Fusion Energy Sciences

Overview

The mission of the Fusion Energy Sciences (FES) program is to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific 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.

Plasma science is wide-ranging, with various types comprising 99% of the visible universe. It is the state of matter in the sun's center, corona, and solar flares. Plasma dynamics are at the heart of the formation of galactic jets and accretion of stellar material around black holes. On Earth it is the substance of lightning and flames. Plasma physics describes the processes giving rise to the aurora that illuminates the far northern and southern nighttime skies. Practical applications of plasmas are found in various forms of lighting and semiconductor manufacturing. High-temperature fusion plasmas at hundreds of millions of degrees occur in national security applications, albeit for very short times. The same fusion plasmas may be exploited in the laboratory in a controlled fashion to become the basis for a future clean nuclear power source, which could provide domestic energy independence and security. This is a large driver for the FES subprograms focused on the scientific study of "burning plasma." In the burning plasma state of matter, the nuclear fusion process itself provides the dominant heat source for sustaining the plasma temperature. Such a self-heated plasma can continue to undergo fusion reactions that produce energy, without requiring the input of heating power from the outside, and thus resulting in a large net energy yield.

In the FES program, foundational science for burning plasmas is obtained by investigating the behavior of laboratory fusion plasmas confined with strong magnetic fields. The DIII-D National Fusion Facility and the National Spherical Torus Experiment-Upgrade (NSTX-U), the latter of which is currently down for recovery and repair, are world-leading Office of Science (SC) user facilities for experimental research available to and used by scientists from national laboratories, universities, and industry research groups.

Complementing these experimental activities is a significant effort in fusion theory and simulation to predict and interpret the complex behavior of plasmas as self-organized systems. As part of this effort, FES supports several Scientific Discovery through Advanced Computing (SciDAC) centers, in partnership with the Advanced Scientific Computing Research (ASCR) program office. The FES program also investigates the behavior of plasmas that are confined near steady state. U.S. scientists take advantage of international partnerships to conduct research on superconducting tokamaks and stellarators with long-duration capabilities. In addition, the development of novel materials, a research area of high interest to many scientific fields, is especially important for fusion energy sciences since fusion plasmas create an environment of high-energy neutrons and huge heat fluxes that impinge on and damage the material structures containing the plasmas.

The frontier scientific area of the actual creation of strongly self-heated fusion burning plasmas, which will be enabled by the ITER facility, will allow the discovery and study of new scientific phenomena relevant to fusion as a future energy source.

The FES program also supports discovery plasma science in research areas such as plasma astrophysics, high-energy-density laboratory plasmas (HEDLP), and low-temperature plasmas. Some of this research is carried out through partnerships with the National Science Foundation (NSF) and the National Nuclear Security Administration (NNSA). Also, U.S. scientists are world leaders in the invention and development of new high-resolution plasma measurement techniques. Advances in plasma science have led to many spinoff applications and enabling technologies with considerable economic and societal impact for the American quality of life.

The FES program addresses several of the Administration's research and development (R&D) budget priorities[a]. Research in fusion has the potential to contribute to American energy dominance by making available to the American people a clean energy technology that relies on widely available and virtually inexhaustible fuel sources. Research in plasma science, within and beyond fusion, will contribute to American prosperity through the tremendous potential for spinoff applications (described in a 2015 report by the Fusion Energy Sciences Advisory Committee [FESAC][b]) as well as targeted investments

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[a] https://www.whitehouse.gov/wp-content/uploads/2018/07/M-18-22.pdf
[b] https://science.energy.gov/~/media/fes/fesac/pdf/2015/2101507/FINAL_FES_NonFusionAppReport_090215.pdf

(e.g., in early-stage low temperature plasma research) that can lead to the development of transformative technologies. Investments in our major fusion facilities and smaller-scale experiments will help maintain and modernize our research infrastructure for continuing to conduct world-leading research. Established partnerships within and outside DOE maximize leverage and increase the cost effectiveness of FES research activities. Also, FES partnerships with industry will propagate scientific discoveries that could transition into the private sector. Investments in transformational technologies such as machine learning, quantum information science (QIS), microelectronics, and high-performance strategic computing could accelerate progress in several mission areas. Finally, the unique scientific challenges and rigor of fusion and plasma physics research lead to the development of a well-trained STEM workforce, which will contribute to maintaining and advancing U.S. competitiveness and world-leadership in key areas of future technological and economic importance, as well as national security.

Highlights of the FY 2020 Request

The FY 2020 Request is $402,750,000. Strategic choices in this Request are informed by the priorities described in "The Office of Science's Fusion Energy Sciences Program: A Ten-Year Perspective,"[a] the research opportunities identified in a series of community engagement workshops held in 2015[b], and the FY 2017 FESAC report on the potential for transformative developments in fusion science and technology[c]. Priorities include keeping SC fusion user facilities world-leading, investing in high-performance computing and preparing for exascale, exploring the potential of QIS and machine learning, 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, continuing stewardship of discovery plasma science (e.g., via intermediate-scale facilities), and initiating private-public partnerships. Furthermore, research priorities for burning plasma science in FY 2020 will be informed by the 2018 report[d] of the National Academies of Sciences, Engineering, and Medicine burning plasma study commissioned by FES.

Key elements in the FY 2020 Request include:

<u>Research</u>

- *DIII-D research* – DIII-D research will utilize the facility enhancements implemented during the FY 2018–2019 Long Torus Opening. Research goals will aim at resolving predictive burning plasma physics, validation of impurity transport models, and integration of core and edge plasma solutions.
- *NSTX-U research* – The NSTX-U research budget will fund a focused effort on physics topics that directly support the recovery of robust NSTX-U plasma operations, as well as collaborative research at other facilities to support NSTX-U research program priorities.
- *Partnerships with private fusion efforts* – Private-public collaborations will leverage opportunities in critical fusion research areas (e.g., diagnostics, theory and simulation, materials science, and magnet technology).
- *Enabling technology and discovery plasma science* – Research on high-temperature superconductors, additive manufacturing, low-temperature plasmas (relevant to microelectronics), and high-energy-density plasmas lead to connections with and spinoffs for U.S. industry.
- *Scientific Discovery through Advanced Computing* – SciDAC projects will address high-priority research on tokamak disruptions and large-scale fusion data analysis challenges, including machine learning and QIS, and also continue development of an integrated whole-device modeling capability, in partnership with the ASCR program.
- *Long-pulse tokamak and stellarator research* – Long-pulse tokamak research enables U.S. scientists to work on superconducting tokamaks with world-leading capabilities. In addition, there will be research opportunities for U.S. collaborations in the deuterium–tritium (DT) experimental campaign on the Joint European Torus (JET). Long-pulse stellarator research will allow U.S. teams to take full advantage of U.S. hardware investments on Wendelstein 7-X (W7-X) and enhance the scientific output on this device.
- *Fusion nuclear science* – FES will continue to evaluate options for a neutron source that will test materials in fusion-relevant environments.

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[a] https://science.energy.gov/~/media/fes/pdf/workshop-reports/2016/FES_A_Ten-Year_Perspective_2015-2025.pdf
[b] https://science.energy.gov/fes/community-resources/workshop-reports/
[c] https://science.energy.gov/~/media/fes/fesac/pdf/2018/TEC_Report_15Feb2018.pdf
[d] https://www.nap.edu/catalog/25331/final-report-of-the-committee-on-a-strategic-plan-for-us-burning-plasma-research

- *Discovery plasma science* – Basic plasma research is partially carried out in partnership with NSF and NNSA. Research and operations will focus on the intermediate-scale plasma science facilities and on HEDLP research on the Matter in Extreme Conditions (MEC) instrument, an end station on the Linac Coherent Light Source (LCLS) facility at SLAC National Accelerator Laboratory (SLAC), stewarded by the SC Basic Energy Sciences (BES) program, and on LaserNetUS, a new national consortium of laser facilities for enhanced user access.

Facility Operations

- *DIII-D operations* – The funding will allow 13 weeks of facility operations, along with machine and infrastructure refurbishments and improvements needed for new research capabilities.
- *NSTX-U recovery activities* – The NSTX-U facility is down for recovery and repair, which will continue through FY 2020. The NSTX-U Operations budget will support high-priority activities to implement repairs and corrective actions required to achieve research operations, as well as to increase machine reliability.
- *Major Item of Equipment (MIE) project for world-leading fusion materials research* – The Materials Plasma Exposure eXperiment (MPEX) MIE project will be a world-leading facility for steady-state, high-heat-flux testing of fusion materials and will be a great resource for advancing the FES strategic priority in materials research. The project is expected to be baselined in FY 2020. The FY 2020 funding will maintain the required detailed design and R&D activities and allow for initiation of long-lead major procurements for the device.

Projects

- *Continued U.S. hardware development and delivery to ITER* – The FY 2020 Request will support the continued design and fabrication of the highest-priority "in-kind" hardware systems. This includes continued fabrication of the Central Solenoid magnet system, which consists of seven superconducting modules, structural components, and assembly tooling. The U.S. will deliver the first Central Solenoid magnet module to the ITER site and also continue design and fabrication efforts for other hardware systems.
- *High energy density laboratory plasmas* – FES will initiate a line-item construction project for a significant upgrade to the MEC instrument on the LCLS facility at SLAC.

Other

- *GPP/GPE* – Funding is provided for General Plant Projects/General Purpose Equipment, to support Princeton Plasma Physics Laboratory (PPPL) infrastructure improvements and repairs as well as support a study of FES infrastructure needs at Oak Ridge National Laboratory (ORNL).

FES supports the following FY 2020 Administration Priorities.

FY 2020 Administration Priorities

(dollars in thousands)

	Artificial Intelligence (AI)	**Quantum Information Science (QIS)**
Fusion Energy Sciences	7,000	7,520

Fusion Energy Sciences
Funding

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Burning Plasma Science: Foundations				
Advanced Tokamak	121,115	130,500	88,500	-42,000
Spherical Tokamak	93,550	96,000	67,500	-28,500
Theory & Simulation	50,000	50,000	44,000	-6,000
GPE/GPP/Infrastructure	13,000	10,204	1,000	-9,204
Total, Burning Plasma Science: Foundations	**277,665**	**286,704**	**201,000**	**-85,704**
Burning Plasma Science: Long Pulse				
Long Pulse: Tokamak	15,000	14,000	9,000	-5,000
Long Pulse: Stellarators	10,069	8,500	8,500	—
Materials & Fusion Nuclear Science	27,177	38,746	32,500	-6,246
Total, Burning Plasma Science: Long Pulse	**52,246**	**61,246**	**50,000**	**-11,246**
Discovery Plasma Science				
Plasma Science Frontiers	54,000	52,050	25,000	-27,050
Measurement Innovation	7,000	8,000	4,000	-4,000
SBIR/STTR & Other	19,200	24,000	14,750	-9,250
Total, Discovery Plasma Science	**80,200**	**84,050**	**43,750**	**-40,300**
Subtotal, Fusion Energy Sciences	**410,111**	**432,000**	**294,750**	**-137,250**
Construction				
20-SC-61 Matter in Extreme Conditions Petawatt Upgrade	—	—	1,000	+1,000
14-SC-60 U.S. Contributions to ITER	122,000	132,000	107,000	-25,000
Total, Construction	**122,000**	**132,000**	**108,000**	**-24,000**
Total, Fusion Energy Sciences	**532,111**	**564,000**	**402,750**	**-161,250**

SBIR/STTR Funding:

- FY 2018 Enacted: SBIR $11,598,000 and STTR $1,631,000
- FY 2019 Enacted: SBIR $12,992,000 and STTR $1,827,000
- FY 2020 Request: SBIR $8,899,000 and STTR $1,252,000

Fusion Energy Sciences
Explanation of Major Changes

	(dollars in thousands) FY 2020 Request vs FY 2019 Enacted
Burning Plasma Science: Foundations The Request for DIII-D prioritizes funding to ensure scientific utilization of the significant facility enhancements implemented during the FY 2018–FY 2019 Long Torus Opening, with 13 weeks of research operation. Funding for the NSTX-U program will support the ongoing recovery activities and maintain collaborative research at other facilities to support NSTX-U research program priorities. SciDAC continues to make progress toward whole-device modeling; this subprogram will also explore the potential of transformative approaches to fusion science, such as machine learning and QIS. Enabling R&D will focus attention on high-temperature superconductor development. Funding is provided for General Plant Projects/General Purpose Equipment (GPP/GPE), to support critical infrastructure improvements and repairs at PPPL, as well as a study of FES infrastructure needs at ORNL.	**-85,704**
Burning Plasma Science: Long Pulse The Request will continue to provide support for high-priority international collaboration activities, both for tokamaks and stellarators. Materials research and fusion nuclear science research programs are focused on high priorities, such as advanced plasma-facing and structural materials. The Request supports design and R&D activities for the MPEX MIE project, expected to be baselined in FY 2020, and initiates long-lead major procurements.	**-11,246**
Discovery Plasma Science For General Plasma Science, the Request emphasizes research and operations of intermediate-scale scientific user facilities and participation in the NSF-DOE Partnership. For High Energy Density Laboratory Plasmas, the focus remains on supporting research utilizing the Matter in Extreme Conditions instrument of the LCLS user facility at SLAC, supporting research on medium-scale laser facilities through the new LaserNetUS network, and exploring research opportunities of QIS.	**-40,300**
Construction FES will initiate a line-item construction project for a significant upgrade to the MEC instrument. The U.S. Contributions to ITER project will continue design, fabrication, and delivery of highest-priority First Plasma hardware.	**-24,000**
Total, Fusion Energy Sciences	**-161,250**

Basic and Applied R&D Coordination
FES participates in coordinated intra- and inter-agency initiatives within DOE and with other federal agencies on science and technology issues related to fusion and plasma science. Within SC, FES operates the MEC instrument at the SLAC LCLS user facility operated by BES, and supports high-performance computing research with ASCR. Within DOE, FES operates a joint program with NNSA in HEDLP physics. FESAC provides technical and programmatic advice to FES and NNSA for the joint HEDLP program. Outside DOE, FES carries out a discovery-driven plasma science research program in partnership with 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. The joint programs with NNSA and NSF involve coordination of solicitations, peer reviews, and workshops.

Program Accomplishments
Doubled efficiency of sustaining plasma pressure in spherical tokamaks. Spherical tokamaks are able to support high plasma pressures, relative to the pressure of the applied confining magnetic field. Recent experiments on the Pegasus spherical tokamak at the University of Wisconsin-Madison were able to achieve a 100% value for the beta parameter (the ratio of plasma pressure to applied magnetic pressure); the previous record for achieved beta was ~35%. Beta is an important metric in fusion science, since fusion power output increases quadratically as the value for beta goes up. The beta value represents the efficiency with which the applied magnetic field in any fusion system is utilized.

Addressing the transients challenge for tokamak fusion. DIII-D has made significant advances in the mitigation and avoidance of large-scale transient events ("disruptions") that can abruptly terminate a fusion plasma. This includes testing a new shell-pellet concept that uses a thin-walled, hollow, pea-sized diamond “pellet” filled with metallic dust to suppress the high-energy runaway electrons that are often generated during a disruption and that can damage the vacuum vessel. The experiments showed successful delivery of the dust into the current channel formed by these runaway electrons. Computer algorithms informed by modern machine-learning techniques are being developed to provide supervisory logic for comprehensive disruption avoidance and machine protection.

Massively parallel supercomputer simulations shed light on the behavior of magnetic islands. Magnetic islands, which are bubble-like structures that form in magnetically confined fusion plasmas, can grow and lead to plasma disruptions, which are among the critical challenges confronting future fusion reactors. Simulation research supported by the Scientific Discovery through Advanced Computing (SciDAC) program and carried out on the Cori supercomputer at the National Energy Research Scientific Computing Center (NERSC) showed that—contrary to long-held assumptions—the plasma profile inside the island can maintain a radial structure and the plasma flow can be strongly sheared, which is known to have a beneficial effect on plasma transport. These findings will improve the ability to predict and avoid the onset of the deleterious plasma disruptions.

Optimal magnetic fields stabilize dangerous instabilities in tokamak plasmas. Researchers have succeeded in developing a breakthrough predictive method for improving the operation of tokamaks using magnetic fields. In tokamaks, magnetic field perturbations are often used to avoid undesirable plasma instabilities; however, other unwanted side effects may occur, such as excessive leakage of heat. The research showed how to use plasma simulations and an efficient numerical method to identify the most effective fields, while keeping certain components of the field below critical thresholds. The modeling motivated experimental studies on the Korean superconducting tokamak KSTAR that validated the new methods, which are now being applied to ITER and future fusion facility designs.

U.S.-provided trim coils improve performance of Wendelstein 7-X stellarator. The recent second round of W7-X experiments demonstrated the ability of the five large copper magnetic trim coils and their sophisticated control system to measure and correct deviations of the magnetic fields from their designated configuration. Any deviation of these “error fields” can cause divertor plates to overheat and limit the performance of the plasma. Controlling such fields at the edge of the plasma enabled W7-X to produce plasma discharges lasting up to 30 seconds. Complementary experiments confirmed predictions about the power needed by the trim coils to correct the deviations—only 10% of the full power of the coils, which is a testament to the precision with which W7-X was constructed.

First-of-a-kind fusion materials irradiation experiment completed. The U.S. and Japan “PHENIX” collaboration has successfully completed an extensive, first-of-a-kind irradiation campaign to study the feasibility of tungsten-based plasma-facing materials for future fusion devices. This campaign utilized novel gadolinium shield technologies to achieve realistic displacement damage to transmutation ratios in the High Flux Isotope Reactor facility at ORNL. This was the first-ever exploration of fusion-relevant neutron damage in tungsten. The full disassembly of the irradiation experiment was completed on cost and schedule, and extensive post-irradiation examination has been initiated, after five years of experimentation. The information gleaned from this experiment is expected to provide lasting guidance for the international fusion materials community.

New discovery reveals how solar-wind electrons are heated in the Earth's magnetic shield. Analyses of observational data from the NASA Magnetospheric Multiscale spacecraft demonstrated that the solar-wind electron stream is accelerated, upon interacting with Earth's magnetic field, to such high speeds that the streaming breaks down and is transformed into heat. The discovery reveals a never-before-seen picture about how solar-wind electrons are heated when reaching Earth's magnetic shield. These ground-breaking results will stimulate further theories, simulations, and laboratory experiments to resolve a longstanding question about collisionless heating at shocks. The discovery has broad applicability to the understanding of shocks and particle acceleration in solar flares and supernovae, as well as to astrophysics in general.

Turning plastic into diamonds. Scientists at SLAC have successful produced the "diamond rain" that forms in the interior of icy giant planets. In these laboratory experiments, the environment inside these planets was recreated at the MEC instrument by the irradiation of plastic targets with a high-power optical laser. Nearly every carbon atom of the original plastic was incorporated into small diamond structures up to a few nanometers in size. This study predicts that on Uranus and Neptune, diamonds would become much larger, maybe millions of carats in weight.

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 tokamak 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 Princeton Plasma Physics Laboratory (PPPL) and other possible DOE laboratories where fusion research is ongoing.

Research in the Burning Plasma Science: Foundations area in FY 2020 will focus on high-priority scientific issues and opportunities in the areas of transients in tokamaks, plasma-material interactions, and whole-device modeling, as identified by research needs workshops and other community-led studies. It will also support new approaches with transformational potential to advance the FES mission, such as machine learning and QIS.

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. Its extensive set of diagnostic systems, many unique in the world, and its extraordinary flexibility to explore various operating regimes make it a world-leading tokamak research facility. 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 broad 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 energy-producing fusion reactors.

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. The Request will also allow for partnership opportunities with the private sector on enabling technology research issues.

Versatile university-led small-scale advanced tokamak research is complementary to the efforts at the major user facilities, providing cost-effective development of new techniques and exploration of new concepts. These activities are often the first step in a multi-stage approach toward the extension of the scientific basis for advanced tokamaks or the maturation of new experimental techniques. Recent efforts are focused on improving fusion plasma control physics for advanced tokamaks through application of modern digital tokamak control theory and validation of fundamental plasma stability theory.

Spherical Tokamak
The NSTX-U user facility at PPPL has been designed to explore the physics of plasmas confined in a spherical tokamak (ST) configuration, characterized by a compact (apple-like) shape. If the predicted ST energy confinement improvements are experimentally realized in NSTX-U, then the ST might provide a more compact fusion reactor than other plasma confinement geometries. In FY 2020, NSTX-U recovery activities will focus on the continued execution of facility repairs and corrective actions required to resume reliable plasma operations.

Small-scale ST plasma research involves focused experiments to provide data in regimes of relevance to the ST magnetic confinement program. These efforts can 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 also involves high-risk, but high-payoff, experimental efforts useful to advancing ST science.

Theory and Simulation

The Theory and Simulation activity is a key component of the FES program's strategy to develop the predictive capability needed for a sustainable fusion energy source. It also represents a world-leading U.S. strength and competitive advantage in fusion research. Its long-term goal is to enable a transformation in predictive power based on fundamental science and high-performance computing to minimize risk in future development steps and shorten the path toward the realization of fusion energy. This activity includes two main interrelated but distinct elements: Theory and SciDAC.

The Theory element is focused on advancing the scientific understanding of the fundamental physical processes governing the behavior of magnetically confined plasmas. The research ranges from foundational analytic theory to mid- and large-scale computational work with the use of high-performance computing resources. In addition to its scientific discovery mission, the Theory element provides the scientific grounding for the physics models implemented in the advanced simulation codes developed under the SciDAC activity described below and also supports validation efforts at major experiments.

The FES SciDAC element, a component of the SC-wide SciDAC program, is aimed at accelerating scientific discovery in fusion plasma science by capitalizing on SC investments in leadership-class computing systems and associated advances in computational science The portfolio that emerged from the FY 2017 SC-wide SciDAC-4 re-competition consists of eight multi-institutional interdisciplinary partnerships, seven of which are jointly supported by FES and ASCR while one is supported entirely by FES, and addresses the high-priority research directions identified in recent community workshops. A ninth project focused on the critical area of avoidance and mitigation of runaway electrons was added in FY 2018, following a competitive review. The new portfolio emphasizes increased integration and whole-device modeling, as well as synergy with the fusion-relevant projects of the SC Exascale Computing Project (SC-ECP) to increase the readiness of the fusion community for the upcoming Exascale era.

Additional objectives of this element include the support of emerging computational approaches, such as machine learning and other data-centric technologies, and the support of longer-term transformative research opportunities such as computing aspects of QIS, as identified in the 2018 FES Roundtable on QIS[a]. The Request will also allow for partnership opportunities with the private sector in theory and simulation research areas.

GPE/GPP/Infrastructure

This activity supports critical general infrastructure (e.g., utilities, roofs, roads, facilities, environmental monitoring, and equipment) at the PPPL site and other DOE laboratories where fusion research is ongoing.

[a] https://science.energy.gov/~/media/fes/pdf/workshop-reports/FES-QIS_report_final-2018-Sept14.pdf

Fusion Energy Sciences
Burning Plasma Science: Foundations

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Burning Plasma Science: Foundations	**$286,704,000**	**$201,000,000**	**-$85,704,000**
Advanced Tokamak	$130,500,000	$88,500,000	-$42,000,000
DIII-D Research	*$46,000,000*	*$40,500,000*	*-$5,500,000*
DIII-D Operations	*$75,500,000*	*$44,000,000*	*-$31,500,000*
The FY 2019 Enacted budget continues numerous enhancements/improvements to the DIII-D facility, to include the neutral beam modification to add bi-directional off-axis injection capability; and supports 12 weeks of operations. Research continues to determine the optimal path to steady-state tokamak plasmas, explore techniques to avoid and mitigate transients in tokamaks, and develop the plasma-material interaction boundary solutions necessary for future devices. Experiments exploit additional heating and current drive systems added in FY 2018. Researchers utilize the new neutral beam capability to examine the physics of self-driven tokamak plasmas. Specific research goals include further integration of the core and edge conditions in high-performance plasmas and studying the role of neutral fueling and transport in determining the edge pedestal structure.		At the Request level, operations funding will support 13 weeks of research at the DIII-D facility. Facility improvements to increase auxiliary heating power, current drive, and 3D magnetic field shaping capabilities will be supported. Research will utilize new heating and current drive systems to access steady-state tokamak plasma scenarios at high pressure and low rotation, further refine techniques to avoid and mitigate transients in tokamaks, and exploit new diagnostics to improve the understanding of divertor material erosion and transport. Specific research goals will aim at resolution of predictive burning plasma physics, validation of impurity transport models, and integration of core and edge plasma solutions that extrapolate to future fusion reactors.	Research efforts will focus on highest-priority science issues, including funding for key facility collaborators and off-site users. Operations will support critical machine improvements to maintain DIII-D world-leading status.
Enabling R&D	*$7,000,000*	*$3,000,000*	*-$4,000,000*
The FY 2019 Enacted budget continues research in superconducting magnet technology and plasma fueling and heating technologies required to enhance the performance for existing and future magnetic confinement fusion devices.		The Request supports continuing research in high-temperature superconducting magnet technology and in plasma fueling and heating technologies. The Request will allow for exploration of partnership opportunities with the private sector.	Research efforts will continue to emphasize high-priority R&D. Efforts will be made to enhance research into high-temperature superconducting magnet technology.

FY 2019 Enacted		FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Small-scale Experimental Research	*$2,000,000*	*$1,000,000*	*-$1,000,000*
The FY 2019 Enacted budget allows versatile university-led experiments to focus on improving fusion plasma control physics for advanced tokamaks.		At the Request level, university-led experiments will continue to develop innovative strategies to improve the performance of advanced tokamaks.	Highest-priority experimental research and model validation efforts will continue.
Spherical Tokamak	$96,000,000	$67,500,000	-$28,500,000
NSTX-U Research	*$25,000,000*	*$27,000,000*	*+$2,000,000*
NSTX-U Operations	*$68,000,000*	*$38,500,000*	*-$29,500,000*
The FY 2019 Enacted budget supports NSTX-U operations of high-priority activities to implement repairs and corrective actions required to obtain robust, reliable research operations. Research supports the continued analysis of high-impact data, a focused effort on physics topics that directly support the recovery of robust plasma operations, and enhanced collaborative research at other facilities to support NSTX-U research program priorities.		At the Request level, operations will support recovery procurements and construction activities that are necessary to realize robust research operations. Research will support analysis and modeling efforts at other facilities to support NSTX-U research program priorities and the installation of high-priority diagnostic instruments on the device.	Operations will support continued critical recovery activities. Research efforts will focus on high-priority science issues in preparation for return to operations.
Small-scale Experimental Research	*$3,000,000*	*$2,000,000*	*-$1,000,000*
The FY 2019 Enacted budget supports experimental studies of plasmas surrounded by liquid lithium material surfaces, which was identified as a priority research direction in the recent plasma-materials interactions workshop, continues. In addition, techniques to operate spherical tokamaks without the use of a central solenoid continue to be experimentally tested.		At the Request level, studies and experiments will focus on exploring operational scenarios without a central solenoid and model validation and detailed core turbulent transport mechanisms that elucidate experimental observations of improved confinement when the plasma is surrounded by liquid lithium.	Highest-priority experimental research and model validation efforts will continue.

FY 2019 Enacted		FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Theory & Simulation	$50,000,000	$44,000,000	-$6,000,000
Theory	*$25,000,000*	*$18,000,000*	*-$7,000,000*
In the FY 2019 Enacted budget, theory continues to focus on providing the scientific grounding for the physical models implemented in the large-scale simulation codes developed under SciDAC and addressing foundational problems in the science of magnetic confinement, as identified in recent community workshops.		At the Request level, theory will continue to address foundational problems in the science of magnetic confinement. Emphasis will be placed on research that maximizes synergy with large-scale simulation efforts and addresses recommendations from community workshops. The Request will allow for partnership opportunities with the private sector.	Research efforts will focus on the highest-priority activities.
SciDAC	*$25,000,000*	*$26,000,000*	*+$1,000,000*
In the FY 2019 Enacted budget, the SciDAC portfolio continues to emphasize high-priority areas such as plasma disruptions (including runaway electron effects), boundary physics, and plasma-materials interactions. The activities of all the partnerships are coordinated to accelerate progress toward whole-device modeling. Synergy with whole-device modeling activities supported by the DOE Exascale Computing Project is strengthened.		At the Request level, the nine FES SciDAC partnerships will continue to address challenges in burning plasma science, with emphasis on integration and whole-device modeling, as well as Exascale readiness. Progress in plasma disruptions will accelerate following the addition of a partnership focusing on runaway electron physics in FY 2018. Validation of the simulation codes against experimental data will also be emphasized. Research efforts focusing on emerging technologies with transformational potential, such as machine learning and computing aspects of QIS, will continue.	The Request will maintain the existing portfolio at the same level of effort. Research efforts focusing on emerging technologies with transformational potential, such as machine learning /artificial intelligence and computing aspects of QIS, will be strengthened.
GPE/GPP/Infrastructure	$10,204,000	$1,000,000	-$9,204,000
The FY 2019 Enacted budget supports Princeton Plasma Physics Laboratory (PPPL) infrastructure improvements, repair, and maintenance.		The Request will support PPPL infrastructure improvements, repair, monitoring, and maintenance. Funding will also support a study of FES infrastructure needs at ORNL.	The focus will be on highest-priority infrastructure needs and improvements.

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 primarily 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. These efforts will be augmented by research on non-superconducting overseas tokamaks and spherical tokamaks with unique capabilities.

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, including the provision of a pellet fueling injector for quasi-steady-state plasma experiments. 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 strong 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.

U.S. domestic compact stellarator research is focused on improvement of the stellarator magnetic confinement 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., offers an improved solution for stable, well confined, steady-state stellarator plasmas.

Materials and Fusion Nuclear Science

The Materials and Fusion Nuclear Science activity seeks to address the large scientific and technical gaps that exist between current-generation fusion experiments and future fusion reactors. Traditional materials used in present-day experiments will not be acceptable in an intense fusion nuclear environment, and the development of new materials and components suitable for fusion power plants is necessary in order to adequately provide the multiple functions of heat extraction, tritium breeding, and particle control. The scientific challenge is understanding the complex fusion environment, which combines extremely strong nuclear heating and damage, high temperatures, fluid-solid interactions, high tritium concentrations, and strong magnetic fields, as well as large variations of these parameters from the first wall to the vacuum vessel, and the impact of this extreme environment on materials and component performance. To help develop solutions for this complex scientific challenge, new experimental capabilities along with game-changing types of research will be required. Facilities with these experimental capabilities will need to replicate or effectively simulate various aspects of the harsh fusion environment. These experimental capabilities can lead to an increased understanding of materials and could aid in the development of new materials for use in fusion as well as other extreme environments. The Request described below will also allow for partnership opportunities with the private sector on fusion materials research.

The highest-priority objective for the fusion materials science effort is to continue pursuing the design and fabrication of the new world-leading experimental device, the Materials Plasma Exposure eXperiment (MPEX) at ORNL, which will enable dedicated studies of reactor-relevant heat and particle loads on neutron-irradiated materials. The overall motivation is to gain entry into a new class of fusion materials science wherein the combined effects of fusion-relevant heat and particle fluxes on materials can be studied for the first time anywhere in the world.

Fusion Energy Sciences
Burning Plasma Science: Long Pulse

Activities and Explanation of Changes

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Burning Plasma Science: Long Pulse $61,246,000	**$50,000,000**	**-$11,246,000**
Long Pulse: Tokamak $14,000,000	$9,000,000	-$5,000,000
In the FY 2019 Enacted budget, research on the EAST and KSTAR superconducting tokamaks continues to establish the physics bases and control tools for steady-state plasma scenarios, disruption avoidance and mitigation, and control of plasma-material interfaces. On the Joint European Torus, U.S. scientists are commissioning a shattered pellet disruption mitigation system and collaborating on optimization of burning plasma scenarios with deuterium and tritium fuels.	In the Request, research on overseas superconducting tokamaks will continue to integrate new diagnostics and control tools to improve the performance and duration of a wide range of steady-state, long-pulse plasma scenarios in collaboration with international partners. Research goals will support the pursuit of robust disruption and runaway mitigation solutions, validation of theoretical tools for plasma scenario development and optimization, and refinement of power exhaust control solutions that are consistent with transient-free plasma operation.	High-priority research activities by U.S. multi-institutional teams will be maintained in areas critical to the advancement of long-pulse, steady-state plasma operation.
Long Pulse: Stellarators $8,500,000	$8,500,000	$—
Superconducting Stellarator Research $5,000,000	*$6,000,000*	*+$1,000,000*
In the FY 2019 Enacted budget, U.S. scientists are using data from the first major experimental campaign on W7-X to strengthen the basis for long-pulse operation with pellet fueling, testing the innovative island divertor concept, investigating impurity recycling, studying the effect of the U.S.-provided trim coils on fast-ion confinement and on modulation of divertor heat loads, and determining the effect of the radial electric field on impurity transport.	In the Request, on W7-X, U.S. scientists will build and install a continuous high-speed pellet system to provide fueling for quasi-steady-state plasma experiments; develop a complete set of powder droppers for boron powder injection to enable steady-state wall conditioning; examine the effect of plasma turbulence and coherent modes on energy and particle transport; and explore edge radiative cooling with an island divertor, including 3D equilibrium effects.	Research activities by U.S. multi-institutional teams will be enhanced, including deployment and utilization of U.S. experimental hardware on international stellarator facilities.

FY 2019 Enacted		FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Compact Stellarator Research	*$3,500,000*	*$2,500,000*	*-$1,000,000*
In the FY 2019 Enacted budget, research is providing experimental data in regimes of relevance to the mainline stellarator magnetic confinement efforts and helping confirm theoretical models and simulation codes in support of the goal to develop an experimentally-validated predictive capability for magnetically confined fusion plasmas.		In the Request, research will continue on experiments that are providing data in regimes relevant to mainline stellarator confinement and experimental validation of models and codes.	The highest-priority research activities will be supported.
Materials & Fusion Nuclear Science	$38,746,000	$32,500,000	-$6,246,000
Fusion Nuclear Science	*$14,000,000*	*$8,500,000*	*-$5,500,000*
In the FY 2019 Enacted budget, research efforts continue to focus on the priority areas of plasma-facing components, safety, tritium fuel cycle, and breeder blanket technologies. In addition, a study is being initiated to evaluate options for a neutron source to test materials in fusion-relevant environments.		In the Request, research will continue to focus on the priority areas of plasma-facing components, safety, tritium fuel cycle, and breeder blanket technologies. Opportunities will be considered for expanding into high-priority research area of novel technologies for tritium fuel cycle control, as identified by the recent FESAC report on Transformative Enabling Capabilities. In addition, FES will continue to evaluate options for a near-term fusion-relevant neutron source.	Research efforts will be focused on the highest-priority activities, including novel technologies for the tritium fuel cycle and evaluation of near-term fusion-relevant neutron sources.
Materials Research	*$10,000,000*	*$12,000,000*	*+$2,000,000*
In the FY 2019 Enacted budget, research efforts continue to focus on the development of materials that can withstand the extreme fusion environment expected in future fusion reactors.		In the Request, research efforts will continue to focus on the development of materials that can withstand the extreme fusion environment. Opportunities will be considered for expanding into high-priority research in the area of advanced materials and manufacturing, as identified by the recent FESAC report on Transformative Enabling Capabilities.[a]	Research efforts will focus on highest-priority activities and expansion into advanced materials and manufacturing. The Request will also allow for partnership opportunities with the private sector.

[a] https://science.energy.gov/~/media/fes/fesac/pdf/2018/TEC_Report_1Feb20181.pdf

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Projects *$14,746,000*	*$12,000,000*	*-$2,746,000*
In the FY 2019 Enacted budget, a new MIE project, the Materials Plasma Exposure eXperiment (MPEX) at ORNL, will develop a world-leading capability for reactor-relevant plasma exposures of neutron-irradiated materials. Funding is provided for project engineering and design efforts and some long-lead procurements.	The Request will support MPEX project engineering design and also preparation for baseline approval and long-lead procurements.	Critical design activities for the MPEX MIE project will continue.

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 synthesis of nanomaterials and artificial diamonds, fabrication of micro- and opto-electronic devices, energy-efficient lighting, low-heat chemical-free sterilization processes, tissue healing, combustion enhancement, and satellite communication.

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 (PSF) activities involve research in largely unexplored areas of plasma science, with a combination of theory, computer modeling, and experimentation. These frontiers encompass 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 degrees) 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. These activities are carried out on small- and mid-scale experimental collaborative research facilities.

The PSF portfolio includes coordinated research activities in the following three areas:

- *General Plasma Science* – Research at the frontiers of basic and low temperature plasma science, including dynamical processes in laboratory, space, and astrophysical plasmas, such as magnetic reconnection, dynamo, shocks, turbulence cascade, structures, waves, flows and their interactions; behavior of dusty plasmas, non-neutral, single-component matter or antimatter plasmas, and ultra-cold neutral plasmas; plasma chemistry and processes in low-temperature plasma, interfacial plasma, synthesis of nanomaterials, and interaction of plasma with surfaces, materials or biomaterials.
- *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, magnetohydrodynamics and magnetized plasmas, and plasma atomic physics and radiation transport. Additionally, this portfolio will support HEDLP QIS priority research opportunities outlined in the 2018 Report of the Fusion Energy Sciences Roundtable on Quantum Information Science.
- *Exploratory Magnetized Plasma* – Basic research involving the creation, control, and manipulation of magnetically confined plasmas to increase our understanding of terrestrial, space, and astrophysical phenomena or applications.

The PSF activity stewards world-class plasma science experiments and collaborative research 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 simulation codes. This effort maintains strong partnerships with NSF and NNSA.

<u>Measurement Innovation</u>

The Measurement Innovation activity supports the development of world-leading transformative and innovative diagnostic techniques and their application to new, unexplored, or unfamiliar plasma regimes or scenarios. The challenge is to develop diagnostics with the high 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

Science: Long Pulse subprograms. The utilization of mature diagnostics systems is then supported via the research programs at major fusion facilities. The Request will also allow for partnership opportunities with the private sector on fusion diagnostics issues.

SBIR/STTR & Other

Funding for SBIR/STTR is included in this activity. Other items 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; outreach programs; and support for the FESAC.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Discovery Plasma Science	**$84,050,000**	**$43,750,000**	**-$40,300,000**
Plasma Science Frontiers	$52,050,000	$25,000,000	-$27,050,000
General Plasma Science	*$31,050,000*	*$13,000,000*	*-$18,050,000*
In the FY 2019 Enacted budget, core research areas of this activity continue to address questions related to plasma dynamo, magnetic reconnection, particle acceleration, turbulence, and magnetic self-organization. New efforts in low-temperature plasma are being competitively selected.		In the Request, core research areas of this activity will continue, with a focus on basic plasma science and low-temperature plasma collaborative research facilities, including support for users of these facilities.	Research efforts will focus on highest-priority scientific activities in both basic plasma science and low-temperature plasmas.
High Energy Density Laboratory Plasmas	*$18,400,000*	*$12,000,000*	*-$6,400,000*
In the FY 2019 Enacted budget, research emphasizes utilizing the MEC at LCLS for warm dense matter studies. Support continues for the MEC beam-line science team and the experimental HEDLP research groups at SLAC. With the approval of a Critical Decision-0 for Mission Need, a study is initiated to evaluate options for a MEC upgrade. Modest support is provided to make medium-scale HEDLP facilities accessible to university researchers.		In the Request, research will emphasize utilizing the MEC at LCLS. Support will continue for the MEC beam-line science team and the LaserNetUS initiative. Application of HEDLP to advance QIS will be supported.	Research efforts will focus on highest-priority science activities.
Exploratory Magnetized Plasma	*$1,000,000*	*$—*	*-$1,000,000*
In the FY 2019 Enacted budget, core research areas of this activity continue.		No funding is requested.	No funding is requested.
Projects	*$1,600,000*	*$—*	*-$1,600,000*
The FY 2019 Enacted budget provides OPC funding for the Matter in Extreme Conditions (MEC) Petawatt Upgrade project.		No funding is requested.	No funding is requested.

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Measurement Innovation $8,000,000	$4,000,000	-$4,000,000
In the FY 2019 Enacted budget, Measurement Innovation is funding new transformative and innovative diagnostics for plasma transient instabilities, plasma-materials interactions, modeling validation, and basic plasma science identified in the community workshops.	In the Request, Measurement Innovation will support the development of transformative and innovative diagnostics for plasma transient instabilities, plasma-materials interactions, modeling validation, and basic plasma science identified in the community workshops. The Request will allow for partnership collaboration opportunities with the private sector.	Research efforts will focus on the highest-priority activities.
SBIR/STTR & Other $24,000,000	$14,750,000	-$9,250,000
The FY 2019 Enacted budget continues support for USBPO activities, HBCUs, peer reviews for solicitations, and FESAC. SBIR/STTR funding is statutorily set at 3.65 percent of noncapital funding in FY 2019.	The Request will continue support for USBPO activities, HBCUs, peer reviews for solicitations, outreach programs, and FESAC. SBIR/STTR funding is statutorily set at 3.65 percent of noncapital funding in FY 2020.	The SBIR/STTR funding will be consistent with the FES total budget.

Fusion Energy Sciences
Construction

Description
This subprogram supports all line-item construction for the entire FES program. All Total Estimated Costs (TEC) are funded in this subprogram.

Matter in Extreme Conditions (MEC) Petawatt Upgrade
The National Academies of Sciences, Engineering, and Medicine (NAS) 2017 report "Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light[a]" recommended that "The Department of Energy should plan for at least one large-scale open-access high-intensity laser facility that leverages other major science infrastructure in the Department of Energy complex". This project is a new start in FY 2020 and will be an upgrade to MEC. The MEC Petawatt Upgrade is aimed at providing an experimental collaborative National User Facility for High-Energy-Density Science that will help address this NAS recommendation as well as helping the U.S. regain leadership in this important field of study. MEC is an experimental research end-station that utilizes the SLAC's Linac Coherent Light Source. The project received CD-0, "Approve Mission Need" on January, 4, 2019. The FY 2020 Request will support conceptual design of the MEC Petawatt Upgrade. The estimated total project cost is $50 million to $200 million.

ITER
The ITER facility, currently under construction in St. Paul-lez-Durance, France, and nearly 60% complete for First Plasma, aims to provide 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, Republic of 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 also a financial contribution, e.g. for the installation and assembly of the components provided by the U.S. and other Members to the ITER Organization (IO). An independent review of CD-2, "Approve Performance Baseline" for the First Plasma (FP) subproject was completed in November 2016 and then subsequently approved by the Project Management Executive (PME) on January 13, 2017, with a total project cost of $2.5 billion.

The U.S. in-kind contribution represents 9% of the overall cost, but will allow access to 100% of the science and engineering associated with what will be the largest magnetically confined burning plasma experiment ever created. Recent advances in validated theory indicate that ITER will outperform its currently stated performance, including higher fusion power gain, longer plasma duration, demonstration of advanced operating scenarios, and improvements in divertor power handling.

[a] https://www.nap.edu/read/24939/chapter/1

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Construction	**$132,000,000**	**$108,000,000**	**-$24,000,000**
Matter in Extreme Conditions (MEC) Petawatt Upgrade	$—	$1,000,000	+$1,000,000
		The Request will initiate design activities for this project, which is a new start.	The Request supports the initiation of a line-item construction project for an upgrade to MEC.
U.S. Contributions to ITER	$132,000,000	$107,000,000	-$25,000,000
In the FY 2019 Enacted budget, the primary focus is on First Plasma hardware, including continued design and fabrication of the highest-priority in-kind deliverables. A financial contribution is provided.		The Request will support the continued design and fabrication of the highest priority “in-kind” hardware systems.	Work will focus on the highest-priority First Plasma hardware activities.

Fusion Energy Sciences
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Capital Operating Expenses Summary						
Capital Equipment	N/A	N/A	10,490	16,874	16,300	-574
Minor Construction Activities						
General Plant Projects (GPP)	N/A	N/A	12,190	9,134	380	-8,754
Total, Capital Operating Expenses	**N/A**	**N/A**	**22,680**	**26,008**	**16,680**	**-9,328**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Capital Equipment						
Major Items of Equipment[a]						
Burning Plasma Science: Long Pulse Materials Plasma Exposure eXperiment (MPEX)	40,000–60,000	—	—	14,746	12,000	-2,746
Total Non-MIE Capital Equipment	N/A	N/A	10,490	2,128	4,300	2,172
Total, Capital Equipment	**N/A**	**N/A**	**10,490**	**16,874**	**16,300**	**-574**

Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
General Plant Projects						
Total GPPs less than $5M[b]	N/A	N/A	12,190	9,134	380	-8,754

[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] GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or additions to roads, and general area improvements.

Fusion Energy Sciences
Major Items of Equipment Description(s)

Burning Plasma Science: Long Pulse MIE:

Materials Plasma Exposure eXperiment (MPEX): FES has conducted substantial research and development over the past five years to identify and develop an innovative linear, high-intensity plasma source capable of producing the extreme plasma parameters required to simulate a burning plasma environment. FES is now building on this research to develop a first-of-a-kind, world-leading experimental capability that will be used to explore solutions to the daunting plasma-materials interactions challenge. MPEX, which will be located at ORNL, will allow dedicated studies of reactor-relevant heat and particle loads on neutron-irradiated materials. The overall motivation is to gain entry into a new class of fusion materials science wherein the combined effects of fusion-relevant heat, particle, and neutron fluxes can be studied for the first time anywhere in the world. The project is expected to be baselined in FY 2020. The proposed funding will maintain the required design and R&D activities and allow for initiation of long-lead major procurements for the device. (TPC $40–$60 million)

Fusion Energy Sciences
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade						
TEC	TBD	—	—	—	1,000	+1,000
OPC	TBD	—	—	1,600	—	-1,600
TPC	**TBD**	—	—	**1,600**	**1,000**	-600
14-SC-60, U.S. Contributions to ITER						
TEC	TBD	1,117,617	122,000	132,000	107,000	-25,000
OPC	TBD	70,302	—	—	—	—
TPC	**TBD**	**1,187,919**	**122,000**	**132,000**	**107,000**	**-25,000**
Total, Construction						
TEC	**TBD**	**1,117,617**	**122,000**	**132,000**	**108,000**	**-24,000**
OPC	**TBD**	**70,302**	**—**	**1,600**	**—**	**-1,600**
TPC	**TBD**	**1,187,919**	**122,000**	**133,600**	**108,000**	**-25,600**

Funding Summary

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Research	272,447	261,950	199,250	-62,700
Facility Operations	124,664	143,500	82,500	-61,000
Projects	122,000	148,346	120,000	-28,346
Other (GPP, GPE, and Infrastructure)	13,000	10,204	1,000	-9,204
Total, Fusion Energy Sciences	**532,111**	**564,000**	**402,750**	**-161,250**

Fusion Energy Sciences
Scientific User Facility Operations and Research

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 will 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.

(dollars in thousands)

	FY 2018 Enacted	FY 2018 Current	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
TYPE A FACILITIES					
DIII-D National Fusion Facility	**$114,915**	**$111,180**	**$121,500**	**$84,500**	**-37,000**
Number of Users	603	673	673	600	-73
Achieved operating hours	N/A	812	N/A	N/A	N/A
Planned operating hours	720	720	480	520	+40
Optimal hours	720	720	480	800	+320
Percent optimal hours	100%	112.8%	100%	65.0%	-35%
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A

(dollars in thousands)

	FY 2018 Enacted	FY 2018 Current	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
National Spherical Torus Experiment—Upgrade	**$90,050**	**$88,590**	**$93,000**	**$65,500**	**-$27,500**
Number of Users	390	248	385	307[a]	-78
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	—	—	—	—	—
Optimal hours	—	—	—	—	—
Percent optimal hours	N/A	N/A	N/A	N/A	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A
Total Facilities	**$204,965**	**$199,770**	**$214,500**	**$150,000**	**-$64,500**
Number of Users	993	921	1,058	907	-151
Achieved operating hours	N/A	812	N/A	N/A	N/A
Planned operating hours	720	720	480	520	+40
Optimal hours	720	720	480	800	+320
Percent of optimal hours[b]	100%	112.8%	100%	65.0%	-35%
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A

Scientific Employment

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Number of permanent Ph.D.'s (FTEs)	933	931	618	-313
Number of postdoctoral associates (FTEs)	116	115	77	-38
Number of graduate students (FTEs)	311	310	206	-104
Other[c]	1,393	1,390	923	-467

[a] While the facility is down, users are still accessing data from previous operational runs to evaluate what is seen in NSTX-U as compared to other devices both domestically and internationally.

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

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

20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade
SLAC National Accelerator Laboratory
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the Matter in Extreme Conditions (MEC) Petawatt Upgrade project is $1,000,000. The MEC is an experimental research end-station that utilizes the Linac Coherent Light Source (LCLS) Office of Science (SC) User Facility at the SLAC National Accelerator Laboratory. The estimated total project range is $50 million to $200 million. SC plans for the MEC Petawatt Upgrade project to achieve CD-1, "Approve Alternative Selection and Cost Range" in FY 2020.

Significant Changes

This project is a new start in FY 2020 and will be an upgrade to MEC. The project achieved CD-0, "Approve Mission Need" on January, 4, 2019. Other Project Costs funding in FY 2019 will support conceptual design of the MEC Petawatt Upgrade and is expected to continue into FY 2020. When the project achieves CD-1, "Approve Alternative Selection and Cost Range", which is expected in early FY 2020, SC will then initiate TEC design efforts. A Federal Project Director will be assigned to the MEC Petawatt Upgrade project prior to CD-2 approval ("Approved Performance Baseline").

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2020	1/4/2019	3Q FY 2019	1Q FY 2020	TBD	TBD	TBD	TBD	TBD

CD-0 – Approve Mission Need for a construction project with a conceptual scope and cost range
Conceptual Design Complete – Actual date the conceptual design was or will be completed (if applicable)
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Estimated/Actual date the project design will be/was complete (d)
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D work
CD-4 – Approve Start of Operations or Project Closeout

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2020	1,000	—	1,000	1,600	—	1,600	2,600

2. Project Scope and Justification

Scope

The scope of the MEC Petawatt Upgrade is still being formulated. At a minimum, it will include the design and procurement of a petawatt-class laser system and the design, construction, and installation of a new shield wall.

Justification

The FES mission is to build the scientific foundations needed to develop a fusion energy source and to expand the fundamental understanding of matter at very high temperatures and densities. To meet this mission, there is a scientific need for a petawatt or greater laser facility that is currently not available in the U.S. The National Academies of Science, Engineering, and Medicine (NAS) 2017 study titled “Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light[a]” found that about 80 percent to 90 percent of the high-intensity laser systems are overseas, and all of the highest powered lasers currently in construction or already built are overseas as well. The report noted that the U.S. is losing ground in a second laser revolution of highly-intense, ultrafast lasers that have broad applications in manufacturing, medicine, and national security. The report makes five recommendations that would improve the nation’s position in the field, including a recommendation for the U.S. Department of Energy (DOE) to plan for at least one large-scale, open-access, high-intensity laser facility that leverages other major science infrastructures in the DOE complex.

The NAS report focuses on highly-intense, pulsed petawatt-class lasers (1 petawatt is equal to 1 million billion watts). Such laser beams can drive nuclear reactions, heat and compress matter to mimic conditions found in stars, and create electron-positron plasmas. In addition to curiosity-driven science, petawatt-class lasers can generate particle beams with potential applications in cancer radiation therapy, intense neutron and gamma ray beams for homeland security applications, directed energy for Department of Defense (DOD) applications, and extreme ultraviolet lithography (EUV) radiation.

Co-location of high-intensity lasers with existing infrastructure such as particle accelerators has been recognized as a key advantage of the U.S. laboratories over the Extreme Light Infrastructure (ELI) concept in Europe. A laser facility with high-power, high-intensity beam parameters that is co-located with hard X-ray laser probing capabilities (i.e. with an X-ray wavelength that allows atomic resolution) will provide the required diagnostic capabilities for fusion discovery science and related fields. This co-location enables novel pump-probe experiments with the potential to dramatically improve our understanding of the ultrafast response of materials in extreme conditions, e.g., found in the environment of fusion plasmas, astrophysical objects, and highly stressed engineering materials. Recent research on ultrafast pump-probe experiments using the Linac Coherent Light Source (LCLS) at the SLAC National Accelerator Laboratory has demonstrated exquisite ultrafast measurements of the material structural response to radiation, but higher flux sources of deuterons, neutrons, and gamma rays are needed to properly emulate the environment and physics processes that occur in materials next to fusion plasmas. This strategy holds the potential to validate inter-atomic potentials in molecular dynamics simulations of materials to enable long-term predictions of the material behavior in fusion facilities.

FES is seeking to develop a new, world-class petawatt laser capability to address the FES mission and the recommendations from the NAS report.

The project will be conducted in accordance with the project management requirements in DOE O 413.3B, Program and Project Management for the Acquisition of Capital Assets.

Key Performance Parameters (KPPs)

The Threshold KPPs, represent the minimum acceptable performance that the project must achieve. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion. The Objective KPPs represent the desired project performance.

Performance Measure	Threshold	Objective
TBD	TBD	TBD

[a] https://www.nap.edu/catalog/24939/opportunities-in-intense-ultrafast-lasers-reaching-for-the-brightest-light

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2020	1,000	1,000	1,000
Total, Design	TBD	TBD	TBD
Construction			
FY 2020	—	—	—
Total, Construction	TBD	TBD	TBD
Total Estimated Costs (TEC)			
FY 2020	1,000	1,000	1,000
Total, TEC	**TBD**	**TBD**	**TBD**
Other Project Costs (OPC)			
FY 2019	1,600	1,600	1,600
FY 2020	—	—	—
Total, OPC	**TBD**	**TBD**	**TBD**
Total Project Costs (TPC)			
FY 2020	2,600	2,600	2,600
Total, TPC	**TBD**	**TBD**	**TBD**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	TBD	TBD	TBD
Contingency	TBD	TBD	TBD
Total, Design	TBD	TBD	TBD
Construction			
Site Work	TBD	TBD	TBD
Equipment	TBD	TBD	TBD
Construction	TBD	TBD	TBD
Other, as needed	TBD	TBD	TBD
Contingency	TBD	TBD	TBD
Total, Construction	TBD	TBD	TBD
Other TEC			
Cold Startup	TBD	TBD	TBD
Contingency	TBD	TBD	TBD
Total, Other TEC	TBD	TBD	TBD
Total, TEC	TBD	TBD	TBD
Contingency, TEC	*TBD*	*TBD*	*TBD*

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Other Project Costs (OPC)			
OPC except D&D			
R&D	TBD	TBD	TBD
Conceptual Planning	TBD	TBD	TBD
Conceptual Design	TBD	TBD	TBD
Other OPC Costs	TBD	TBD	TBD
Contingency	TBD	TBD	TBD
Total, OPC	TBD	TBD	TBD
Contingency, OPC	*TBD*	*TBD*	*TBD*
Total Project Costs	TBD	TBD	TBD
Total Contingency (TEC+OPC)	*TBD*	*TBD*	*TBD*

5. Schedule of Appropriation Requests

(dollars in thousands)

Request	Type	Prior	FY 2019	FY 2020	Outyears	Total
FY 2020	TEC	N/A	—	1,000	TBD	TBD
	OPC	N/A	1,600	—	TBD	TBD
	TPC	N/A	1,600	1,000	TBD	TBD

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	1Q FY 2026
Expected Useful Life (number of years)	TBD
Expected Future Start of D&D of this capital asset (fiscal quarter)	1Q FY 2045

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations and Maintenance	TBD	TBD	TBD	TBD

7. D&D Information

The new area being constructed for this project is under analysis at this time.

	Square Feet
New area being constructed by this project at SLAC National Accelerator Laboratory	TBD
Area of D&D in this project at SLAC National Accelerator Laboratory	TBD
Area at SLAC National Accelerator Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked"	TBD
Area of D&D in this project at other sites	TBD
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	TBD
Total area eliminated	TBD

8. Acquisition Approach

An Acquisition Strategy has not yet been formulated, but will be completed prior to seeking Critical Decision 2 approval.

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

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the U.S. ITER project is $107,000,000. ITER is a major fusion research facility being constructed in Saint-Paul-lez-Durance, France by an international partnership of seven Members or Domestic Agencies: U.S., China, European Union, India, the Republic of Korea, Japan, and the Russian Federation, that comprise 34 countries. Since it will not result in a facility owned by the U.S. or located in the U.S., the U.S. ITER project is not classified as a Capital Asset Project, but is classified as a Major System Project. It is a U.S. Department of Energy (DOE) project to provide the U.S. share of ITER construction, classified as in-kind hardware (i.e., subsystems, equipment, and components), as well as financial resources to support the ITER Organization (IO), as delineated in the Joint Implementation Agreement (JIA). Sections of this Construction Project Data Sheet (CPDS) have been tailored accordingly to reflect the unique nature of the U.S. ITER project.

Critical Decision (CD) CD-0, "Approve Mission Need" was signed on July 5, 2005. CD-1, "Approve Alternative Selection and Cost Range," was approved on January 25, 2008, with a preliminary cost range of $1.45 billion to $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 PME for the U.S. ITER project is the Deputy Secretary of Energy. The cost range reassessment was completed in November 2016 and was subsequently approved by the PME on January 13, 2017. The CD-1 Revised cost range is now $4.7 billion to $6.5 billion.

As outlined in the May 2016 Secretary of Energy's Report to Congress, DOE was to baseline the "First Plasma" portion of the U.S. ITER project. As such, DOE has divided the U.S. ITER project hardware scope into two distinct subprojects, which represent the two phases of the project: First Plasma (FP) subproject (SP-1), and Post-First Plasma subproject (SP-2). The FP subproject scope consists of: 1) completing the design for all twelve systems the U.S. is contributing to ITER; 2) completing fabrication and delivery of the Toroidal Field (TF) superconductor; completing fabrication and delivery of the Steady-State Electrical Network (SSEN), and the Central Solenoid (CS) superconducting magnet modules, assembly tooling, and associated structures; and 3) completing the partial fabrication of and delivering seven other subsystems: Tokamak Cooling Water, Roughing Pumps, Vacuum Auxiliary, Pellet Injection, Ion Cyclotron Heating, Electron Cyclotron Heating, and two of seven Diagnostics. An independent review of CD-2, "Approve Performance Baseline" for the SP-1 was completed in November 2016 and then subsequently approved by the PME on January 13, 2017, with a total project cost of $2.5 billion, and a CD-4, "Project Completion" date of December 2027. In addition, the PME also approved CD-3, "Approve the Start of Construction" for the SP-1 on January 13, 2017. This CPDS focuses on the First Plasma subproject activities.

Subproject 2 (SP-2) is the second element of the U.S. ITER project, and includes the remainder of U.S. hardware contributions for Post-First Plasma operations leading up to Deuterium-Tritium Operations. SP-2 is planned to be baselined at a future timeframe (e.g., FY 2021/2022).

The financial contributions to the IO operational costs during construction are shared among the seven Members, pursuant to the ITER JIA, and is the third element of the U.S. ITER Total Project Cost.

The U.S. ITER project is managed as a DOE Office of Science (SC) project through the U.S. ITER Project Office (USIPO). The USIPO is managed by Oak Ridge National Laboratory (ORNL), in partnership with Princeton Plasma Physics Laboratory (PPPL) and the Savannah River National Laboratory (SRNL). The project began as a Major Item of Equipment (MIE) in FY 2006, and was changed to a Congressional control point Line-Item construction project in FY 2014. The principles and practices of DOE Order 413.3B are applied in the effective management of the U.S. ITER project, including Critical Decision approvals; establishment of Key Performance Parameters; and the application of Earned Value Management. SC applies the requirements for project documentation, monitoring and reporting, change control, and regular independent project reviews (IPRs) with the same degree of rigor as other SC line-item projects. The USIPO regularly reports progress and performance in monthly performance metrics and project status reports.

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

Significant Changes

This CPDS is an update of the FY 2019 CPDS and does not include a new start for FY 2020. The First Plasma subproject (SP-1), which includes fabrication and delivery of all hardware required for First Plasma and the completion of design for all U.S. hardware contributions, is more than 56% complete.

The FY 2020 Request will support the continued design and fabrication of the highest priority "in-kind" hardware systems. This includes continued fabrication of the Central Solenoid (CS) magnet system, which consists of seven superconducting magnet modules, structural components, and assembly tooling. In FY 2020, the U.S. will deliver the first CS magnet module (Module 1) to the ITER site, as well as continue design and fabrication efforts associated with other "in-kind" hardware systems. The U.S. ITER project has obligated $980 million through the end of FY 2018 to U.S. industry, universities, and DOE laboratories.

Critical Milestone History

Fiscal Year	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, and Cost Range
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 (07/2017); Roughing Pumps I&C (04/2017); VAS 03 Supply I&C (07/2017); 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).

Fiscal Year	Performance Baseline Validation	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	1Q FY 2027	2034–2038
FY 2019	7/5/2005	1/13/17	1/13/17	2019	1Q FY 2027	2034–2038
FY 2020	7/5/2005	1/13/17	1/13/17	2021/2022	1Q FY 2028	2034–2038

Project Cost History

At the time of CD-1 approval in January 2008, the preliminary cost range was $1.45 to $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 poor project management and leadership issues in the ITER Organization) have affected the project cost and schedule. 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 $6.5 billion would likely encompass the final total TPC. This range, recommended in 2013, was included in subsequent President's Budget Requests. In May 2016, DOE provided a "Report on the Continued U.S. Participation in the ITER Project" to Congress, which stated that the First Plasma part of the U.S. ITER project would be baselined in FY 2017. In preparation for baselining SP-1, based on the results of the IPR, a decision was made by the acting SC-1 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 $6.5 billion. This updated CD-1R range incorporates increases in the projects hardware estimate that have occurred since August 2013. The SP-1 TPC has been baselined at $2.5 billion.

Subproject 1 (First Plasma Hardware for US ITER)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2017[b]	696,025	1,723,334	2,419,359	80,641	N/A	80,641	2,500,000
FY 2018	696,025	1,723,334	2,419,359	80,641	N/A	80,641	2,500,000
FY 2019	696,025	1,723,334	2,419,359	80,641	N/A	80,641	2,500,000
FY 2020	696,025	1,733,673	2,429,698	70,302	N/A	70,302	2,500,000

2. Project Scope and Justification

Introduction

ITER is an international partnership among seven Members (China, the European Union, India, Japan, the Republic of Korea, the Russian Federation, and the U.S.) 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 IO, which is an international legal entity located in France.

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

[b] Prior to FY2017 the TPC for U.S. ITER was reported as "TBD"; estimates reported beginning in FY 2017 represent the validated baseline values for Subproject 1 First Plasma Hardware. These values for the SP-1 baseline have not been updated to reflect impacts from FY 2017 and FY 2018 funding reductions and allocations.

Scope

U.S. Contributions to ITER – Construction Project Scope

The overall U.S. ITER project includes three major elements:

- Hardware components, built under the responsibility of the U.S., then shipped to the ITER site for IO assembly, installation, and operation.
- 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.
- Other project costs, including R&D and conceptual design related activities.

The U.S. is to contribute the hardware to ITER, the technical components of which are split between SP-1 (First Plasma) and SP-2 (Post-First Plasma). The percentage of hardware components to be delivered in each system for SP-1 are indicated for each system:

- Tokamak Cooling Water System (TCWS): manages the thermal energy generated during the operation of the tokamak. (58% of system for SP-1)
- 15% of ITER Diagnostics: provides the measurements necessary to control, evaluate, and optimize plasma performance and to further the understanding of plasma physics. (6% for SP-1)
- Disruption Mitigation (DM) Systems: limits the impact of plasma disruptions to the tokamak vacuum vessel, blankets, and other components. All of DM design is done in SP-1.
- Electron Cyclotron Heating (ECH) Transmission Lines: brings additional power to the plasma and deposits power in specific areas of the plasma to minimize instabilities and optimize performance. (55% for SP-1)
- Tokamak Exhaust Processing (TEP) System: separates hydrogen isotopes from tokamak exhaust. (All of TEP design is done in SP-1)
- Tokamak Fueling System (Pellet Injection): injects fusion fuels in the form of deuterium-tritium ice pellets into the vacuum chamber. (9% for SP-1)
- Ion Cyclotron Heating (ICH) Transmission Lines: bring additional power to the plasma. (15% for SP-1)
- Central Solenoid (CS) Magnet System: confines, shapes and controls the plasma inside the vacuum vessel. All CS workscope is SP-1.
- 8% of Toroidal Field (TF) Conductor: component of the TF magnet that confines, shapes, and controls the plasma. All TF work scope was completed in FY 2017.
- 75% of the Steady-State Electrical Network (SSEN): supplies the electricity needed to operate the entire plant, including offices and the operational facilities. All SSEN work scope was completed in FY 2017.
- Vacuum Auxiliary System (VAS): creates and maintains low gas densities in the vacuum vessel and connected vacuum components. (85% for SP-1)
- Roughing Pumps: evacuate the tokamak, cryostat, and auxiliary vacuum chambers prior to and during operations. (56% for SP-1)

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.

Although not classified as a Capital Asset, the U.S. ITER project is being conducted in accordance with the project management principles of DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets.

Key Performance Parameters (KPPs)

The U.S. ITER project will not deliver an integrated operating facility, but rather in-kind hardware contributions, which represent a portion of the subsystems for the international ITER facility. Therefore, typical KPPs are not practical for this type of project. The U.S. ITER project defines project completion as delivery and IO acceptance of the U.S. in-kind hardware. For SP-1, in some cases (e.g., Tokamak Exhaust Processing and Disruption Mitigation), only the completion of the design is required, which requires IO approval of the final designs. Below is the list of SP-1 deliverables that were approved when the SP-1 baseline was approved.

Table 1. SP-1 In-Kind Hardware Description

System/Subsystem	Description
Central Solenoid Magnet System	Provide 7 (including spare) independent coil packs made of superconducting niobium-tin providing 13 Tesla at 45 kA, the vertical pre- compression structure, and assembly tooling.
Toroidal Field Magnet Conductor	Provide 9 active lengths (~765m), 1 dummy length (~765m) for winding trials and 2 active lengths (~100m each) for superconducting qualification.
Steady State Electrical Network	Provide components for a large AC power distribution system (transformers, switches, circuit breakers, etc.) at high-voltage (400kV) and medium-voltage (22kV) levels.
Tokamak Cooling Water System	Provide Final Designs for major industrial components (heat exchangers, pumps, valves, pressurizers, etc.) capable of removing 1 GW of heat. Among those components, also fabricate and deliver certain IO-designated items.
Diagnostics	Provide Final Designs for 4 diagnostic port plugs and 7 instrumentation systems (Core Imaging X-ray Spectrometer, Electron Cyclotron Emission Radiometer, Low Field Side Reflectometer, Motional Stark Effect Polarimeter, Residual Gas Analyzer, Toroidal Interferometer/Polarimeter, and Upper IR/Visible Cameras). Among those components, also fabricate and deliver certain IO-designated items.
Electron Cyclotron Heating Transmission Lines	Provide Final Designs for approximately 4 km of aluminum waveguide lines (24 lines) capable of transmitting up to 1.5 MW per line. Among those components, also fabricate and deliver certain IO-designated items.
Ion Cyclotron Heating Transmission Lines	Provide Final Designs for approximately 1.5 km of coaxial transmission lines (8 lines) capable of transmitting up to 6 MW per line. Among those components, also fabricate and deliver certain IO-designated items.
Pellet Injection System	Provide Final Designs for injector system capable of delivering deuterium/tritium fuel pellets up to 16 times per second. Among those components, also fabricate and deliver certain IO-designated items.
Vacuum Roughing Pumps	Provide Final Designs for a matrix of pump trains consisting of approximately 400 vacuum pumps. Among those components, also fabricate and deliver certain IO-designated items.
Vacuum Auxiliary Systems	Provide Final Designs for vacuum system components (valves, pipe manifolds, auxiliary pumps, etc.) and approximately 6 km of vacuum piping. Among those components, also fabricate and deliver certain IO-designated items.
Tokamak Exhaust Processing System	Provide Final Designs for an exhaust separation system for hydrogen isotopes and non-hydrogen gases.
Disruption Mitigation System	Provide design, and research and development (R&D) (up to a limit of $25M*[a]) for a system to mitigate plasma disruptions that could cause damage to the tokamak inner walls and components.

[a] Any additional costs would be funded by the ITER organization.

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC) [a]			
Hardware			
FY 2006	13,754	13,754	6,169
FY 2007	36,588	36,588	24,238
FY 2008	23,500	23,500	24,121
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]	91,453	91,441	99,249
FY 2013	107,635	107,669	110,074
FY 2014[c]	166,605	166,605	153,995
FY 2015	134,043	134,043	114,129
FY 2016[d]	115,000	115,000	106,519
FY 2017	50,000	50,000	123,117
FY 2018	122,000	122,000	98,185
FY 2019	117,000	117,000	107,435
FY 2020	107,000	107,000	117,182
Subtotal	1,319,120	1,319,142	1,241,064
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[f]	13,214	13,214	13,214
FY 2013	13,805	13,805	13,805
FY 2014[c]	32,895	32,895	32,895
FY 2015	15,957	15,957	15,957
FY 2016	—	—	—
FY 2017	—	—	—
FY 2018	—	—	—
FY 2019	15,000	15,000	15,000
FY 2020	—	—	—
Subtotal	159,497	159,497	159,497
Total, Cash Contributions	TBD	TBD	TBD

[a] Costs through FY 2017 reflect actual costs; costs for FY 2019 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] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Hardware and Cash Contributions			
FY 2006	15,866	15,866	8,281
FY 2007	44,000	44,000	31,650
FY 2008	26,144	26,144	26,765
FY 2009	109,000	109,000	49,877
FY 2010	115,000	115,000	75,786
FY 2011	67,000	67,000	87,446
FY 2012	104,667	104,655	112,463
FY 2013	121,440	121,474	123,879
FY 2014	199,500	199,500	186,890
FY 2015	150,000	150,000	130,086
FY 2016	115,000	115,000	106,519
FY 2017	50,000	50,000	123,117
FY 2018	122,000	122,000	98,185
FY 2019	132,000	132,000	122,435
FY 2020	107,000	107,000	117,182
Subtotal	1,478,617	1,478,639	1,400,561
Total, TEC	**TBD**	**TBD**	**TBD**
Other Project Costs (OPC)[a]			
FY 2006	3,449	3,449	1,110
FY 2007	16,000	16,000	7,606
FY 2008	-74	-74	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[b]	333	311	22,302
FY 2013	2,560	2,560	5,984
FY 2014[c]	—	—	2,090
FY 2015	—	—	600
FY 2016	34	34	–
FY 2017	—	-50	58
FY 2018	—	—	2
Subtotal	70,302	70,230	70,123
Total, OPC	**TBD**	**TBD**	**TBD**
Total Project Costs (TPC) [d]			
FY 2006	19,315	19,315	9,391
FY 2007	60,000	60,000	39,256
FY 2008	26,070	26,070	34,278
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[b]	105,000	104,966	134,765

[a] Costs through FY 2017 reflect actual costs; costs for FY 2018 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] Costs through FY 2017 reflect actual costs; costs for FY 2018 and the outyears are estimates.

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
FY 2013	124,000	124,034	129,863
FY 2014[c]	199,500	199,500	188,980
FY 2015	150,000	150,000	130,686
FY 2016	115,034	115,034	106,519
FY 2017	50,000	49,950	123,175
FY 2018	122,000	122,000	98,187
FY 2019	132,000	132,000	122,435
FY 2020	107,000	107,000	117,182
Subtotal	1,548,919	1,548,869	1,470,684
Total, TPC	**TBD**	**TBD**	**TBD**

4. Details of Project Cost Estimate

The project has an approved updated CD-1 Cost Range, and DOE has chosen to divide the project hardware scope into two distinct subprojects (FP SP-1, and Post-FP SP-2). The baseline for SP-1 was approved in January 2017. Baselining of SP-2 will follow when the Administration has made a decision about whether the U.S. commitment to ITER. No procurements for SP-2 scope are anticipated until FY 2022 at the earliest. An IPR 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 SP-1, as well as for the proposed updated CD-1 Cost Range. Outcomes from the IPR indicated that the project was ready for approval of SP-1 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. In addition, the IPR committee found no compelling reason to deviate from the cost range identified in the May 2016 Report to Congress ($4.0 to $6.5 billion) and recommended that this range be adopted and approved as the Updated CD-1 cost range. However, as noted above, in preparation for baselining SP-1 and based on the outcome of the IPR, 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 billion to $6.5 billion.

Subproject – 1 First Plasma Hardware Only

(dollars in thousands)

	Current Total Estimate[a]	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	573,660	—	573,660
Contingency	122,365	—	122,365
Total, Design	696,025	—	696,025
Construction			
Equipment	1,362,521	—	1,362,521
Contingency	371,152	—	371,152
Total, Construction	1,733,673	—	1,733,673
Total, TEC	2,429,698	—	2,429,698
Contingency, TEC	*493,517*	—	*493,517*

[a] The estimate value reflected here has not been adjusted to reflect the FY 2017 and FY 2018 appropriations.

Subproject – 1 First Plasma Hardware Only

(dollars in thousands)

	Current Total Estimate[a]	Previous Total Estimate	Original Validated Baseline
Other Project Cost (OPC)			
OPC except D&D			
Other OPC Costs	70,302	—	70,302
Total, OPC	70,302	—	70,302
Total Project Cost[a]	**2,500,000**	**—**	**2,500,000**
Total, Contingency (TEC+OPC)	***493,517***	**—**	***493,517***

5. **Schedule of Appropriation Requests**

(dollars in thousands)

Request	Type	Prior	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2006	TEC	1,038,000	—	—	—	—	—	—	—	1,038,000
	OPC	84,000	—	—	—	—	—	—	—	84,000
	TPC	1,122,000	—	—	—	—	—	—	—	1,122,000
FT 2007	TEC	1,077,051	—	—	—	—	—	—	—	1,077,051
	OPC	44,949	—	—	—	—	—	—	—	44,949
	TPC	1,122,000	—	—	—	—	—	—	—	1,122,000
FY 2008	TEC	1,078,230	—	—	—	—	—	—	—	1,078,230
	OPC	43,770	—	—	—	—	—	—	—	43,770
	TPC	1,122,000	—	—	—	—	—	—	—	1,122,000
FY 2009[b]	TEC	266,366	—	—	—	—	—	—	—	TBD
	OPC	38,075	—	—	—	—	—	—	—	TBD
	TPC	304,441	—	—	—	—	—	—	—	TBD
FY 2010	TEC	294,366	—	—	—	—	—	—	—	TBD
	OPC	70,019	—	—	—	—	—	—	—	TBD
	TPC	364,385	—	—	—	—	—	—	—	TBD
FY 2011	TEC	379,366	—	—	—	—	—	—	—	TBD
	OPC	65,019	—	—	—	—	—	—	—	TBD
	TPC	444,385	—	—	—	—	—	—	—	TBD
FY 2012[c]	TEC	394,366	—	—	—	—	—	—	—	TBD
	OPC	75,019	—	—	—	—	—	—	—	TBD
	TPC	469,385	—	—	—	—	—	—	—	TBD
FY 2013[d]	TEC	617,261	—	—	—	—	—	—	—	TBD
	OPC	82,124	—	—	—	—	—	—	—	TBD
	TPC	699,385	—	—	—	—	—	—	—	TBD

[a] The TPC reported here is only for Subproject 1 (and does not include Subproject 2 or cash contributions estimates), prior to FY 2017 the Total Project Cost for US ITER was identified as "TBD".

[b] 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.

[c] 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.

[d] 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	Type	Prior	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2014[a]	TEC	806,868	—	—	—	—	—	—	—	TBD
	OPC	73,159	—	—	—	—	—	—	—	TBD
	TPC	880,027	—	—	—	—	—	—	—	TBD
FY 2015	TEC	942,578	—	—	—	—	—	—	—	TBD
	OPC	80,341	—	—	—	—	—	—	—	TBD
	TPC	1,022,919	—	—	—	—	—	—	—	TBD
FY 2016	TEC	1,092,544	—	—	—	—	—	—	—	TBD
	OPC	80,341	—	—	—	—	—	—	—	TBD
	TPC	1,172,885	—	—	—	—	—	—	—	TBD
FY 2017	TEC	1,182,578	—	—	—	—	—	—	—	TBD
	OPC	80,341	—	—	—	—	—	—	—	TBD
	TPC	1,262,919	—	—	—	—	—	—	—	TBD
FY 2018	TEC	1,107,244	63,000	—	—	—	—	—	—	TBD
	OPC	80,641	—	—	—	—	—	—	—	TBD
	TPC	1,187,885	63,000	—	—	—	—	—	—	TBD
FY 2019	TEC	1,107,244	63,000	75,000	—	—	—	—	—	TBD
	OPC	80,641	—	—	—	—	—	—	—	TBD
	TPC	1,187,885	63,000	75,000	—	—	—	—	—	TBD
FY 2020	TEC	1,117,617	122,000	132,000	107,000	—	—	—	—	TBD
	OPC	70,302	—	—	—	—	—	—	—	TBD
	TPC	1,187,919	122,000	132,000	107,000	—	—	—	—	TBD

6. 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 which currently indicates 2025.

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	12/2025
Expected Useful Life (number of years)	15–25
Expected Future start of D&D for new construction (fiscal quarter)	TBD

7. D&D Information

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.

8. Acquisition Approach

The U.S. ITER 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

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

the Procurement Arrangements established with the international IO. The USIPO will subcontract with a variety of research and industry sources for design and fabrication of its ITER components, ensuring that designs are developed that permit fabrication, to the maximum extent possible, under fixed-price subcontracts (or fixed-price arrangement documents with the IO) based on performance specifications, or more rarely, on build-to-print designs. USIPO will use cost-reimbursement type subcontracts only when the work scope precludes accurate and reasonable cost contingencies being gauged and established beforehand. USIPO will utilize best value, competitive source selection procedures to the maximum extent possible, including foreign firms on the tender/bid list where appropriate. Such procedures shall allow for cost and technical trade-offs during source selection. For the large-dollar-value subcontracts (and critical path subcontracts as appropriate), USIPO will utilize unique subcontract provisions to incentivize cost control and schedule performance. 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.