on 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 ($11,000,000)* Research efforts will continue to emphasize the utilization of existing experimental capabilities, as well as explore opportunities for developing new ones, to conduct research in the area of fusion material science. The research effort will continue to focus on the development of materials that can withstand long term exposure to unprecedented fluxes of high-energy neutrons and particles, intense thermomechanical stresses, and novel, high temperatures coolants.	*-$1,782,000* Research efforts will be focuses on the highest-priority fusion material science issues.

Fusion Energy Sciences
Discovery Plasma Science

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, such as energy efficient lighting, sterilization and improved wound healing, combustion enhancement, and carbon storage.

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 ultra-cold (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 be translated 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 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* – Research directed at exploring the behavior of matter at extreme conditions of temperature, density, and pressure, including laboratory astrophysics and planetary science, structure and dynamic of matter at the atomic scale, laser-plasma interactions and relativistic optics, magneto hydrodynamics (MHD) and magnetized plasmas, and plasma atomic physics and radiation transport.

- *Exploratory Magnetized Plasma* – Basic and applied research directed at developing the understanding of laboratory 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 stewards world-class, laboratory-based plasma science experiments and user facilities at small and intermediate scales. These platforms not only facilitate addressing frontier plasma science questions but also provide critical data for the verification and validation of plasma science codes. This effort maintains strong partnerships with the NSF and NNSA.

<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 FESAC.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
Plasma Science Frontiers $46,504,000	**$23,600,000**	**-$22,904,000**
General Plasma Science ($14,196,000) Research continued 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 was enhanced.	*General Plasma Science ($12,750,000)* Core research areas of this activity will continue with a program focus on intermediate-scale, plasma science user facilities, as well as research in areas identified in the 2015 Frontiers of Plasma Science Workshops Report.	*-$1,446,000* Research and operations on intermediate-scale user facilities will be emphasized to pursue opportunities identified in the 2015 community workshops.
High Energy Density Laboratory Plasmas ($21,495,000) Research emphasized utilizing the Matter in Extreme Conditions (MEC) instrument at the LCLS 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 was 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.	*High Energy Density Laboratory Plasmas ($6,850,000)* Research will emphasize utilizing the MEC at LCLS, including continued support for the MEC beam-line science team and the experimental and theoretical HEDP research groups at SLAC.	*-$14,645,000* Support will be focused on research and operations for the MEC.
Exploratory Magnetized Plasma ($10,813,000) This portfolio was evaluated through a competitive peer-review process.	*Exploratory Magnetized Plasma ($4,000,000)* Research efforts will focus on discovery at the frontier of laboratory magnetized-plasma physics, emphasizing research in areas identified in the 2015 community workshops.	*-$6,813,000* Research and operations on intermediate-scale user facilities will be emphasized to pursue opportunities identified in the 2015 community workshops.

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
Measurement Innovation $3,568,000	**$900,000**	**-$2,668,000**
Core research elements of the Measurement Innovation activity continued 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 identified in the 2015 community workshops.	Funding will support activities initiated through the FY 2017 measurement innovation solicitation.
SBIR/STTR & Other $15,218,000	**$9,517,000**	**-$5,701,000**
Funding continued 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 2018.	Funding supports SBIR/STTR and other activities.

Fusion Energy Sciences
Construction

Description

The ITER facility, currently under construction in St. Paul-lez-Durance, France, aims to provide access to burning plasmas with fusion power output approaching reactor levels of hundreds of megawatts, for hundreds of seconds. Construction of ITER is a collaboration among the United States, European Union, Russia, Japan, India, South Korea, and China, governed by an international agreement (the "ITER Joint Implementing Agreement"), through which the U.S. contributes in-kind-hardware components, personnel, and direct monetary funding to the ITER Organization (IO).

Fusion Energy Sciences
Construction

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
U.S. Contributions to ITER Project $115,000,000 Funding supported 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.	**$63,000,000** Funding is provided for ITER.	**-$52,000,000** Funding is reduced for the ITER project. No funding is provided for the annual IO monetary contribution for FY 2018.

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.

	FY 2016	FY 2017	FY 2018
Performance Goal (Measure)	**FES Facility Based Experiments - Experiments conducted on major fusion facilities [DIII-D National Fusion Facility (DIII-D) and National Spherical Torus Experiment Upgrade (NSTX)-U] leading toward predictive capability for burning plasmas and configuration optimization**		
Target	Conduct research to detect and minimize the consequences of disruptions in present and future tokamaks. 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 preexisting 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. 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.	Conduct research to test predictive models of fast ion transport by multiple Alfvén eigenmodes. Fusion alphas and injected energetic neutral particle beams provide an important source of heating and current drive in advanced tokamak operating scenarios and burning plasma regimes. Alfvén eigenmode instabilities can cause the redistribution or loss of fast ions and driven currents, as well as potentially decreasing fusion performance and leading to localized losses. Measured fast ion fluxes in DIII-D and NSTX-U plasmas with different levels of Alfvén eigenmode activity will be used to determine the threshold for significant fast ion transport, assess mechanisms and models for such transport, and quantify the impact on beam power deposition and current drive. Measurements will be compared with theoretical predictions, including quantitative fluctuation data and fast ion density, in order to validate models and improve understanding of underlying mechanisms. Model predictions will guide the development of attractive operating regimes.
Result	Met	TBD	TBD
Endpoint Target	Magnetic fields are the principal means of confining the hot ionized gas of a plasma long enough to make practical fusion energy. The detailed shape of these magnetic containers leads to many variations in how the plasma pressure is sustained within the magnetic bottle and the degree of control that experimenters can exercise over the plasma stability. These factors, in turn, influence the functional and economic credibility of		

	the eventual realization of a fusion power reactor. The key to their success is a detailed physics understanding of the confinement characteristics of the plasmas in these magnetic configurations. The major fusion facilities can produce plasmas that provide a wide range of magnetic fields, plasma currents, and plasma shapes. By using a variety of plasma control tools, appropriate materials, and having the diagnostics needed to measure critical physics parameters, scientists will be able to develop optimum scenarios for achieving high performance plasmas in future burning plasma devices and, ultimately, in power plants.		
Performance Goal (Measure)	**FES Facility Operations - Average achieved operation time of FES user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 90 %	≥ 90 %	≥ 90 %
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. 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	Predicting the magnitude and scaling of the divertor heat load width in magnetically confined burning plasmas is a high priority for the fusion program. 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 DIIID, 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, 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.	The interaction of the boundary plasma with the material surfaces in magnetically confined plasmas is among the most critical problems in fusion energy science. In FY 2018, perform high-performance computational simulations with coupled boundary plasma physics and materials surface models to predict the fuel recycling and tritium retention of the divertor for deuterium-tritium burning plasma conditions, accounting for erosion, re-deposition and impurity transport in the plasma boundary, and an initial evaluation of the influence of material deposition on the recycling and retention.
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 Office of Science high performance computing resources and associated advances in computational science. These simulations are able to address the multiphysics and multiscale 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 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Capital Operating Expenses Summary						
Capital equipment	n/a	n/a	7,566	-		-7,566
General plant projects (GPP)	n/a	n/a	5,521	-	0	-5,521
Accelerator Improvement Projects (AIP) (<$5M)				-		
Total, Capital Operating Expenses	**n/a**	**n/a**	**13,087**	**-**	**0**	**-13,087**
Capital Equipment						
Major items of equipment[b]						
National Spherical Torus Experiment Upgrade (TPC $94,300)	83,665	80,195	0	-	0	0
Total MIEs	**n/a**	**80,195**	**0**	**-**	**0**	**0**
Total Non-MIE Capital Equipment	n/a	n/a	7,566	-		
Total, Capital equipment	**n/a**	**n/a**	**7,566**	**-**		
General Plant Projects[c]						
General Plant Projects under $2 million TEC	n/a	n/a	5,521	-		

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.
[b] Each MIE located at a DOE facility Total Estimated Cost (TEC) >$5M and each MIE not located at a DOE facility TEC > $2M.
[c] Each Plant Project (GPP/GPE) Total Estimated Cost (TEC) > $5M

Fusion Energy Sciences
Construction Projects Summary ($K)

	Total	Prior Years	FY 2016 Enacted	FY 2017 Enacted	FY 2018 Request	FY 2018 vs FY 2016
14-SC-60, U.S. Contributions to ITER Project						
Total Estimated Cost (TEC)	TBD	947,905	115,000	50,000	63,000	-52,000
Other Project Cost (OPC)	TBD	74,980	0		0	0
Total, Project Cost (TPC), 14-SC-60	**TBD**	**1,022,885**	**115,000**	**50,000**	**63,000**	**-52,000**

Fusion Energy Sciences
Funding Summary ($K)

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Research	218,978	-	166,340	-52,638
Scientific user facility operations	98,147	-	80,600	-17,547
Major items of equipment	0	-	0	0
Other (GPP, GPE, and infrastructure)	5,875	-	0	-5,875
Construction	115,000	-	63,000	-52,000
Total, Fusion Energy Sciences	**438,000**	**437,167**	**309,940**	**-128,060**

[a]FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

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 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
TYPE A FACILITIES				
DIII-D National Fusion Facility	**$79,407**	**-**	**$83,000**	**+$3,593**
Number of Users	618	-	650	+32
Achieved operating hours	691	-	N/A	
Planned operating hours	600	-	720	+120
Optimal hours	1,000	-	720	-280
Percent optimal hours	69.1%	-	100%	+31%
Unscheduled downtime hours	0	-	N/A	N/A

[a]FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Alcator C-Mod	**$18,049**	**-**	**0**	**-$18,049**
Number of Users	140	-	0	0
Achieved operating hours	N/A	-	N/A	N/A
Planned operating hours	160	-	0	0
Optimal hours	800	-	0	0
Percent optimal hours	20%	-	0	0
Unscheduled downtime hours	N/A	-	N/A	N/A
National Spherical Torus Experiment-Upgrade	**$72,568**	**-**	**$55,600**	**-$16,968**
Number of Users	362	-	297	-65
Achieved operating hours	402	-	N/A	N/A
Planned operating hours	720	-	0	-720
Optimal hours	1,000	-	0	-1,000
Percent optimal hours	40%	-	N/A	-40%
Unscheduled downtime hours	318	-	N/A	N/A
Total Facilities	**$170,024**	**-**	**138,600**	**-$31,424**
Number of Users	1,206	-	970	+8
Achieved operating hours	1,650	-	N/A	N/A
Planned operating hours	1,480	-	720	-760
Optimal hours	2,800	-	720	-1,800
Percent of optimal hours[b]	55.9%	-	100%	+44.1%
Unscheduled downtime hours	318	-	N/A	N/A

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

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

Scientific Employment

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Number of permanent Ph.D.'s (FTEs)	767	-	510	-253
Number of postdoctoral associates (FTEs)	98	-	65	-33
Number of graduate students (FTEs)	293	-	160	-133
Other[b]	1,025	-	785	-240

[a] FY 2017 amounts shown reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.
[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 2017 CPDS and does not include a new start for FY 2018. The DOE Order 413.3B approved Critical Decision (CD) CD-1, "Approve Alternative Selection and Cost Range" was approved on January 25, 2008 with a preliminary cost range of $1.45–$2.2 billion. Since 2008, the estimated cost range for the project increased such that the upper bound of the approved CD-1 cost range increased by more than 50% triggering the need for a reassessment of the project cost range and re-approval by the Project Management Executive (PME). The Project Management Executive for the U.S. ITER project is the Deputy Secretary of Energy. The cost range reassessment was completed in November 2016 and it was then subsequently approved by the PME in January 13, 2017. The CD-1 Revised cost range is now $4.7B to $6.5B.

DOE has divided the U.S. ITER project hardware scope into two distinct subprojects, which represent the two phases of the project: subproject 1 is the hardware scope leading to First Plasma (FP), and subproject 2 is hardware for the post-First Plasma project. This CPDS focuses only on the FP subproject activities. A review of CD-2, "Approve Performance Baseline" for the First Plasma subproject was completed in November 2016 and then subsequently approved by the PME on January 13, 2017, with a total project cost of $2.5B, with a CD-4, "Project Completion" date of December 2027.

The FP subproject scope consists of: 1) completing the design for all twelve subsystems the U.S. was contributing to ITER; 2) complete fabrication and delivery of the Toroidial Field (TF) coil superconductor, Steady State Electrical Network (SSEN), and the Central Solenoid (CS) superconducting magnet modules and associated structures; and 3) partial fabrication and delivery of seven other subsystems: Tokamak Cooling Water, Roughing Pumps, Vacuum Auxillary, Pellet Injection, Ion Cyclotron Heating, Electron Cyclotron Heating, Diagnostics.

Summary

ITER is a major fusion research facility being constructed in St. Paul-lez-Durance, 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 (U.S. ITER) project is not classified as a Capital Asset project, but is classified as a Major System Project. The U.S. ITER project is a U.S. Department of Energy project to provide the U.S. share of the ITER project (in-kind hardware i.e., subsystems, equipment, and components, as well as monetary resources to support the ITER Organization (IO) in France). Sections of this CPDS have been tailored accordingly to reflect the nature of this project.

The U.S. ITER 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 Line-Item beginning in FY 2014. 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. Progress and performance are reported regularly in monthly performance metrics and project status reports.

As of the end of September, 2017, the U.S. ITER FP project is more than 50% complete; design of hardware needed for FP technical systems is 86% complete; and 19% of the hardware deliveries are complete. Active fabrication is underway in five of the U.S. twelve hardware systems (TCWS, Steady State Electric Network [SSEN] Components, Toroidal Field [TF] Conductor and CS Magnets and Vacuum Auxiliary Systems [VAS]). The U.S. has also procured 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 were completed in FY 2017. Fabrication of the TF coil superconductor was also competed in FY 2017. The U.S. ITER project has subcontracted with General Atomics (GA) for the fabrication of the world's largest pulsed superconducting magnets for the ITER CS magnet system. In FY 2017, commissioning was completed for all of the eleven work stations in the CS magnet module fabrication facility for the fabrication of the seven (six production and one spare) magnet modules the U.S. is responsible for delivering to the international ITER project. The U.S. completed fabrication of a mockup (non-superconducting) copper coil which was to provide assurance of all the CS manufacturing processes. Also, GA completed the winding of the first two magnet modules in FY 2017. By the end of CY 2017, five of seven modules will be in fabrication. To date the U.S. ITER project has awarded and obligated over $860 million to U.S. industry, universities, and DOE laboratories.

FY 2018 funding will support ITER Project Office operations including project management. Additional planning will follow discussions with Congress and ITER partners.

The U.S ITER Federal Project Director with certification level 3 has been assigned to this Project and has approved this CPDS.

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

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

[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 AT, 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 (12/02/2015).
[l] Roughing Pumps (03/2017); VAS 03 Supply (06/2017); Roughing Pumps I&C (06/2017); VAS 03 Supply I&C (04/2017); CS AT Bus Bar Alignment and Coaxial Heater (04/2017); VAS Main Piping L3/L4 (03/2017); VAS 02 CGVS (&C Part 1 (06/2017).

	CD-1 Cost Range Update	CD-2/3		CD-4	
		SP-1	SP-2	SP-1	SP-2
FY 2018[a] 7/5/2005	1/13/17	1/13/17	2019	1Q2027	2034-2038

3. Project Cost History

At the time of CD-1 approval in January 2008, the preliminary cost range for the total U.S. ITER project was $1.45–$2.2 billion. Until recently, however, it has not been possible to confidently baseline the project due to past 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. In response to a 2013 Congressional request, a DOE Office of Science IPR Committee assessed the project and determined that the existing cost range estimate of $4.0 to $6.5B would likely encompass the final TPC. This range, recommended in 2013, was included in subsequent Budget Requests and in the May 2016 DOE "Report on the Continued U.S. Participation in the ITER Project" to Congress. Following briefings and discussions with the Secretary's Project Management Risk Committee, the Undersecretary for Science and Energy, and the Director of the Office of Science, in preparation for baselining FP, a decision was made to update the lower end of this range to reflect updated cost estimates resulting in the current approved CD-1R range of $4.7 to 6.5B. This updated CD-1R range incorporates increases in the projects hardware estimate that have occurred since August 2013. The First Plasma subproject TPC has been baselined at $2.5B.

4. Project Scope and Justification

Scope
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 U.S. ITER 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.

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.

[a] VAS 02 Supply Part 1 (05/2018); ICH RF Building and I&C (11/2017); TCWS Captive Piping and First Plasma (10/2017); ICH RF components supporting INDA/IO testing (01/2018).

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	107,635	107,669	110,074
FY 2014[c]	161,605	161,605	153,368
FY 2015	128,682	128,682	105,908
FY 2016[d]	115,000	115,000	102,561
FY 2017	50,000	50,000	158,942
FY 2018	63,000	63,000	73,000
Subtotal	1,025,747	1,025,747	1,014,248
Total, Hardware	TBD	TBD	TBD
Cash Contributions[e]			
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[f]	0	0	0
FY 2017	0	0	0
FY 2018	0	0	0
Subtotal	144,497	144,497	144,497
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

[a] Costs through FY 2016 reflect actual costs; costs for FY 2017 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 2017 Hardware funding amount.
[e] Includes cash payments, secondees, taxes and tax support.
[f] No FY 2016 funding is provided to support the ITER organization.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
FY 2011	13,000	13,000	10,032
FY 2012[a]	345	345	22,336
FY 2013	2,560	2,560	5,984
FY 2014[b]	5,000	5,000	2,717
FY 2015	5,361	5,361	5,500
FY 2016	0	0	3,958
FY 2017	0	0	1,058
FY 2018	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	124,000	124,034	129,863
FY 2014[b]	199,500	199,500	188,980
FY 2015	150,000	150,000	127,365
FY 2016	115,000	115,000	106,519
FY 2017	50,000	50,000	160,000
FY 2018	63,000	63,000	73,000
Subtotal	1,250,885	1,250,885	1,239,386
Total, TPC	TBD	TBD	TBD

6. Details of the 2018 Project Cost Estimate

An Independent Project Review of U.S. ITER was conducted on November 14-17, 2016, to consider the project's readiness for CD-2 (Performance Baseline) and CD-3 (Begin / Continue Fabrication) for FP as well as the proposed updated CD-1 Cost Range. Outcomes from the IPR indicated that the project was ready for approval of FP CD-2/3 following a reassessment of contingency to account for risk in the areas of escalation and currency exchange. This recommendation has been addressed.

7. Schedule of Appropriation Requests

		Prior Years	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	Outyears	Total
FY 2006	TEC	1,009,000	29,000	0	0	0	0	0	0	1,038,000
	OPC	80,600	3,400	0	0	0	0	0	0	84,000
	TPC	1,089,600	32,400	0	0	0	0	0	0	1,122,000
FT 2007	TEC	930,151	116,900	30,000	0	0	0	0	0	1,077,051
	OPC	44,949	0	0	0	0	0	0	0	44,949
	TPC	975,100	116,900	30,000	0	0	0	0	0	1,122,000

[a] 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.

		Prior Years	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	Outyears	Total
FY 2008	TEC	931,330	116,900	30,000	0	0	0	0	0	1,078,230
	OPC	43,770	0	0	0	0	0	0	0	43,770
	TPC	975,100	116,900	30,000	0	0	0	0	0	1,122,000
FY 2009[a]	TEC	266,366	0	0	0	TBD	TBD	TBD	TBD	TBD
	OPC	38,075	0	0	0	TBD	TBD	TBD	TBD	TBD
	TPC	304,441	0	0	0	TBD	TBD	TBD	TBD	TBD
FY 2010	TEC	294,366	0	0	0	TBD	TBD	TBD	TBD	TBD
	OPC	70,019	0	0	0	TBD	TBD	TBD	TBD	TBD
	TPC	364,385	0	0	0	TBD	TBD	TBD	TBD	TBD
FY 2011	TEC	379,366	0	0	0	TBD	TBD	TBD	TBD	TBD
	OPC	65,019	0	0	0	TBD	TBD	TBD	TBD	TBD
	TPC	444,385	0	0	0	TBD	TBD	TBD	TBD	TBD
FY 2012[b]	TEC	394,566	0	0	0	TBD	TBD	TBD	TBD	TBD
	OPC	75,019	0	0	0	TBD	TBD	TBD	TBD	TBD
	TPC	469,585	0	0	0	TBD	TBD	TBD	TBD	TBD
FY 2013[c]	TEC	476,296	140,965	0	0	TBD	TBD	TBD	TBD	TBD
	OPC	73,089	9,035	0	0	TBD	TBD	TBD	TBD	TBD
	TPC	549,385	150,000	0	0	TBD	TBD	TBD	TBD	TBD
FY 2014[d]	TEC	476,296	105,572	225,000	0	TBD	TBD	TBD	TBD	TBD
	OPC	73,089	70	0	0	TBD	TBD	TBD	TBD	TBD
	TPC	549,385	105,642	225,000	0	TBD	TBD	TBD	TBD	TBD
FY 2015	TEC	481,940	121,465	194,500	144,639	TBD	TBD	TBD	TBD	TBD
	OPC	67,445	2,535	5,000	5,361	TBD	TBD	TBD	TBD	TBD
	TPC	549,385	124,000	199,500	150,000	TBD	TBD	TBD	TBD	TBD
FY 2016	TEC	481,940	121,465	194,500	144,639	150,000	TBD	TBD	TBD	TBD
	OPC	67,445	2,535	5,000	5,361	0	TBD	TBD	TBD	TBD
	TPC	549,385	124,000	199,500	150,000	150,000	TBD	TBD	TBD	TBD
FY 2017[a]	TEC	481,940	121,499	194,500	144,639	115,000	125,000	TBD	TBD	TBD
	OPC	67,445	2,535	5,000	5,361	0	0	TBD	TBD	TBD
	TPC	549,385	124,034	199,500	150,000	115,000	125,000	TBD	TBD	TBD
FY 2018	TEC	481,665	121,440	194,500	144,639	115,000	50,000	63,000	TBD	TBD
	OPC	67,720	2,560	5,000	5,361	0	0	0	TBD	TBD
	TPC	549,385	124,000	199,500	150,000	115,000	50,000	63,000	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 2012.
[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.
[d] Prior to FY 2015, the requests were for a major item of equipment broken out by TEC, OPC, and TPC.