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 percent 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. FES 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 a clean energy technology that relies on widely available and virtually inexhaustible fuel sources available to the American people. Research in plasma science, within and beyond fusion, will contribute to American prosperity through the tremendous potential for spinoff applications

[a] https://www.whitehouse.gov/wp-content/uploads/2018/07/M-18-22.pdf

(described in a report by the Fusion Energy Sciences Advisory Committee [FESAC][a]) as well as targeted investments (e.g., in early-stage low temperature plasma research) that can lead to the development of transformative technologies. Investments in SC's major fusion facilities and smaller-scale experiments will help maintain and modernize the research infrastructure necessary 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 through the Innovation Network for Fusion Energy (INFUSE) program will propagate scientific discoveries that could transition into the private sector. Investments in transformational technologies such as artificial intelligence and machine learning (AI/ML), 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 2021 Request

The FY 2021 Request is $425,151,000. The priorities described in "The Office of Science's Fusion Energy Sciences Program: A Ten-Year Perspective,"[b] the research opportunities identified in a series of community engagement workshops held in 2015,[c] and the FY 2017 FESAC report on the potential for transformative developments in fusion science and technology[d] informed the strategic choices in this Request. 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 continuing to seek opportunities with private-public partnerships. Furthermore, the 2018 report[e] of the National Academies of Sciences, Engineering, and Medicine burning plasma study commissioned by FES also informs the research priorities for burning plasma science.

Key elements in the FY 2021 Request include:

<u>Research</u>

- DIII-D research: DIII-D research will focus on assessing the reactor potential of current-drive systems to inform the design of next-step devices, integrating core and edge plasma solutions that extrapolate to future fusion reactors, and advancing the understanding of power exhaust strategies.
- 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 through the INFUSE program will leverage opportunities in critical fusion research areas (e.g., diagnostics, theory and simulation, materials science, and magnet technology).
- Enabling technology, fusion nuclear science, and materials: Research will continue on high-temperature superconductors and additive manufacturing. FES will continue to explore options for a neutron source that will test materials in fusion-relevant environments.
- Scientific Discovery through Advanced Computing: SciDAC projects will continue development of an integrated whole-device modeling capability, in partnership with the ASCR program, and pursue transformative approaches such as machine learning and QIS.
- Long-pulse tokamak and stellarator research: Long-pulse tokamak research enables U.S. scientists to work on superconducting tokamaks with world-leading capabilities. Long-pulse stellarator research will allow U.S. teams to take full advantage of U.S. hardware investments on the Wendelstein 7-X (W7-X) stellarator and enhance the scientific output on this device.

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[a] https://science.osti.gov/~/media/fes/fesac/pdf/2015/2101507/FINAL_FES_NonFusionAppReport_090215.pdf
[b] https://science.osti.gov/-/media/fes/pdf/workshop-reports/2016/FES_A_Ten-Year_Perspective_2015-2025.pdf
[c] https://science.osti.gov/fes/Community-Resources/Workshop-Reports
[d] https://science.osti.gov/-/media/fes/fesac/pdf/2018/TEC_Report_15Feb2018.pdf
[e] https://www.nap.edu/catalog/25331/final-report-of-the-committee-on-a-strategic-plan-for-us-burning-plasma-research

- Discovery plasma science: Research continues to support small- and intermediate scale basic plasma science and HEDLP facilities, and also future fusion design studies. FES will partner with ASCR, Basic Energy Sciences (BES), and High Energy Physics (HEP) to support multi-disciplinary microelectronics research that will promote basic research to accelerate the advancement of microelectronic technologies in a co-design innovation ecosystem in which materials, chemistries, devices, systems, architectures, algorithms, and software are developed in a closely integrated fashion.
- QIS: In support of the National Quantum Initiative, the Request continues support for the SC QIS Center(s) established in FY 2020. These centers constitute an interdisciplinary partnership among SC Program Offices. This partnership complements a robust core research portfolio stewarded by the individual SC programs to create the ecosystem across universities, national laboratories, and industry that is needed to advance developments in QIS and related technology.

Facility Operations

- DIII-D operations: The funding will allow 13 weeks of facility operations, along with machine and infrastructure refurbishments and improvements for new research capabilities.
- NSTX-U recovery activities: The NSTX-U facility is down for recovery and repair, which will continue through FY 2021. 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.

Projects

- Continued U.S. hardware development and delivery to ITER: The FY 2021 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 also continue design and fabrication efforts for other hardware systems.
- High energy density laboratory plasmas: FES will support design activities for a significant upgrade to the MEC instrument on the LCLS facility at SLAC.
- 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. The project is expected to achieve Critical Decision (CD) 1 in FY 2020. FY 2021 funding will maintain required detailed design and R&D activities, develop the performance baseline, and allow for initiation of long-lead major procurements for the device.

Other

- GPP/GPE: Funding is provided for General Plant Projects/General Purpose Equipment, to support Princeton Plasma Physics Laboratory (PPPL) infrastructure improvements and repairs.

FY 2021 Research Initiatives

Fusion Energy Sciences supports the following FY 2021 Research Initiatives

	(dollars in thousands)			
	FY 2019 Enacted	**FY 2020 Enacted**	**FY 2021 Request**	**FY 2021 Request vs FY 2020 Enacted**
Ongoing Research Initiatives				
Artificial Intelligence and Machine Learning	—	7,000	7,000	—
Microelectronics Innovation	4,000	—	5,000	+5,000
Quantum Information Science	—	7,520	9,520	+2,000
U.S. Fusion Program Acceleration program[a][b]	2,000	4,000	5,000	+1,000
Total, Ongoing Research Initiatives	**6,000**	**18,520**	**26,520**	**+8,000**

[a] In FY 2021, the U.S. Fusion Program Acceleration initiative focuses on strengthening fusion research within the United States. This initiative includes the INFUSE program ($4 million) and a study to determine the needs for a future fusion facility ($1 million).
[b] In FY 2019, INFUSE funding was included under Science Discovery through Advanced Computing (SciDAC) and High Energy Density Laboratory Plasmas (HEDLP) activities. Starting in FY 2020, INFUSE is identified as a separate activity.

Fusion Energy Sciences
Funding

	(dollars in thousands)			
	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
Burning Plasma Science: Foundations				
Advanced Tokamak	130,500	123,500	92,500	-31,000
Spherical Tokamak	96,000	101,000	72,500	-28,500
Theory & Simulation	50,000	44,000	51,000	+7,000
GPE/GPP/Infrastructure	10,204	7,000	1,000	-6,000
Innovation Network for Fusion Energy (INFUSE) program[a]	—	4,000	4,000	—
Total, Burning Plasma Science: Foundations	**286,704**	**279,500**	**221,000**	**-58,500**
Burning Plasma Science: Long Pulse				
Long Pulse: Tokamak	14,000	14,000	8,000	-6,000
Long Pulse: Stellarators	8,500	8,500	7,500	-1,000
Materials & Fusion Nuclear Science	38,746	47,500	33,500	-14,000
Total, Burning Plasma Science: Long Pulse	**61,246**	**70,000**	**49,000**	**-21,000**
Discovery Plasma Science				
Plasma Science Frontiers	52,050	42,500	25,000	-17,500
Measurement Innovation	8,000	3,000	3,000	—
SBIR/STTR & Other	24,000	19,000	15,151	-3,849
Total, Discovery Plasma Science	**84,050**	**64,500**	**43,151**	**-21,349**
Subtotal, Fusion Energy Sciences	**432,000**	**414,000**	**313,151**	**-100,849**

[a] In FY 2019, INFUSE funding was included under Science Discovery through Advanced Computing (SciDAC) and High Energy Density Laboratory Plasmas (HEDLP) activities. Starting in FY 2020, INFUSE is identified as a separate activity.

(dollars in thousands)

	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
Construction				
20-SC-61, Matter in Extreme Conditions Petawatt Upgrade	—	15,000	5,000	-10,000
14-SC-60, U.S. Contributions to ITER	132,000	242,000	107,000	-135,000
Total, Construction	**132,000**	**257,000**	**112,000**	**-145,000**
Total, Fusion Energy Sciences	**564,000**	**671,000**	**425,151**	**-245,849**

SBIR/STTR funding:

- FY 2019 Enacted: SBIR $12,992,000 and STTR $1,827,000
- FY 2020 Enacted: SBIR $12,348,000 and STTR $1,737,000
- FY 2021 Request: SBIR $8,469,000 and STTR $1,191,000

Fusion Energy Sciences
Explanation of Major Changes

	(dollars in thousands) FY 2021 Request vs FY 2020 Enacted
Burning Plasma Science: Foundations	**-58,500**
The Request for DIII-D supports the transition to extended shift operations to allow increased utilization of the facility, with 13 weeks of research operations, as well as some continued facility enhancements to ensure the world-leading status of the facility. Funding for the NSTX-U program will support the completion of the NSTX-U Recovery project and initiation of machine commissioning, 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 continue exploring 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 and other DOE laboratories where fusion research is conducted. Private-public partnership collaborations through the INFUSE program will continue.	
Burning Plasma Science: Long Pulse	**-21,000**
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 2021, and initiates long-lead major procurements.	
Discovery Plasma Science	**-21,349**
For General Plasma Science, the Request emphasizes user research on collaborative research facilities at universities and national laboratories 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 (MEC) instrument of the LCLS user facility at SLAC, supporting research on medium-scale laser facilities through the LaserNetUS network, and exploring research opportunities of QIS.	
Construction	**-145,000**
FES will support design activities 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.	
Total, Fusion Energy Sciences	**-245,849**

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 and, in FY 2020, conducted joint solicitations with the Advanced Research Projects Agency-Energy (ARPA-E). 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. Research supported through this joint program extends 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
The need for a new fusion materials irradiation capability.
The FES sponsored U.S. Virtual Laboratory for Technology (VLT) organized a workshop to discuss the need for a fusion prototypic neutron source (FPNS) and to determine the parameters required to fill this need. The workshop reached the unanimous conclusion that a near term, moderate cost FPNS would significantly advance the scientific understanding of materials degradation in the intense fusion neutron environment and would be a major asset to the U.S. fusion program. A FPNS is a potential intermediate step to next generation sources such as the International Fusion Materials Irradiation Facility (IFMIF) being pursued by the EU and Japan if it becomes available near-term. Achieving this role requires start of construction within about three years.

The Innovation Network for Fusion Energy (INFUSE) pilot program.
Recognizing the surge in interest and investments by the private sector in the development of fusion energy, FES launched a pilot program to accelerate progress in fusion energy by establishing research partnerships with the private sector. These private-public research partnerships enable applicants to access and leverage the world-class expertise and capabilities in fusion science available at the DOE national laboratories. This new FES program is modeled after the successful Gateway for Accelerated Innovation in Nuclear (GAIN) Nuclear Energy Voucher program established by the Office of Nuclear Energy.

Machine learning allows NSTX-U to accurately model external heating during plasma discharges.
Neutral beam injectors are an effective source of heating for fusion experimental plasmas, but understanding this power tends to be a slow, analysis intensive process requiring many discharges. Recently, researchers at the Princeton Plasma Physics Laboratory (PPPL) were able to develop a new model of neutral beam injection that is fast and accurate enough to be useful in controlling discharges as they evolve. The scientists used neural networks and trained the model using a database of NSTX-U discharges. If this new model is used to control the plasma, it is expected that the optimization of plasma performance scenarios could be achieved many times faster than is typical.

Establishment of LaserNetUS.
FES established a network of laser facilities in the U.S. that includes nine institutions: the University of Texas at Austin, The Ohio State University, Colorado State University, The University of Michigan, University of Nebraska- Lincoln, University of Rochester, SLAC National Accelerator Laboratory, Lawrence Berkeley National Laboratory, and Lawrence Livermore National Laboratory. LaserNetUS will provide scientists with access to these facilities, promote networking and collaboration, develop next generation workforce for DOE laboratories, and help the U.S. regain the recently lost leadership in high intensity laser science.

U.S. diagnostic is key to Wendelstein 7-X (W7-X) stellarator world record.
W7-X attained the stellarator world record for the fusion triple product of ion temperature, plasma density, and energy confinement. This represents further progress towards achieving the reactor values needed to ignite a plasma. This value of the fusion triple product is excellent for a device of this size, achieved under realistic conditions, i.e. at a high temperature of the plasma ions. The temperature was measured by the x-ray imaging crystal spectrometer, built and operated by PPPL. The record could not have been confirmed without the crucial spectrometer measurement.

Never-before-seen Parker spiral created in the Laboratory.
The Sun is a spinning ball of plasma that generates its own magnetic field. Fueled by the nuclear fusion in its core, the Sun spews plasma out into the solar system forming the solar wind. The solar wind sweeps away the Sun's magnetic field. As the Sun rotates, the magnetic field bends into a spiral structure known as the Parker spiral. For the very first time, researchers recreated the Parker spiral in the laboratory by forcing a helium plasma to rotate in the plasma confinement vessel. Once the plasma spun fast enough, its magnetic field formed a spiral. Although the Parker spiral is far more complex and expansive than its laboratory equivalent, this laboratory plasma model accurately reproduces the structure of the Sun's magnetic field. The results can be used to further examine the origin and evolution of the solar wind.

Plasma syntheses of nanoparticles.
Exact mechanisms of nanoparticle growth in an arc discharge are not fully understood because it is difficult to make in situ measurements of nanoparticles. For the first time, spatially-resolved measurements with a planar laser-induced incandescence technique, and simulations were performed to identify the plasma parameters and location where nanoparticles form and grow in an atmospheric pressure carbon arc. The measurements revealed that large clouds of nanoparticles have formed in the arc periphery bordering the region with a high density of diatomic carbon molecules. Two-dimensional fluid simulations of the arc combined with thermodynamic modeling show that the nanoparticle cloud shape is determined by the convection flow pattern, and nanoparticle size is determined by the rate of the condensation of carbon molecular species and particle agglomeration. These results will contribute to the development of more accurate models for the growth of nanoparticles and nanotubes in plasma environments.

Several key DIII-D facility enhancements completed.
In May, 2018, the DIII-D National Fusion Facility began an extended shutdown period in order to implement several major facility enhancements that could not be completed while the facility was operating. This work was completed on schedule in April 2019, and research operations resumed as planned in June. The enhancements to the facility will give DIII-D researchers several new world-unique tools to investigate the physics of advanced tokamak fusion plasmas. The new heating and current drive capabilities, as well as improvements to DIII-D's interior structure and diagnostic systems, have already been commissioned and are being used in experiments. These new resources will help DIII-D scientists to further optimize the advanced tokamak as a fusion energy source.

Building the world's largest pulsed electromagnet.
ITER's giant central solenoid was designed to induce a powerful current in the ITER plasma and maintain it during long pulses. The ITER project intends to demonstrate that through magnetically confined super-hot plasma, more energy will be given off than what it took to make the fusion reaction for a sustained period of time. The implications of a successful demonstration are world changing and may eventually lead to fusion energy power plants. One of the critical systems the U.S. is providing is the central solenoid (CS), which serves as the backbone of the ITER Magnet System. The CS consists of six independent coil modules held together by a vertical pre-compression structure. The U.S. is responsible for the six modules, an additional spare module, the structure that connects them together, and the required assembly tooling. When installed, the CS will be able to generate 6.4 Gigajoules of stored magnetic energy. The manufacturing process takes approximately 22 to 24 months per module plus an additional five to six months of testing. In April 2019, the first of seven modules successfully passed the first round of extensive testing. Six modules are currently in various stages of production and the first will be ready in early 2020 for shipment.

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 DOE laboratories where fusion research is ongoing.
- Support for private-public partnerships through the INFUSE program.

Research in the Burning Plasma Science: Foundations area in FY 2021 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 basic research needs workshops and other community-led studies. It will also support new transformational approaches, such as machine learning, QIS, and other SC-wide initiatives.

<u>Advanced Tokamak</u>

The DIII-D user facility at General Atomics in San Diego, California, is the largest magnetic fusion research experiment in the U.S. It can magnetically confine plasmas at temperatures relevant to burning plasma conditions. Its extensive set of advanced diagnostic systems and 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.

Versatile, university-led, small-scale advanced tokamak research is complementary to the efforts at the major user facilities, providing rapid and 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. 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.

<u>Spherical Tokamak</u>

The NSTX-U user facility at PPPL is 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 2021, NSTX-U recovery activities will continue with component fabrication and installation, as well as addressing corrective actions that will ensure 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 and follow-up targeted reviews in FY 2018 consists of nine multi-institutional interdisciplinary partnerships, seven of which are jointly supported by FES and ASCR, and addresses the high-priority research directions identified in recent community workshops. The current 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 ML 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].

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.

Innovation Network for Fusion Energy Program

The Innovation Network for Fusion Energy (INFUSE) program provides private-sector fusion companies with access to the expertise and facilities of DOE's national laboratories to overcome critical scientific and technological hurdles in pursuing development of fusion energy systems. Initiated in FY 2019, this private-public research partnership program, the first of its kind in SC, is modeled after the successful Gateway for Accelerated Innovation in Nuclear (GAIN) Nuclear Energy Voucher program. The INFUSE program does not provide funding directly to the private companies, but instead provides support to DOE laboratories to enable them to collaborate with their industrial partners. Among the areas supported by INFUSE are the development of fusion technologies, such as new and improved magnets; materials science, including engineered materials, testing and qualification; plasma diagnostic development; modeling and simulation; and access to magnetic fusion experimental capabilities.

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

Activities and Explanation of Changes

(dollars in thousands)

FY 2020 Enacted		FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
Burning Plasma Science: Foundations	**$279,500**	**$221,000**	**-$58,500**
Advanced Tokamak	$123,500	$92,500	-$31,000
DIII-D Research	*$56,000*	*$40,500*	*-$15,500*
DIII-D Operations	*$60,500*	*$49,000*	*-$11,500*
Funding supports 20 weeks of research at the DIII-D facility. The facility begins a transition to an extended shift mode of operation to support optimal facility operations levels for DIII-D. Facility improvements to increase auxiliary heating power, current drive, and 3D magnetic field shaping capabilities are supported. Research utilizes 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 exploits new diagnostics to improve the understanding of divertor material erosion and transport. Specific research goals 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.		The Request will support 13 weeks of operations at the DIII-D facility. Research will utilize newly installed capabilities including innovative current drive systems, tungsten tiles to study the transport of metal impurities, and new diagnostics to study pedestal and power exhaust physics. A new helium liquifier system will be installed and operated to improve availability of the facility. Specific research goals will aim at assessing the reactor potential of current-drive systems to inform the design of next-step devices, integrating core and edge plasma solutions that extrapolate to future fusion reactors, and advancing the understanding of power exhaust strategies.	Funding will support research and operations. Progress will continue on several high-priority facility enhancement projects aimed at ensuring the world-leading status of the facility.

(dollars in thousands)

FY 2020 Enacted		FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
Enabling R&D	*$6,000*	*$2,000*	*-$4,000*
Funding supports research in high-temperature superconducting magnet technology and plasma fueling and heating technologies. Developing high-field magnet cable testing capabilities, in collaboration with the HEP continues.		The Request will support continuing research in high-temperature superconducting magnet technology and plasma fueling and heating technologies.	Funding will focus on high-temperature superconducting magnet technology and heating and fueling technologies.
Small-scale Experimental Research	*$1,000*	*$1,000*	$—
Funding supports university-led experiments in developing innovative strategies to improve the performance of advanced tokamaks.		The Request will continue university-led experiments to develop new optical-based tokamak control schemes, measure boundary and wall current dynamics during plasma disruptions, and refine scrape-off layer current control methods.	Support for research activities will continue at the same level of effort.
Spherical Tokamak	$101,000	$72,500	-$28,500
NSTX-U Research	*$30,000*	*$27,000*	*-$3,000*
NSTX-U Operations	*$68,000*	*$43,500*	*-$24,500*
Funding supports continual recovery procurements and fabrication activities that are necessary to realize robust research operations. Research supports analysis and modeling efforts at other facilities that support NSTX-U research program priorities and the installation of high-priority diagnostic instruments on the device continues.		The Request for operations funding will continue to support recovery procurements, fabrication, and machine reassembly activities that are necessary to resume robust research operations. Research efforts will focus on analysis and modeling activities at other facilities that support NSTX-U program priorities.	Operations funding will continue to support the NSTX-U Recovery activity as PPPL continues machine reassembly activities and prepares for machine commissioning and plasma start-up. Research funding will be dedicated to the highest-priority scientific objectives of NSTX-U.

(dollars in thousands)

FY 2020 Enacted		FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
Small-scale Experimental Research	*$3,000*	*$2,000*	*-$1,000*
Funding supports studies and experiments 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.		The Request will continue to support studies and experiments focused on exploring operational scenarios without a central solenoid, model validation, and detailed core turbulent transport mechanisms observed in plasmas with low recycling liquid lithium walls.	Research efforts will focus on the highest-priority activities.
Theory & Simulation	$44,000	$51,000	+$7,000
Theory	*$19,000*	*$21,000*	*+$2,000*
Funding supports the foundational problems in the science of magnetic confinement. Emphasis is placed on research that maximizes synergy with large-scale simulation efforts and addresses recommendations from community workshops.		The Request will continue to support theory and modeling efforts focusing on advancing the scientific understanding of the fundamental physical processes governing the behavior of magnetically confined plasmas. The activity will emphasize research that addresses critical burning plasma challenges, including plasma disruptions, runaway electrons, three-dimensional and non-axisymmetric effects, and the physics of the plasma boundary.	The increase in funding will strengthen efforts that address the needs of large-scale simulation projects.
SciDAC	*$25,000*	*$30,000*	*+$5,000*
Funding supports nine FES SciDAC partnerships to address challenges in burning plasma science, with emphasis on integration and whole-device modeling, as well as Exascale readiness. Progress in plasma disruptions accelerates following the addition of a partnership focusing on runaway electron physics in FY 2018. Validation of the simulation codes against experimental data is also emphasized. Research efforts focusing on emerging technologies with transformational potential, such as machine learning and computing aspects of QIS, continues.		The Request will continue to support the nine FES SciDAC partnerships, now in their fifth and final year. Emphasis on whole-device modeling and Exascale readiness will continue. The Request will also support research on fusion-relevant quantum computing, machine learning, and artificial intelligence.	SciDAC partnerships will continue at the same level of effort. Additional funding will support new efforts in QIS and fusion-relevant AI/ML applications.

(dollars in thousands)

FY 2020 Enacted		FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
GPE/GPP/Infrastructure	$7,000	$1,000	-$6,000
Funding supports PPPL infrastructure improvements, repair, maintenance and environmental monitoring. In addition, a study of FES infrastructure needs at ORNL continues.		The Request will support PPPL infrastructure improvements, repair, maintenance and environmental monitoring.	Funding efforts will focus on the highest-priority activities.
Innovation Network for Fusion Energy (INFUSE) program	$4,000	$4,000	—
Funding enables more awards, allows the participation of additional DOE laboratories in the program, and expands the eligibility requirements to include foreign companies, provided their participation in this activity is in the economic interest of the U.S.		The Request will enable the INFUSE program to continue to provide funding opportunities for partnerships with the private sector through DOE laboratories in multiple research areas.	The INFUSE program will continue at the same level of effort.

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 nuclear device. This subprogram includes long-pulse international tokamak and stellarator research, and fusion nuclear science and materials research.

Long Pulse: Tokamak

This program supports interdisciplinary teams from multiple U.S. institutions for collaborative research aimed at advancing the scientific and technology basis for sustained long-pulse burning plasma operation in tokamaks. Bilateral research on international facilities with capabilities not available in the U.S. targets critical topical areas identified in recent FESAC reports and detailed community workshop reports, including prediction and avoidance of transient events in fusion reactors, advanced algorithms such as AI/ML, plasma-material interactions, and integrated simulations. Research on overseas superconducting tokamaks, conducted onsite and also via fully remote facility operation, leverages progress made in domestic experimental facilities and provides access to model validation platforms for mission critical applications supported through the FES/ASCR partnership within the SciDAC portfolio. Efforts are augmented by research on non-superconducting tokamaks with access to burning plasma scenarios and mature diagnostic suites.

Long Pulse: Stellarator

Stellarators offer the promise of steady-state confinement regimes without transient events such as harmful disruptions. The three-dimensional (3D) shaping of the plasma in a stellarator provides for a broader range in design flexibility than is achievable in a 2D system. The participation of U.S. researchers on W7-X in Germany provides an opportunity to develop and assess 3D 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. 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 extreme 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. Developing solutions for this complex scientific challenge requires new experimental capabilities along with game-changing types of research. Facilities with these experimental capabilities will need to replicate or effectively simulate various aspects of the harsh fusion environment. These experimental capabilities will 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 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) facility 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.

Activities and Explanation of Changes

(dollars in thousands)

FY 2020 Enacted		FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
Burning Plasma Science: Long Pulse	**$70,000**	**$49,000**	**-$21,000**
Long Pulse: Tokamak	$14,000	$8,000	-$6,000
Funding supports research on overseas superconducting tokamaks 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 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.		The Request will support U.S. teams to develop prediction, avoidance, and mitigation strategies for potentially damaging transient events in large tokamaks, validate computational tools for integrated simulation of burning plasmas, and assess the potential of solid metal walls as the main plasma facing material in long-pulse tokamak facilities.	Research efforts will focus on high-priority topics aimed at resolving critical design issues for large long-pulse tokamaks such as ITER, and validation of predictive models that support facility and plasma control design frameworks.
Long Pulse: Stellarators	$8,500	$7,500	-$1,000
Superconducting Stellarator Research	*$6,000*	*$5,000*	*-$1,000*
Funding supports U.S. scientist to complete fabrication and installation of 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.		The Request will support U.S. scientists to utilize the continuous pellet fueling system, which was installed on W7-X, to understand optimum profiles for turbulence suppression. This U.S.-built system, which is critical for long-pulse operation, will help address a number of scientific issues involved with quasi-steady-state operation for the stellarator configuration.	Research efforts will focus on the highest-priority activities.

(dollars in thousands)

FY 2020 Enacted		FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
Compact Stellarator Research	*$2,500*	*$2,500*	*$—*
Funding supports research on experiments that are providing data in regimes relevant to mainline stellarator confinement and experimental validation of models and codes.		The Request will support experiments in regimes relevant to the mainline stellarator magnetic confinement efforts and help confirm theoretical models and simulation codes to support the development of an experimentally-validated predictive capability for magnetically-confined fusion plasmas.	Research efforts will continue at the same level of support.
Materials & Fusion Nuclear Science	$47,500	$33,500	-$14,000
Fusion Nuclear Science	*$11,000*	*$8,500*	*-$2,500*
Funding supports research to focus on the core areas of plasma-facing components, safety, tritium fuel cycle, and breeder blanket technologies. Opportunities are pursued for expansion into other novel technologies as identified by the FESAC report on Transformative Enabling Capabilities. In addition, FES continues to evaluate options for a near-term fusion-relevant neutron source.		The Request will continue to focus on the core research areas of tritium fuel cycle, breeder blanket technologies, safety, and plasma-facing components. The program will continue expanding efforts into the areas of novel fusion blanket and tritium fuel cycle research. In addition, FES will continue to evaluate options for a near-term neutron source to test materials in fusion-relevant environments.	Research efforts will focus on the highest-priority areas across the entire fusion nuclear science technology portfolio to balance the core programs and expansion into new areas.
Materials Research	*$15,500*	*$13,000*	*-$2,500*
Funding supports research efforts to focus on the development of materials that can withstand the extreme fusion environment. Working toward opportunities for expansion into high-priority research in advanced materials and manufacturing.		The Request will continue to focus research on the development of materials that can withstand the extreme fusion environment, including further expansion into the high impact topics of advanced materials and manufacturing.	Research efforts will focus on high-priority activities in fusion materials research.
Projects	*$21,000*	*$12,000*	*-$9,000*
Funding supports the MPEX MIE project and enables engineering design activities and preparation for baseline approval and long-lead procurements.		The Request will continue to support the MPEX MIE project. Activities will include the establishment of the project performance baseline and the initiation of long-lead procurement items.	Funding will continue to support critical activities required to develop a cost, schedule, and scope baseline and initiate long-lead procurements for the MPEX MIE project.

Fusion Energy Sciences
Discovery Plasma Science

Description

The Discovery Plasma Science subprogram supports research that explores the fundamental properties and complex behavior of matter in the plasma state to improve the understanding required to control and manipulate plasmas for a broad range of applications. Plasma science is not only fundamental to understanding the nature of visible matter throughout the universe, but also to achieving the eventual production and control of fusion energy. Discoveries in plasma science are leading to an ever-increasing array of practical applications, such as synthesis of nanomaterials and artificial diamonds, fabrication of microelectronics 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.

Plasma Science Frontiers

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. In addition, this portfolio supports microelectronics and QIS research opportunities.
- 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. In addition, this portfolio supports QIS research opportunities.
- Exploratory Magnetized Plasma: Basic research involving the creation, control, and manipulation of magnetically confined plasmas to increase the 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, and comparisons with space observations. This effort maintains strong partnerships with NSF and NNSA.

Measurement Innovation

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. In addition, this portfolio supports new QIS research opportunities on fusion-relevant quantum sensing applications.

SBIR/STTR & Other

Funding for SBIR/STTR and future fusion design studies are 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 FESAC.

Activities and Explanation of Changes

(dollars in thousands)

FY 2020 Enacted		FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
Discovery Plasma Science	**$64,500**	**$43,151**	**-$21,349**
Plasma Science Frontiers	$42,500	$25,000	-$17,500
General Plasma Science	*$18,000*	*$13,000*	*-$5,000*
Funding supports core research areas focused on basic plasma science and low-temperature plasma collaborative research facilities, including support for users of these facilities.		The Request supports core research activities in basic and low temperature plasma science focused on supporting user research on collaborative research facilities at universities and national laboratories.	Research efforts will focus on highest-priority science issues in both basic and low temperature plasmas.
High Energy Density Laboratory Plasmas	*$20,000*	*$12,000*	*-$8,000*
Funding supports research with an emphasis on utilization of the Matter in Extreme Conditions (MEC) instrument at the LCLS at SLAC. Support continues for the MEC beam-line science team and the LaserNetUS initiative. Application of HEDLP to advance QIS is supported.		The Request will emphasize research utilizing the MEC, LaserNetUS, and QIS.	Research efforts will focus on the highest-priority science issues.
Projects	*$4,500*	*$—*	*-$4,500*
Funding continues to support the conceptual design of the MEC Petawatt Upgrade.		No funding is requested.	No funding is requested.
Measurement Innovation	$3,000	$3,000	$—
Funding supports 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 as well as for partnership opportunities with the private sector.		The Request will continue to support the development of transformative and innovative diagnostics for plasma transient instabilities, plasma-material interactions, modeling validation, QIS research activities, and basic plasma science identified in the community engagement workshops.	Research efforts will focus on highest-priority activities.

(dollars in thousands)

FY 2020 Enacted	FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
SBIR/STTR & Other $19,000	$15,151	-$3,849
Funding supports 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 Request will continue to support USBPO activities, HBCUs, peer reviews for solicitations, outreach programs, and FESAC. In addition, the Request will support the initiation of a study for a future fusion facility complex that will support both public and private activities. SBIR/STTR is statutorily set at 3.65 percent of noncapital funding in FY 2021.	The study effort on a future fusion facility complex is a new activity for this program element. The SBIR/STTR funding will be consistent with the FES total budget.

Fusion Energy Sciences
Construction

Description

This subprogram supports all line-item construction projects 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”. The MEC Petawatt Upgrade project was a new start in FY 2020 and is an upgrade to the existing MEC facility. This project is aimed at providing an experimental collaborative National User Facility for High-Energy-Density Science that will address this NAS recommendation as well as maintain U.S. leadership in this important field of study. MEC is an experimental research end-station that utilizes SLAC’s Linac Coherent Light Source. The project received CD-0, “Approve Mission Need” on January, 4, 2019. The FY 2021 Request of $5,000,000 will support conceptual design of the MEC Petawatt Upgrade. The estimated total project cost is $50,000,000 to $200,000,000.

ITER

The ITER facility, currently under construction in St. Paul-lez-Durance, France, and more than 65 percent complete for First Plasma, is designed 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 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 FY 2021 Request of $107,000,000 will support the highest priority activities. The estimated total project cost is $4,700,000,000 to $6,500,000,000.

The U.S. in-kind contribution represents 9 percent of the overall cost, but will allow access to 100 percent 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

(dollars in thousands)

FY 2020 Enacted		FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
Construction	**$257,000**	**$112,000**	**-$145,000**
Matter in Extreme Conditions (MEC) Petawatt Upgrade	$15,000	$5,000	-$10,000
Funding supports design activities for this project to achieve CD-1.		The Request will support design activities, preparation for developing a project baseline, and long-lead procurements for an upgrade to MEC.	Funding will support critical activities required to develop a cost, schedule, and scope baseline and initiate long-lead procurements for the MEC upgrade project.
U.S. Contributions to ITER	$242,000	$107,000	-$135,000
Funding supports continuing design and fabrication of the highest priority "in-kind" hardware systems.		The Request will support continued design and fabrication of in-kind hardware systems for the First Plasma subproject (SP-1).	Funding will continue to focus on the highest-priority SP-1 activities.

Fusion Energy Sciences
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	16,874	21,760	48,112	+26,352
Minor Construction Activities						
General Plant Projects (GPP)	N/A	N/A	9,134	6,350	380	-5,970
Total, Capital Operating Expenses	**N/A**	**N/A**	**26,008**	**28,110**	**48,492**	**+20,382**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
Capital Equipment						
Major Items of Equipment[a]						
Burning Plasma Science: Long Pulse						
Materials Plasma Exposure eXperiment (MPEX)	86,000-175,000	—	14,746	21,000	12,000	-9,000
Total, Non-MIE Capital Equipment	N/A	N/A	2,128	760	36,112	+35,352
Total, Capital Equipment	**N/A**	**N/A**	**16,874**	**21,760**	**48,112**	**+26,352**

Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
General Plant Projects (GPP)						
Total GPPs less than $5M[b]	N/A	N/A	9,134	6,350	380	-5,970

[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 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 2021. The proposed funding will allow for the project to obtain baseline performance approval in FY 2021 and initiate long-lead time procurements for the device. Following conceptual design completion, the preliminary cost range is between $86,000,000 –$175,000,000.

Fusion Energy Sciences
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade						
TEC	TBD	—	—	15,000	5,000	-10,000
OPC	TBD	—	1,600	4,500	—	-4,500
TPC	**TBD**	**—**	**1,600**	**19,500**	**5,000**	**-14,500**
14-SC-60, U.S. Contributions to ITER						
TEC	TBD	1,239,617	132,000	242,000	107,000	-135,000
OPC	TBD	70,302	—	—	—	—
TPC	**TBD**	**1,309,919**	**132,000**	**242,000**	**107,000**	**-135,000**
Total, Construction						
TEC	**TBD**	**1,239,617**	**132,000**	**257,000**	**112,000**	**-145,000**
OPC	**TBD**	**70,302**	**1,600**	**4,500**	**—**	**-4,500**
TPC	**TBD**	**1,309,919**	**133,600**	**261,500**	**112,000**	**-149,500**

Fusion Energy Sciences
Funding Summary

(dollars in thousands)

	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
Research	261,950	253,000	207,651	-45,349
Facility Operations	143,500	128,500	92,500	-36,000
Projects				
Major Items of Equipment	14,746	21,000	12,000	-9,000
Construction	133,600	261,500	112,000	-149,500
Total, Projects	148,346	282,500	124,000	-158,500
Other	10,204	7,000	1,000	-6,000
Total, Fusion Energy Sciences	**564,000**	**671,000**	**425,151**	**-245,849**

Fusion Energy Sciences
Scientific User Facility Operations

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

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

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

Percent of Optimal Hours – An indication of utilization effectiveness in the context of available funding; it is not a direct indication of scientific or facility productivity.
- For BY and CY, Planned Operating Hours divided by Optimal Hours expressed as a percentage.
- For PY, Achieved Operating Hours divided by Optimal Hours.

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

(dollars in thousands)

	FY 2019 Enacted	FY 2019 Current	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
TYPE A FACILITIES					
DIII-D National Fusion Facility	**$121,500**	**$121,443**	**$116,500**	**$89,500**	**-27,000**
Number of users	673	718	718	600	-118
Achieved operating hours	N/A	480	N/A	N/A	N/A
Planned operating hours	480	480	800	520	-280
Optimal hours	480	480	960	960	—
Percent optimal hours	100%	100%	83%	54%	-29.2%
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A

(dollars in thousands)

	FY 2019 Enacted	FY 2019 Current	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
National Spherical Tours Experimental—Upgrade	**$93,000**	**$92,250**	**$98,000**	**$70,500**	**-27,500**
Number of users	385	308	326	320	-6
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	**$214,500**	**$213,693**	**$214,500**	**160,000**	**-54,500**
Number of users	1,058	1,026	1,044	920	-124
Achieved operating hours	N/A	480	N/A	N/A	N/A
Planned operating hours	480	480	800	520	-280
Optimal hours	480	480	960	960	—
Percent optimal hours[a]	100%	100%	83%	54%	-29.2%
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A

Fusion Energy Sciences
Scientific Employment

	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
Number of permanent Ph.D.'s (FTEs)	932	859	646	-213
Number of postdoctoral associates (FTEs)	114	106	79	-27
Number of graduate students (FTEs)	310	287	216	-71
Other scientific employment (FTEs)[b]	1,390	1,284	964	-320

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

[b] 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 2021 Request for the Matter in Extreme Conditions (MEC) Petawatt Upgrade project is $5,000,000. The MEC is an experimental research end-station that utilizes the Linac Coherent Light Source (LCLS) SC User Facility at the SLAC National Accelerator Laboratory. The preliminary estimated Total Project Cost (TPC) range for the MEC Petawatt Upgrade is $50,000,000 to $200,000,000. SC plans for the project to achieve Critical Decision-1 (CD-1), “Approve Alternative Selection and Cost Range” in FY 2020.

SLAC is developing options with wide-ranging cost and schedule implications. In the 2nd quarter of FY 2020, FES will select the option that considers how best to achieve and maintain world leading fusion discovery science. The best option will include a large-scale, open-access, high-intensity laser facility that is co-located with hard X-ray laser-probing capabilities (i.e., with an X-ray wavelength that allows atomic resolution).

Significant Changes

The project achieved CD-0, “Approve Mission Need” on January, 4, 2019. Other Project Costs funding in FY 2020 will support preliminary design of the civil infrastructure and technical hardware. When the project achieves CD-1, “Approve Alternative Selection and Cost Range”, which is planned for FY 2020, SC will then initiate TEC design efforts. A Federal Project Director has been assigned to the MEC Petawatt Upgrade project.

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	1/04/19	3Q FY 2019	1Q FY 2020	TBD	TBD	TBD	TBD	TBD
FY 2021	1/04/19	4Q FY 2020	4Q FY 2020	3Q FY 2022[a]	4Q FY 2021[a]	3Q FY 2023[a]	FY 2040[a]	1Q FY 2028[a]

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 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
FY 2021	20,000	170,400	190,400	9,600	—	9,600	200,000[a]

[a] This project is pre-CD-2; therefore, funding and schedule estimates are preliminary.

2. Project Scope and Justification

Scope

The scope of the MEC Petawatt Facility project includes the development of a facility that couples high-energy and high-intensity drive lasers, including a system with at least a range of 1 to 10 pettawatt (PW) peak power, to an X-ray source capable of producing ultrafast, high-peak-brightness pulses. The laser will be placed in a dedicated MEC experimental hall (located at the end of the LCLS-II Far Experimental hall), comprised of a new access tunnel with a range of 100 to 500 feet in length, a new cavern with 6,000 to 10,000 square feet, and associated safety systems and infrastructure.

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 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 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 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 LCLS at the SLAC National Accelerator Laboratory has demonstrated exquisite ultrafast measurements of the material structural response to radiation. Higher flux sources of deuterons, neutrons, and gamma rays are needed however 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 utilizing the project management principles described in DOE O 413.3B*, Program and Project Management for the Acquisition of Capital Assets*.

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project

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

must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion. The project is in conceptual design phase and the KPPs reflect the types of parameters being considered and are notional at this stage; the preliminary KPPs will be developed in coordination with FES and proposed for the Project Management Executive (PME) consideration and approval at CD-1.

Performance Measure	Threshold	Objective
Radiation shielded experiment cavern	0.5 PW at 1 Hertz (Hz)	1.0 PW at 10 Hz

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2020	15,000	15,000	15,000
FY 2021	5,000	5,000	5,000
Outyears	—	—	—
Total, Design	20,000	20,000	20,000
Construction			
FY 2020	—	—	—
FY 2021	—	—	—
Outyears	170,400	170,400	170,400
Total, Construction	170,400	170,400	170,400
Total Estimated Cost (TEC)			
FY 2020	15,000	15,000	15,000
FY 2021	5,000	5,000	5,000
Outyears	170,400	170,400	170,400
Total, TEC	**190,400**	**190,400**	**190,400**
Other Project Cost (OPC)			
FY 2019	1,600	1,600	280
FY 2020	4,500	4,500	5,820
FY 2021	—	—	—
Outyears	3,500	3,500	3,500
Total, OPC	**9,600**	**9,600**	**9,600**
Total Project Cost (TPC)			
FY 2019	1,600	1,600	280
FY 2020	19,500	19,500	20,820
FY 2021	5,000	5,000	5,000
Outyears	173,900	173,900	173,900
Total, TPC	**200,000**[a]	**200,000**	**200,000**

[a] This project is pre-CD-2; therefore, funding and schedule estimates are preliminary.

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	17,000	TBD	TBD
Contingency	3,000	TBD	TBD
Total, Design	20,000	TBD	TBD
Construction			
Site Work	—	TBD	TBD
Equipment	60,800	TBD	TBD
Construction	70,000	TBD	TBD
Other, as needed	—	TBD	TBD
Contingency	39,600	TBD	TBD
Total, Construction	170,400	TBD	TBD
Other TEC			
Cold Startup	—	TBD	TBD
Contingency	—	TBD	TBD
Total, Other TEC	—	TBD	TBD
Total, TEC	**190,400**	**TBD**	**TBD**
Contingency, TEC	42,600	TBD	TBD
Other Project Cost (OPC)			
OPC except D&D			
R&D	350	TBD	TBD
Conceptual Planning	850	TBD	TBD
Conceptual Design	1,900	TBD	TBD
Other OPC Costs	3,500	TBD	TBD
Contingency	3,000	TBD	TBD
Total, OPC	**9,600**	**TBD**	**TBD**
Contingency, OPC	3,000	TBD	TBD
Total Project Cost	**200,000**	**TBD**	**TBD**
Total, Contingency (TEC+OPC)	**45,600**	**TBD**	**TBD**

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2019	FY 2020	FY 2021	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
FY 2021	TEC	N/A	—	15,000	5,000	170,400	190,400
	OPC	N/A	1,600	4,500	—	3,500	9,600
	TPC	N/A	1,600	19,500	5,000	173,900	200,000[a]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	1Q FY 2028
Expected Useful Life	TBD
Expected Future Start of D&D of this capital asset	TBD

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

As part of the DOE Order 413.3B CD-1 process, an Acquisition Strategy will be prepared for review and approval of the PME at CD-1.

[a] This project is pre-CD-2; therefore, funding and schedule estimates are preliminary.

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

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

Summary

The FY 2021 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, specifically the U.S., China, the European Union, India, the Republic of Korea, Japan, and the Russian Federation. These Members or Domestic Agencies are comprised of 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. U.S. ITER is a 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.

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 divided the U.S. ITER project hardware scope into two distinct subprojects, which represent the two phases of the project: the First Plasma (FP) subproject (SP-1), and the Post-FP subproject (SP-2). 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 FP subproject (SP-1) activities.

SP-2 is the second element of the U.S. ITER project, and includes the remainder of U.S. hardware contributions for Post-FP operations leading up to Deuterium-Tritium Operations. SP-2 is planned for baselining in the future.

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 CD 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.

Significant Changes

This CPDS is an update of the FY 2020 CPDS and does not include a new start for FY 2021 SP-1, which includes fabrication and delivery of all hardware required for FP and the completion of design for all U.S. hardware contributions, is more than 60 percent complete.

The FY 2021 Request of $107,000,000 will support the continued design and fabrication of 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 $1.2 billion through the end of FY 2019 to U.S. industry, universities, and DOE laboratories.

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

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	7/05/05		TBD	TBD		TBD	N/A	TBD
FY 2007	7/05/05		TBD	TBD		TBD	N/A	2017
FY 2008	7/05/05		1/25/08	4Q FY 2008		TBD	N/A	2017
FY 2009	7/05/05	9/30/09[a]	1/25/08	4Q FY 2010		TBD	N/A	2018
FY 2010	7/05/05	7/27/10[b]	1/25/08	4Q FY 2011		TBD	N/A	2019
FY 2011	7/05/05	5/30/11[c]	1/25/08	4Q FY 2011	4/12/11[d]	TBD	N/A	2024
FY 2012	7/05/05	7/10/12[e]	1/25/08	3Q FY 2012	5/02/12[f]	TBD	N/A	2028
FY 2013	7/05/05	12/11/12[g]	1/25/08	TBD[h]	4/10/13[i]	TBD	N/A	2033
FY 2014	7/05/05		1/25/08	TBD	12/10/13[j]	TBD	N/A	2034
FY 2015	7/05/05		1/25/08	TBD		TBD	N/A	2036
FY 2016[k]	7/05/05		1/25/08	TBD		TBD	N/A	TBD
FY 2017[l]	7/05/05		1/25/08	TBD		TBD	N/A	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 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

Fiscal Year	Performance Baseline Validation	CD-1 Cost Range Update	CD-2/3		CD-4	
			CD-3B	SP-2	SP-1	SP-2
FY 2018[m]	7/05/05	1/13/17	1/13/17	2019	1Q FY 2027	2034-2038
FY 2019	7/05/05	1/13/17	1/13/17	2019	1Q FY 2027	2034-2038

[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).
[m] 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).

Fiscal Year	Performance Baseline Validation	CD-1 Cost Range Update	CD-2/3		CD-4	
			CD-3B	SP-2	SP-1	SP-2
FY 2020	7/05/05	1/13/17	1/13/17	2021/2022	1Q FY 2028	2034-2038
FY 2021	7/05/05	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 billion to $2.2 billion. Until 2016, however, it was not possible to confidently baseline the project due to prior delays in the international ITER construction schedule. Various factors (e.g., schedule delays, design and scope changes, funding constraints, regulatory requirements, risk mitigation, and inadequate project management and leadership issues in the ITER Organization at that time) affected the project cost and schedule. Shortly after Director General Bigot's appointment in March 2015, the ITER Project was baselined for cost and schedule.

In response to a 2013 Congressional request, a DOE SC Independent Project Review (IPR) Committee assessed the project and determined that the existing cost range estimate of $4.0 billion 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 FP 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, the acting Director for the Office of Science updated 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. This updated CD-1R range incorporates increases in the projects hardware estimate that have occurred since August 2013. The SP-1 TPC is now baselined at $2.5 billion.

Subproject 1 (First Plasma Hardware for U.S. ITER)
(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2017[a]	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
FY 2021	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.) designed to demonstrate 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 percent) of the ITER facility's construction cost, while the other six Members, including the U.S., will each support one-eleventh (9.09 percent) 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. and Japan will contribute a 13 percent share; the EU will provide 34 percent and the other Members will each provide 10 percent. Operation, Deactivation, and Decommissioning are not part of the U.S. ITER project funding.

[a] 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.

Responsibility for ITER integration, management, design, licensing, installation, and operation rests with the IO, which is an international legal entity located in France.

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 (FP) and SP-2 (Post-FP). 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 percent of system for SP-1)
- 15 percent of ITER Diagnostics: provides the measurements necessary to control, evaluate, and optimize plasma performance and to further the understanding of plasma physics. (6 percent 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 percent 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 percent for SP-1)
- Ion Cyclotron Heating (ICH) Transmission Lines: bring additional power to the plasma. (15 percent 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 percent 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 percent 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 percent for SP-1)
- Roughing Pumps: evacuate the tokamak, cryostat, and auxiliary vacuum chambers prior to and during operations. (56 percent for SP-1)

Justification

The purpose of ITER is to investigate and conduct research in the “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	Threshold
Central Solenoid Magnet System	Provide 7 (including spare) independent coil packs made of superconducting niobium-tin providing 13 Tesla at 45 kilo Amps (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 gigawatt (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 kilometers (km) of aluminum waveguide lines (24 lines) capable of transmitting up to 1.5 megawatts (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 $25,000,000[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	102,000	102,000	126,726
FY 2020	157,000	157,000	167,182
FY 2021	107,000	107,000	100,348
Outyears	TBD	TBD	TBD
Subtotal	1,461,120	1,461,142	1,410,703
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

[a] Costs through FY 2019 reflect actual costs; costs for FY 2020 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
FY 2014[a]	32,895	32,895	32,895
FY 2015	15,957	15,957	15,957
FY 2016	—	—	—
FY 2017	—	—	—
FY 2018	—	—	—
FY 2019	30,000	30,000	30,000
FY 2020	85,000	85,000	85,000
FY 2021[b]	TBD	TBD	TBD
Outyears	TBD	TBD	TBD
Subtotal	259,497	259,497	259,497
Total, Cash Contributions	TBD	TBD	TBD
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[c]	104,667	104,655	112,463
FY 2013	121,440	121,474	123,879
FY 2014[d]	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	156,726
FY 2020	242,000	242,000	252,182
FY 2021	107,000	107,000	100,348
Outyears	TBD	TBD	TBD
Subtotal	1,720,617	1,720,639	1,670,200
Total, TEC	**TBD**	**TBD**	**TBD**

[a] Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.
[b] From within total ITER funding, in kind contribution and cash payment will be decided during the execution year.
[c] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.
[d] Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
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[a]	333	311	22,302
FY 2013	2,560	2,560	5,984
FY 2014[b]	—	—	2,090
FY 2015	—	—	600
FY 2016	34	34	—
FY 2017	—	-50	58
FY 2018	—	—	2
FY 2019	—	—	107
Subtotal	70,302	70,230	70,230
Total, OPC	**TBD**	**TBD**	**TBD**
Total Project Cost (TPC)[c]			
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[a]	105,000	104,966	134,765
FY 2013	124,000	124,034	129,863
FY 2014[d]	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

[a] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.
[b] Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.
[c] Costs through FY 2019 reflect actual costs; costs for FY 2020 and the outyears are estimates.
[d] Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
FY 2018	122,000	122,000	98,187
FY 2019	132,000	132,000	156,726
FY 2020	242,000	242,000	252,182
FY 2021	107,000	107,000	100,348
Outyears	TBD	TBD	TBD
Subtotal	1,790,919	1,790,869	1,740,323
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 on 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 billion 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 Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2019	FY 2020	FY 2021	Outyears	Total
FY 2006	TEC	1,038,000	—	—	—	—	1,038,000
	OPC	84,000	—	—	—	—	84,000
	TPC	1,122,000	—	—	—	—	1,122,000
FY 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

[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 U.S. 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.

(dollars in thousands)

Request Year	Type	Prior Years	FY 2019	FY 2020	FY 2021	Outyears	Total
FY 2012[a]	TEC	394,366	—	—	—	—	TBD
	OPC	75,019	—	—	—	—	TBD
	TPC	469,385	—	—	—	—	TBD
FY 2013[b]	TEC	617,261	—	—	—	—	TBD
	OPC	82,124	—	—	—	—	TBD
	TPC	699,385	—	—	—	—	TBD
FY 2014[c]	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	1,170,244	—	—	—	—	TBD
	OPC	80,641	—	—	—	—	TBD
	TPC	1,250,885	—	—	—	—	TBD
FY 2019	TEC	1,170,244	75,000	—	—	—	TBD
	OPC	80,641	—	—	—	—	TBD
	TPC	1,250,885	75,000	—	—	—	TBD
FY 2020	TEC	1,239,617	132,000	107,000	—	—	TBD
	OPC	70,302	—	—	—	—	TBD
	TPC	1,309,919	132,000	107,000	—	—	TBD
FY 2021	TEC	1,239,617	132,000	242,000	107,000	—	TBD
	OPC	70,302	—	—	—	—	TBD
	TPC	1,309,919	132,000	242,000	107,000	—	TBD

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

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	12/2025
Expected Useful Life	15–25 years
Expected Future Start of D&D of this capital asset	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. 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 decommissioning and 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 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.