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. In addition, the FES mission includes the development of a competitive fusion power industry in the U.S.

High-temperature fusion plasmas at hundreds of millions of degrees are being exploited to become the basis for a future carbon-free energy source. Once developed, fusion will provide an energy source well-suited for on-demand electrical production and other non-electric applications, supplementing intermittent renewables and fission. Energy from fusion has the potential to be carbon-free, inherently safe, and without the production of long-lived radioactive waste.

The frontier area of high-power, long-pulse fusion burning plasmas, to be enabled by the ITER experimental facility, will allow the discovery and study of new scientific phenomena relevant to fusion as a future carbon-free energy source. The DIII-D National Fusion Facility and the National Spherical Torus Experiment-Upgrade (NSTX-U) are world-leading Office of Science (SC) user facilities for experimental research, used by scientists from national laboratories, universities, and industry research groups, to optimize magnetic confinement regimes. Partnerships with the growing fusion private sector could potentially shorten the time for developing fusion energy by combining efforts to resolve common scientific and technological challenges; along with the Innovation Network for Fusion Energy (INFUSE) voucher program, FES will be establishing a Fusion Development Milestone Program in support of the Administration's Bold Decadal Vision (BDV) for commercializing fusion energy.

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. FES supports a Scientific Discovery through Advanced Computing (SciDAC) portfolio, in partnership with the Advanced Scientific Computing Research (ASCR) program. FES will prioritize transitioning Exascale Computing Project (ECP) researchers, software, and technologies into core research efforts and DOE priorities research areas as ECP concludes. U.S. scientists use international partnerships to conduct research on overseas tokamaks and stellarators with unique capabilities. The development of novel materials that can withstand enormous heat and neutron exposure is important for fusion and the design basis for a fusion pilot plant (FPP).

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. Practical applications of plasmas are found in microelectronics fabrication, nanomaterial synthesis, and space weather forecasting. Some of this research is carried out through partnerships with the National Science Foundation (NSF) and the National Nuclear Security Administration (NNSA).

The FES program invests in several SC cross-cutting initiatives such as artificial intelligence and machine learning (AI/ML), quantum information science (QIS), microelectronics, advanced manufacturing, advanced computing, and Accelerate Innovations in Emerging Technologies (Accelerate). In addition, continued funding for the Established Program to Stimulate Competitive Research (EPSCoR), the Reaching a New Energy Sciences Workforce (RENEW), and the Funding for Accelerated, Inclusive Research (FAIR) initiatives, FES will build stronger programs with underrepresented institutions and regions, including emerging research institutions (ERIs), minority serving institutions (MSIs) and historically black colleges and universities (HBCUs), for a more diverse and inclusive workforce.

FES program directions and activities are informed by the 2020 long-range plan (LRP) "Powering the Future: Fusion and Plasmas"[a] from the Fusion Energy Sciences Advisory Committee (FESAC), as well as reports from the National Academies of Sciences, Engineering, and Medicine (NASEM) and community workshops. Fusion energy is a critical clean energy and climate technology and infrastructure innovation R&D investment mentioned in the annual joint memorandum on "Multi-Agency research and Development Priorities for the FY 2024 Budget" from the Office of Management and Budget and the Office of Science and Technology Policy.[b]

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[a] https://science.osti.gov/-/media/fes/fesac/pdf/2020/202012/FESAC_Report_2020_Powering_the_Future.pdf

[b] https://www.whitehouse.gov/wp-content/uploads/2022/07/M-22-15.pdf

Highlights of the FY 2024 Request

The FY 2024 Request is $1,010.5 million with key elements listed below. The Request is aligned with recommendations in the recent FESAC LRP and the Administration's BDV; in bold font below are some specific examples of FES implementation of both. The FY 2024 Request includes:

Research

- DIII-D research: **Increase access for all users including those from universities pursuing research and development (R&D) at the frontiers of plasma science, and those from private industry by revising the facility user agreements.**
- NSTX-U research: Support initial machine commissioning, along with collaborative research at other facilities for addressing program priorities **including aspect ratio studies for an FPP.**
- Partnerships with private fusion efforts: **Support public-private partnerships with the Fusion Development Milestone and INFUSE programs.**
- Inertial Fusion Energy (IFE) and ITER Research: **Implement priority research opportunities that came out of the Basic Research Needs Workshops in these two scientific areas.**
- Fusion R&D Centers: **Initiate four multi-institutional, multi-disciplinary centers for Blanket/Fuel Cycle, Advanced Simulations, Structural/Plasma Facing Materials, and Enabling Technologies supporting public & private FPP efforts.**
- SciDAC: Continue development of an integrated simulation capability, expanding it from whole-device to whole-facility modeling, in partnership with ASCR.
- Long Pulse—Tokamak: **Support multi-disciplinary, multi-institutional teams working on international facilities, including validation of burning plasma models and FPP design tools.**
- Discovery plasma science: Continue support for basic plasma science collaborative facilities, HEDLP research/facilities, measurement innovation, QIS, and microelectronics research through new Microelectronics Science Research Centers.
- AI/ML: Support multi-institutional teams working to develop AI/ML tools in high-priority areas.
- Future Facilities Studies: **Support studies and research for a future fusion neutron source facility that is critical to the development of materials for fusion energy and was identified as the highest priority new facility in the FESAC LRP.**
- RENEW: **Expand targeted efforts, including a RENEW graduate fellowship, to broaden participation and advance justice, equity, diversity, and inclusion in SC-sponsored research.**
- FAIR: Provide focused investment for enhancing research on clean energy, climate, and related topics at ERIs, HBCUs, and MSIs.
- Accelerate: Support scientific research to accelerate the transition of scientific advances to energy technologies.
- EPSCoR: Support FES research in states and territories with historically lower Federal academic research funding.

Facility Operations

- DIII-D operations: Support 14 weeks of facility operations, representing 90 percent of optimal funding, and complete ongoing machine and infrastructure improvements.
- NSTX-U recovery and operations: Continue the recovery and repair activities. NSTX-U Operations will support machine assembly and hardware commissioning.

Projects

- U.S. hardware development and delivery to ITER: Support the continued design, fabrication, and delivery of U.S. in-kind hardware systems, including the continued fabrication, testing, and delivery of the Central Solenoid magnet modules, tokamak cooling water, tokamak exhaust processing, electron and ion heating transmission lines, diagnostics, tokamak fueling, disruption mitigation, vacuum auxiliary, and roughing pumps.
- Petawatt laser facility upgrade for HEDLP science: Support design activities for a world-leading upgrade to the Matter in Extreme Conditions (MEC) instrument on the Linac Coherent Light Source-II (LCLS-II) facility at SLAC National Accelerator Laboratory (SLAC).
- Major Item of Equipment (MIE) project for plasma-material interaction research: Continue to support the Material Plasma Exposure eXperiment (MPEX) MIE project, which includes the design, fabrication, installation, and commissioning of the MPEX linear plasma device, and associated facility modification and reconfiguration.

Other

- General Plant Projects/General Purpose Equipment (GPP/GPE): Support infrastructure improvements and repairs at the Princeton Plasma Physics Laboratory (PPPL) and other DOE laboratories.

Fusion Energy Sciences
Funding

(dollars in thousands)

	FY 2022 Enacted	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted
Fusion Energy Sciences				
Advanced Tokamak	123,390	134,122	157,722	+23,600
Spherical Tokamak	99,000	107,000	92,350	-14,650
Theory & Simulation	43,000	50,500	70,000	+19,500
GPP/GPE Infrastructure	1,500	1,500	1,000	-500
Public-Private Partnerships	31,000	31,000	135,000	+104,000
Artificial Intelligence and Machine Learning	7,000	11,000	11,000	–
Strategic Accelerator Technology	3,073	–	–	–
Inertial Fusion Energy (IFE)	–	10,000	15,000	+5,000
Total, Burning Plasma Science: Foundations	**307,963**	**345,122**	**482,072**	**+136,950**
Long Pulse: Tokamak	15,000	15,000	15,000	–
Long Pulse: Stellarators	8,500	7,500	7,500	–
Materials & Fusion Nuclear Science	59,500	56,500	147,500	+91,000
Future Facilities Studies	3,000	2,000	14,674	+12,674
Total, Burning Plasma Science: Long Pulse	**86,000**	**81,000**	**184,674**	**+103,674**
ITER Research	2,000	2,000	2,000	–
Total, Burning Plasma Science: High Power	**2,000**	**2,000**	**2,000**	**–**
Plasma Science and Technology	39,000	46,000	39,000	-7,000
Measurement Innovation	3,000	2,915	2,000	-915
Quantum Information Science (QIS)	10,000	10,000	10,000	–
Advanced Microelectronics	5,000	5,000	15,000	+10,000
Other FES Research	4,037	4,185	2,500	-1,685
Reaching a New Energy Sciences Workforce	3,000	6,000	11,250	+5,250
FES-Funding for Accelerated, Inclusive Research (FAIR)	–	2,000	4,000	+2,000
FES-Accelerate Innovations in Emerging Technologies	–	4,000	6,000	+2,000

(dollars in thousands)

	FY 2022 Enacted	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted
FES-Established Program to Stimulate Competitive Research (EPSCoR)	–	2,000	2,000	–
Total, Discovery Plasma Science	**64,037**	**82,100**	**91,750**	**+9,650**
Subtotal, Fusion Energy Sciences	**460,000**	**510,222**	**760,496**	**+250,274**
Construction				
20-SC-61 Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC	11,000	11,000	10,000	-1,000
14-SC-60 U.S. Contributions to ITER	242,000	242,000	240,000	-2,000
Subtotal, Construction	**253,000**	**253,000**	**250,000**	**-3,000**
Total, Fusion Energy Sciences	**713,000**	**763,222**	**1,010,496**	**+247,274**

SBIR/STTR funding:
- FY 2022 Enacted: SBIR $13,457,000 and STTR $1,899,000
- FY 2023 Enacted: SBIR $10,921,000 and STTR $1,536,000
- FY 2024 Request: SBIR $18,765,000 and STTR $2,642,000

Fusion Energy Sciences
Explanation of Major Changes

	(dollars in thousands) FY 2024 Request vs FY 2023 Enacted
Burning Plasma Science: Foundations The Request for DIII-D will support 14 weeks of research operations as well as completion of facility enhancements. Funding for the NSTX-U program will support the recovery activities and maintain collaborative research at other facilities to support NSTX-U research program priorities. The Request will expand support for the Fusion Development Milestone Program with private fusion industry. Support will continue for IFE science and technology. SciDAC will maintain emphasis on whole-facility modeling and will support a new integrated center on advanced simulations. Enabling R&D will focus attention on high-temperature superconductor development and will support a new R&D center on enabling technologies for fusion. Funding is provided for GPP/GPE to support critical infrastructure improvements and repairs.	**+136,950**
Burning Plasma Science: Long Pulse The Request will support high-priority international collaboration activities, for both tokamaks and stellarators. The Request will enhance funding for materials and fusion nuclear science research programs with the establishment of two new centers. The Request will support activities within the approved Critical Decision-2/3 (CD-2/3) baseline/start of construction for the MPEX MIE project. The Request continues support for a Future Facilities Studies program that will focus its efforts on conducting preliminary studies and research of a future fusion neutron source facility that can meet the performance requirements identified in recent community workshops.	**+103,674**
Burning Plasma Science: High Power The Request will continue to support an ITER Research program to prepare the U.S. fusion community to take full advantage of ITER.	**$ —**
Discovery Plasma Science For General Plasma Science (GPS), the Request will emphasize user research on collaborative research facilities at universities and national laboratories as well as interagency coordination and collaboration with the NSF on single investigator projects. For HEDLP, the Request will support research utilizing the MEC instrument of the LCLS user facility at SLAC and supporting research on the ten LaserNetUS network facilities. For QIS, the Request continues support for the National QIS Research Centers and the core research portfolio stewarded by FES. New Microelectronics Science Research Centers begin as authorized under the Micro Act. The RENEW initiative expands targeted efforts to increase participation and retention of individuals from underrepresented groups. Support will continue for FAIR, Accelerate, and the EPSCoR program.	**+9,650**
Construction FES will continue to support design activities for a world-leading upgrade to the MEC experimental hall facility. The U.S. Contributions to ITER project will continue design, fabrication, and delivery of First Plasma hardware, including continued fabrication and delivery of the central solenoid superconducting magnet modules. The Request supports funding for construction financial contributions to the ITER Organization (IO).	**-3,000**
Total, Fusion Energy Sciences	**+247,274**

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 the Basic Energy Sciences (BES) program, supports high-performance computing research with ASCR, uses the BES-supported High Flux Isotope Reactor (HFIR) facility at Oak Ridge National Laboratory (ORNL) for fusion materials irradiation research, and supports the construction of a high field magnet vertical test facility at the Fermi National Accelerator Laboratory with the High Energy Physics (HEP) program. Within DOE, FES manages a joint program with NNSA in HEDLP science and continues to support awards jointly funded with the Advanced Research Projects Agency-Energy (ARPA-E). FES also supports the fusion crosscutting team focusing on the BDV. Outside DOE, FES carries out a discovery-driven plasma science research program in partnership with NSF. The joint programs with NNSA and NSF involve coordination of solicitations, peer reviews, and workshops.

Program Accomplishments

DIII-D researchers develop optimized plasma performance scenarios.

U.S. researchers at the DIII-D National Fusion Facility simulated a unique approach to a compact fusion power plant concept, using physics-based simulations to optimize plasma performance. Optimal solutions were identified with high plasma density and self-driven plasma currents. The plasma current was driven in part from neutral particle beams and ultra-high harmonic (helicon) fast waves, a new technology being tested on the DIII-D facility.

Research on fusion facilities can improve spacecraft technology.

The DIII-D tokamak was used to study carbon ablation under re-entry heat fluxes, demonstrating that the hot plasma created in DIII-D offers a novel and potentially improved way of advancing spacecraft technology. Past heat shield testing approaches suffered from the problem that no single method could simulate the exact heating conditions present during a high-speed atmospheric entry. In the DIII-D experiments, the team was able to gather a range of valuable data, allowing them to improve theoretical models and numerical simulations.

U.S. researchers contribute to fusion energy record at the Joint European Torus (JET) facility.

In JET, a record 59 megajoules (MJ) of fusion energy was generated over a five-second pulse flattop in 2022, more than doubling the 22 MJ record set at JET in 1997. Several U.S. collaborations on JET supported this deuterium-tritium campaign. Their contributions included predictive modeling and simulations of burning plasma scenarios, the use of an external antenna to drive magnetic fluctuations and measure plasma stability, and the provision and operation of a diagnostic to measure the loss of energetic ions that provide heat to the plasma.

Machine learning improves equilibrium reconstruction in fusion experiments.

A team has significantly revised the U.S.-developed plasma Equilibrium reconstruction and FITting (EFIT) code to facilitate application of ML and AI algorithms for fusion data analysis applications. A single device-independent core equilibrium solver called EFIT-AI has been created that can reconstruct equilibria for many tokamaks around the world and is portable to U.S. high-performance computing facilities, including Cori and Perlmutter at the National Energy Research Scientific Computing (NERSC) center. Surrogate artificial neural networks have been trained and used to achieve a 600-fold speedup of reconstructions based on data from magnet field sensors.

INFUSE: Extending partnerships with the fusion private sector.

The INFUSE program was launched in FY 2019. In FY 2022, a major modification was made that enables companies to partner directly with U.S. universities, a first for a DOE voucher-style program. To date, 72 awards totaling $14.7 million have been made to 20 unique private companies partnering with 10 DOE labs and 8 U.S. universities.

All the strength, none of the struggle: An alternative manufacturing path toward advanced steels.

Oxide dispersion-strengthened steels (ODS) are promising structural materials for future fusion reactors but have traditionally struggled due to the need for a complex and unreliable processing route. Recent research under a joint FES/ARPA-E program has demonstrated that powders produced by gas atomization reaction synthesis offer the potential for circumventing the most difficult step of the traditional manufacturing process while enabling a similar level of strength in the end material. This opens the way for new solid-state and additive processing approaches and promises an alternative, scalable route for manufacturing these advanced alloys for future fusion energy systems.

MPEX MIE project receives approval of project baseline and start of construction.
The scientific demonstration of magnetic fusion energy as an environmentally sustainable and economically competitive energy source will require mastery of materials science issues associated with the plasma-material interface. The MPEX MIE project will deliver a world-leading capability for the testing of plasma-facing materials and components under reactor-relevant plasma loading conditions. The MPEX MIE project received formal Approval of Performance Baseline and Start of Construction (CD-2/3) on August 19, 2022, a major milestone for the project.

Spherical tokamak mode discovered after a 13-year hunt.
Researchers at PPPL had found that no matter how much heat they poured into the NSTX plasma, the maximum temperature remained the same. Although the experimental result was clear and repeatable, the physical mechanism causing this trend remained a mystery until this year. Now, scientists have simulated a plasma instability, triggered when the pressure of the plasma reaches a threshold value, that may explain the observed phenomenon. The discovery of this instability is expected to improve designs of future fusion pilot plants.

Precise stellarator quasi-symmetry can be achieved with electromagnetic coils.
Magnetic fields with quasi-symmetry are known to provide good confinement of charged particles and plasmas, but the extent to which quasi-symmetry can be achieved in practice has remained an open question. Recently, toroidal magnetic fields that are quasi-symmetric to orders of magnitude higher precision than previously known fields were discovered for the first time. These fields can be accurately produced with the use of electromagnetic coils of only moderate engineering complexity. When scaled to a reactor, the best-found configuration loses only 0.04 percent of energetic particles.

High energy density research has the potential to advance cancer treatments.
More than 50 percent of all cancer patients are treated with radiation as the current standard of care. Of critical importance in radiotherapy is targeting tumors while sparing the healthy tissues. Supported by the LaserNetUS initiative, scientists developed a new platform for ultra-high dose rate radiobiology using a high-intensity laser. Cell survival measurements of human normal and tumor cells exposed to laser-driven protons showed promising results. These findings and the new platform have the potential to advance cancer radiotherapy with compact high-intensity lasers.

Low-temperature plasma for removing micropollutants from fresh water.
Microcontaminants such as per- and poly-fluoroalkyl substances in fresh water are challenging since they do not degrade and are not easily removed from water by conventional means. One of the most effective ways to degrade these harmful chemicals is using a nonthermal plasma in contact with water. A plasma-liquid interface has been shown to contain a variety of reactive species capable of initiating reduction-oxidation reactions, important for degrading these harmful chemicals. Researchers from the University of Washington at St. Louis and Princeton Collaborative Research Facility at PPPL have carried out controlled redox reactions to infer the reduction potential at the plasma-liquid interface from measured plasma parameters such as electron number density and temperature and obtained promising results.

Further progress in U.S. Contributions to ITER project
The U.S. Contributions to ITER project successfully completed thermal-cycle testing of Central Solenoid Magnet Module 4, awarded subcontracts for Tritium Exhaust Processing system prototypes, and further advanced the Vacuum Auxiliary system design.

Fusion Energy Sciences
Burning Plasma Science: Foundations

Description

Burning Plasma Science: Foundations subprogram advances the predictive understanding of plasma confinement, dynamics, and interactions with surrounding materials and supports the development of a competitive fusion power industry in the U.S. through partnerships with the private sector.

Among the activities supported by this subprogram are:

- Research at major experimental user facilities aimed at resolving fundamental advanced tokamak and spherical tokamak science issues.
- Support for public-private partnerships with the Fusion Development Milestone Program and through INFUSE.
- Research on IFE science and technology.
- Research on small-scale magnetic confinement experiments.
- Theoretical work on the fundamental description of magnetically confined plasmas and the development of advanced simulation codes on current and emerging high-performance computers.
- Research on technologies needed to support continued improvement and capabilities of current and future facilities.
- Infrastructure improvements at PPPL and other DOE laboratories where fusion research is ongoing.
- Research on AI/ML relevant to fusion and plasma science.

Research in the Burning Plasma Science: Foundations area in FY 2024 will focus on high-priority scientific issues in alignment with the recommendations in the recent FESAC LRP and in support of the BDV for commercial fusion energy.

<u>Advanced Tokamak</u>

The Advanced Tokamak (AT) element supports a broad range of activities focused on closing gaps in the scientific and technical basis for the tokamak approach to fusion energy. The advanced tokamak is an integrated fusion energy system that simultaneously achieves a stationary plasma state characterized by high plasma pressure, high fractions of self-generated plasma current, adequate heat and particle confinement, and levels of heat and particle exhaust compatible with plasma-facing surfaces. The AT activity comprises several research lines to support the accompanying R&D in these areas, including the DIII-D National Fusion Facility, small-scale AT research, and Enabling R&D.

The DIII-D user facility at General Atomics is the largest magnetic fusion research experiment in the U.S. It can sustain 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. The current DIII-D five-year plan aims to deliver three major goals: (1) enable a successful ITER research program for both pulsed and steady-state operational scenarios; (2) develop the physics basis for and validation of the AT path to an FPP; and (3) advance the physics understanding of fusion science and technology across a broad front, developing validated predictive capabilities to project solutions to future devices. Small-scale AT 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.

Enabling R&D is aimed at advancing magnet, heating, and fueling technologies that support the confinement and operation of fusion plasmas in both current and future facilities. The Fusion Energy R&D Center for Enabling Technologies will integrate cross-cutting research to enable the next generation of fusion technologies that address both public and private FPP efforts.

<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 FPP than other plasma confinement geometries. NSTX-U recovery efforts will ensure reliable plasma operations of the facility for the future.

Small-scale ST plasma research involves high-risk, high-reward experimental efforts to provide data for this confinement concept. These efforts can help confirm theoretical models and simulation codes that support the development of an experimentally validated predictive capability for fusion plasmas.

Theory & 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. An experimentally validated predictive capability can minimize risk in future development steps and shorten the path toward the development of fusion energy, including the design of FPP concepts. This activity includes three interrelated but distinct elements: Theory, SciDAC, and Advanced Computing.

The Theory element is focused on advancing the scientific understanding of the fundamental physical processes governing the behavior of fusion plasmas. The research ranges from foundational analytic theory to mid- and large-scale computational work with the use of high-performance computing resources.

The FES SciDAC element, part 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 in partnership with ASCR. The portfolio selected in FY 2023 expands the scope of the program from whole-device modeling to whole-facility modeling, addressing recommendations in the FESAC LRP and provides a consistent set of high-fidelity tools for design and performance assessment of FPP concepts. In addition, a new integrated Fusion Energy R&D Center for Advanced Simulations will be established leveraging research performed by the SciDAC partnerships, to develop and apply predictive simulation tools that address both public and private FPP efforts.

The Advanced Computing element supports efforts that address the growing data needs of fusion research, resulting from both experimental and large-scale simulation efforts, by investing in enhanced data infrastructure capabilities. FES will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priorities research areas as ECP concludes.

GPP-GPE 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.

Public-Private Partnerships

INFUSE provides private-sector fusion companies with access to world-class expertise and capabilities available at DOE's national laboratories and U.S. universities to overcome critical scientific and technological hurdles in fusion energy development. Topical areas supported by INFUSE include enabling technologies, materials science, diagnostics, modeling and simulation, and access to unique fusion experimental capabilities.

The Fusion Development Milestone Program aims to accelerate progress toward the development of commercial fusion energy by establishing partnerships with the private sector. It represents a first step toward the implementation of the Administration's BDV for commercial fusion energy. Key goals of this program in the near term include the achievement of preliminary designs and technology roadmaps for an FPP and enabling significant performance improvements of FPP concepts.

Artificial Intelligence and Machine Learning

This program supports the application of AI/ML techniques in partnership with data and computational scientists through the establishment of multi-institutional, interdisciplinary collaborations. Supported activities encompass multiple FES areas, including magnetic fusion, materials science, and discovery plasma science, and contribute to the development of FPP design tools. Activities include the development of fusion data resources and integrated data analysis and modeling tools.

Strategic Accelerator Technology

The objective is to leverage expertise across SC to maximize R&D progress in high-temperature superconducting (HTS) magnets for future facilities. A key aspect is the support of the High Field Vertical Magnet Test Stand at Fermi National Accelerator Laboratory, jointly funded with the SC High Energy Physics program, which will have world-leading capability for testing conductors. The Test Stand should be completed in FY 2024. Funding was not requested in FY 2023 or FY 2024 for this activity.

Inertial Fusion Energy (IFE)
This activity supports the development of the scientific foundations and technologies for IFE. These include advancing theory and modeling of laser-plasma instabilities, evaluating and improving target design and fabrication and robustness with respect to ignition and gain, investigating alternate concepts and advanced fuels, reducing the cost of IFE drivers and increasing the damage threshold optics and crystals, developing IFE target injectors capable of reaching reactor-relevant velocities without damaging the target or its fuel layer, and increasing the number of experiments at existing large-scale facilities.

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Burning Plasma Science: Foundations	**$345,122**	**$482,072**	**+$136,950**
Advanced Tokamak	$134,122	$157,722	+$23,600
Funding supports 20 weeks of operations at the DIII-D facility, which is 90 percent of optimal. Research continues to exploit innovative current drive systems to assess their potential as actuators for a fusion pilot plant and to optimize plasma performance. Upgrades include increasing electron cyclotron power, completing the installation of the high-field-side lower hybrid current drive system and commencing experiments, and increasing the power of the neutral beam injection system. Funding continues to support research in high-temperature superconducting magnet technology, plasma heating and current drive, plasma fueling, and other enabling technologies for fusion. Funding continues support for small-scale AT experiments.		The Request will support 14 weeks of operations in FY 2024 at the DIII-D facility as part of a two-year campaign that will deliver a total of 36 weeks of operations. The program will support a broader user base, completion of facility enhancements, refurbishment of essential equipment, research needed for ITER and a future FPP, and training opportunities for the next generation of fusion scientists. The Request will support the Fusion Energy R&D Center for Enabling Technologies and continued support for magnets, plasma heating and fueling. The Request will continue support for small-scale AT experiments at universities.	The increase will support DIII-D operations, research aligned with the FESAC LRP, major upgrades, training activities, and the Fusion Energy R&D Center for Enabling Technologies.

(dollars in thousands)

FY 2023 Enacted	FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Spherical Tokamak $107,000	$92,350	-$14,650
Funding for operations supports the remaining NSTX-U Recovery fabrication and machine reassembly activities and begins supporting the commissioning of auxiliary heating systems in preparation for plasma operations. Research efforts focus on studies utilizing a variety of domestic and international spherical tokamak facilities; these studies are aligned with the mission of the NSTX-U program, which contributes to the development of the design basis for a next-step FPP. Funding continues supporting small-scale ST studies dedicated to simplifying and reducing the capital cost of future fusion facilities.	The Request for operations funding will support the remaining NSTX-U Recovery fabrication and machine reassembly activities and continue to support the commissioning of auxiliary heating systems in preparation for plasma operations. Research efforts will focus on studies utilizing a variety of domestic and international spherical tokamak facilities; these studies are aligned with the mission of the NSTX-U program, which contributes to the development of the design basis for a next-step FPP. The Request will continue to support small-scale ST studies dedicated to simplifying and reducing the capital cost of future fusion facilities.	Operations funding will support the continuation of the NSTX-U Recovery activities. Research funding will focus on the highest-priority scientific objectives, which are aligned with the FESAC LRP.
Theory & Simulation $50,500	$70,000	+$19,500
Funding supports efforts at universities, national laboratories, and private industry focused on the fundamental theory of magnetically confined plasmas and the development of a predictive capability for magnetic fusion. Funding supports the SciDAC portfolio with emphasis on whole-facility modeling, in alignment with the LRP recommendations. It also provides a consistent set of high-fidelity tools for design and performance assessment of FPP concepts. Funding also supports Advanced Computing, including investments in enhanced data infrastructure capabilities to address the growing data needs of fusion research.	The Request will continue to support efforts at universities, national laboratories, and private industry focused on the fundamental theory of magnetically confined plasmas. The Request will continue to support the SciDAC portfolio selected in FY 2023 and the development of a consistent set of high-fidelity simulation tools for design and performance assessment of FPP concepts. A new integrated Fusion Energy R&D Center for Advanced Simulations will also be established to develop and apply predictive simulation tools that address both public and private FPP efforts. The Request will continue to support Advanced Computing, including investments in enhanced data infrastructure capabilities.	Research efforts will focus on the highest-priority activities, including continuing support of the SciDAC portfolio and the establishment of the Fusion Energy R&D Center for Advanced Simulations. FES will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priorities research areas as ECP concludes.

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
GPP-GPE Infrastructure	$1,500	$1,000	-$500
Funding supports infrastructure improvements, repair, maintenance, and environmental monitoring at PPPL and other DOE laboratories.		The Request will continue to support infrastructure improvements, repair, maintenance, and environmental monitoring at PPPL and other DOE laboratories.	This activity will focus on the highest-priority infrastructure improvements.
Public-Private Partnerships	$31,000	$135,000	+$104,000
Funding continues to support the INFUSE program, providing the private sector with access to DOE developed capabilities at both national laboratories and universities. Funding also continues support for a milestone-based fusion development program through partnerships with the private sector.		The Request will continue to support public-private partnerships through the Fusion Development Milestone Program and the INFUSE program which connects the private sector to DOE developed capabilities at national laboratories and universities.	The increased funding will expand the Fusion Development Milestone Program which supports FPP preliminary designs and technology roadmaps to accelerate progress toward an FPP, by making additional awards and/or enhancing existing efforts.
Artificial Intelligence and Machine Learning	$11,000	$11,000	$ —
Funding supports a competitive solicitation to identify multi-institutional collaborations focused on deploying AI/ML applications across FES program elements.		The Request will continue support for research awards made in FY 2023. The program will include deployment of distributed fusion data capabilities that support the development of FPP design tools and efficient utilization of fusion facilities.	No change.
Inertial Fusion Energy (IFE)	$10,000	$15,000	+$5,000
Funding supports the new IFE program focused on the priority research opportunities in scientific foundations and technologies that were identified in the FY 2022 Basic Research Needs Workshop for IFE.		The Request will support the priority research opportunities identified in the FY 2022 Basic Research Needs Workshop for IFE.	Research efforts will focus on the highest priority activities.

Note:

- *Funding for the subprogram above, includes 3.65 percent of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs, excluding facility operations.*

Fusion Energy Sciences
Burning Plasma Science: Long Pulse

Description

The Burning Plasma Science: Long Pulse subprogram explores new and unique scientific regimes that can be achieved primarily with long-duration superconducting international machines and addresses the development of the materials and technologies required to withstand and sustain a burning plasma. The key objectives of this area are to utilize these unique capabilities to accelerate our scientific understanding of how to control and operate a burning plasma and contribute to the design of a FPP. This subprogram includes long-pulse international tokamak and stellarator research, domestic stellarator research, fusion nuclear science, materials research, and future facilities studies.

<u>Long Pulse: Tokamak</u>

This activity 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. Collaborative research on international facilities with capabilities not available in the U.S. aims at building the science and technology required to control, sustain, and predict a burning plasma, as described in the FESAC LRP. Multidisciplinary teams work together to close key gaps in the design basis for an FPP, especially in the areas of plasma-material interactions, transients control, and current drive for steady-state operation. The team approach provides unique training experiences for the next generation of fusion scientists, as well as the opportunity to establish international collaborations in new areas.

<u>Long Pulse: Stellarators</u>

This activity supports research on stellarators, which offer the potential of steady-state confinement regimes without transient events such as disruptions. The participation of U.S. researchers on the Wendelstein 7-X (W7-X) in Germany provides an opportunity to develop and assess divertor configurations for long-pulse, high-performance stellarators, including the provision of a pellet fueling injector for quasi-steady-state plasma experiments. U.S. researchers will play key roles in developing the operational scenarios and hardware configuration for high-power, steady-state operation, an accomplishment that will advance the performance/pulse length frontier for fusion. The U.S. is participating fully in W7-X research and has full access to data. Domestic compact stellarator research is focused on improvement of the stellarator magnetic confinement concept through quasi-symmetric shaping of the toroidal magnetic field.

<u>Materials & Fusion Nuclear Science</u>

The Materials and Fusion Nuclear Science activities seek to address the significant scientific and technical gaps between current-generation fusion experiments and future fusion nuclear devices, such as an FPP and, later, a first-of-a-kind fusion power plant. These fusion nuclear devices will produce heat, particle, and neutron fluxes that significantly exceed those in present confinement facilities, and new approaches and materials need to be developed and engineered for the anticipated extreme reactor conditions. The goal of Materials research is to develop a scientific understanding of how the properties of materials evolve and degrade due to fusion neutron and plasma exposure, to safely predict the behavior of materials in fusion reactors. The goal of Fusion Nuclear Science research is to advance the neutronics, blanket and fuel cycle, and safety analysis that are required to harness fusion power. To help address these gaps, two new integrated Fusion Energy R&D Centers will be initiated. The SC initiative on Fundamental Science to Transform Advanced Manufacturing has implications for both Materials and Fusion Nuclear Science.

Developing solutions for this scientifically challenging area requires innovative types of research along with new experimental capabilities. In the near term, this includes the MPEX MIE project, which will enable solutions for new plasma-facing materials, and a fusion neutron source, which will provide unique material irradiation capabilities for understanding materials degradation in the fusion nuclear environment.

<u>Future Facilities Studies</u>

The Future Facilities Studies activity supports studies and research for required facilities that are critical to the development of fusion energy and address needs of both the public and private sectors.

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Burning Plasma Science: Long Pulse	**$81,000**	**$184,674**	**+$103,674**
Long Pulse: Tokamak	$15,000	$15,000	$ —
Funding supports the second budget period for U.S. teams conducting research on international facilities, which helps close key gaps in the design basis for an FPP.		The Request will support the final budget period for U.S. teams conducting research on international facilities. Activities will focus on exploitation of tokamak systems installed and commissioned in prior years.	No change.
Long Pulse: Stellarators	$7,500	$7,500	$ —
In the next W7-X experimental campaign, funding supports research on turbulent transport, stability and edge physics, and boundary and scrape-off-layer physics. Funding also supports experiments on domestic stellarators in regimes relevant to the mainline stellarator magnetic confinement efforts.		The Request will support research on W7-X to control the plasma density in real time to minimize turbulence and to improve plasma confinement scenarios. The Request will also support continued research on compact domestic stellarators.	No change.

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Materials & Fusion Nuclear Science	$56,500	$147,500	+$91,000
Funding supports research activities in these areas, consistent with the recommendations of the FESAC Long-Range Plan. This includes continued development of critical technologies for an FPP, such as plasma-facing components, structural and functional materials, and breeding-blanket and tritium-handling systems. Funding also continues to support research into advanced manufacturing technologies consistent with the SC initiative in this area. Finally, funding supports the MPEX MIE project, with efforts focused on construction following the combined baselining and start of construction that was received on August 22, 2022.		The Request will enable growth in the critical areas of materials and nuclear science research, which is vital for the deployment of an FPP. The focus of this program will be development of plasma-facing components, structural and functional materials, and breeding-blanket and tritium-handling systems. The Request will also continue to support research into advanced manufacturing technologies, consistent with the SC initiative in this area. Finally, the Request will continue to support the MPEX MIE project, consistent with the approved baseline for the project during the construction phase.	Funding will support the development of two new integrated Fusion Energy R&D Centers in the areas of structural/plasma facing materials and blanket/fuel cycle which will be key in facilitating both public and private FPP efforts. Support will continue for advanced manufacturing research. Funding for the MPEX project will increase to accommodate the project's new cost/schedule baseline.
Future Facilities Studies	$2,000	$14,674	+$12,674
Funding supports the Future Facilities Studies activity to conduct design studies for an integrated fusion plant, e.g., an FPP, consistent with the FESAC Long-Range Plan recommendation.		The Request will support conducting preliminary studies and research for a future fusion neutron source facility that is critical to the development and evaluation of materials for fusion energy and can meet the performance requirements identified in recent community workshops.	Funding will support R&D activities for a future fusion neutron source facility that was identified as the highest-priority new facility in the FESAC LRP.

Note:

- *Funding for the subprogram above, includes 3.65 percent of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs, excluding facility operations.*

Description

The Burning Plasma Science: High Power subprogram supports research on experimental facilities that can produce large amounts of fusion power and maintain self-heated plasmas for hundreds of seconds, allowing scientists to study the burning plasma state. In a burning or self-heated plasma, at least half of the power needed to maintain the plasma at thermonuclear temperatures is provided by heating sources within the plasma. For the most common deuterium-tritium (D-T) fuel cycle, this internal heating source is provided by the energy of the helium nuclei (alpha particles) which are produced by the D-T reaction itself. A common figure of merit characterizing the proximity of a plasma to burning plasma conditions is the fusion gain or "Q", which is defined as the ratio of the fusion power produced by the plasma to the heating power injected into the plasma that is necessary to bring it, and keep it, at thermonuclear temperatures.

ITER will be the world's first burning plasma experiment that is expected to produce 500 MW of fusion power for pulses of 400 seconds, attaining a fusion gain of Q = 10. It is a seven-member international collaborative project to design, build, operate, and decommission a first-of-a-kind international fusion research facility in St. Paul-lez-Durance, France, aimed at demonstrating the scientific and technological feasibility of fusion energy. In addition to the U.S., the six other ITER members are China, the European Union, India, Japan, South Korea, and Russia. More information about the U.S. Contributions to the ITER project is provided in the FES Construction section.

<u>ITER Research</u>

To ensure that the U.S. fusion community takes full advantage of ITER research operations after First Plasma, it is necessary to organize a U.S. ITER research team to be ready on day one to benefit from the scientific and technological opportunities offered by ITER. Building such a team was also among the highest recommendations in the recent FESAC LRP. A Basic Research Needs workshop was held in FY 2022 to identify the highest-priority research and engagement opportunities for the U.S. to maximize the benefit of its participation in ITER. In addition, this activity supports the efficient dissemination of ITER data in support of FPP activities.

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Burning Plasma Science: High Power	**$2,000**	**$2,000**	**$ —**
ITER Research	$2,000	$2,000	$ —
Funding supports the highest-priority research and engagement opportunities identified in the Basic Research Needs workshop that was held in FY 2022.		The Request will continue supporting the highest-priority research and engagement opportunities identified in the Basic Research Needs workshop that was held in FY 2022, as well as supporting the dissemination of ITER data in support of FPP activities.	No change.

Note:
- *Funding for the subprogram above, includes 3.65 percent of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs, excluding facility operations.*

Description
Discovery Plasma Science subprogram supports research that explores the fundamental properties and complex behavior of matter in the plasma state to understand the plasma universe and to learn how 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, some of them relevant to clean energy technologies, including synthesis of nanomaterials and artificial diamonds, efficient solar and fuel cells, fabrication of microelectronics and opto-electronic devices, energy-efficient lighting, low-heat chemical-free sterilization processes, tissue healing, combustion enhancement, satellite communication, laser-produced isotopes for positron emission tomography, and extreme ultraviolet lithography.

The Discovery Plasma Science subprogram is organized into the following activities:

<u>Plasma Science and Technology</u>
The Plasma Science and Technology (PS&T) activities involve research in largely unexplored areas of plasma science, with a combination of theory, computer modeling, and experimentation. These areas 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 PS&T portfolio includes research activities in the following areas:

- General Plasma Science (GPS): Research at the frontiers of basic and low-temperature plasma science, including dynamical processes in laboratory, space, and astrophysical plasmas, such as magnetic reconnection, dynamo, shocks, turbulence cascade, structures, waves, flows and their interactions; behavior of dusty plasmas, non-neutral, single-component matter or antimatter plasmas, and ultra-cold neutral plasmas; plasma chemistry and processes in low-temperature plasma, interfacial plasma, synthesis of nanomaterials, and interaction of plasma with surfaces, materials or biomaterials.

- High Energy Density Laboratory Plasmas (HEDLP): Research directed at exploring the behavior of plasmas at extreme conditions of temperature, density, and pressure, including relativistic high energy density (HED) plasmas and intense beam physics, magnetized HED plasma physics, multiply ionized HED atomic physics, HED hydrodynamics, warm dense matter, nonlinear optics of plasmas and laser-plasma interactions, laboratory astrophysics, and diagnostics for HEDLP.

The PS&T 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.

<u>Measurement Innovation</u>
The Measurement Innovation activity supports the development of world-leading transformative and innovative diagnostic techniques and their application to new, unexplored, or unfamiliar plasma regimes or scenarios. The challenge is to develop diagnostics with the high spatial, spectral, and temporal resolution necessary to validate plasma physics models used to predict the behavior of fusion plasmas.

Quantum Information Science

The Quantum Information Science (QIS) activity supports basic research in QIS that can have a transformative impact on FES mission areas, including fusion and discovery plasma science, as well as research that takes advantage of unique FES-enabled capabilities to advance QIS development. The direction of the QIS efforts is informed by the findings of the 2018 Roundtable meeting[c] that was held to explore the unique role of FES in this rapidly developing high-priority crosscutting field and help FES build a community of next-generation researchers in this area. Among the areas supported by the QIS subprogram are quantum simulation capabilities for fusion and plasma science, quantum sensing for plasma diagnostics, HEDLP techniques to form novel quantum materials, and plasma science tools to simulate and control quantum systems. FES also participates in supporting the SC-wide crosscutting QIS research centers.

Advanced Microelectronics

The Advanced Microelectronics activity supports discovery plasma research in a multi-disciplinary, co-design framework to accelerate plasma-based microelectronics fabrication and advance the development of microelectronic technologies. The direction of the Advanced Microelectronics efforts is informed by the FESAC LRP, the NASEM Plasma 2020 decadal survey report, a FY 2022 workshop on plasma science for microelectronics nanofabrication, and the Creating Helpful Incentives to Produce Semiconductors for America (CHIPS and Science) Act of 2022. New Microelectronics Science Research Centers as authorized under the Micro Act will focus on a multi-disciplinary co-design innovation ecosystem in which materials, chemistries, devices, systems, architectures, algorithms, and software are developed in a closely integrated fashion.

Other FES Research

This activity supports the Postdoctoral Research Program, which supports postdocs in the fusion and plasma science research areas for two years, and multiple fusion and plasma science outreach programs that work to increase fusion and plasma science literacy among the general public, K-12, undergraduate students, and graduate students. Other activities being supported include the U.S. Burning Plasma Organization (USBPO), peer-reviews for solicitations and project activities, FESAC, and other programmatic activities.

Reaching a New Energy Sciences Workforce (RENEW)

This activity supports the RENEW initiative to provide research and student training opportunities with academic institutions under-represented in the U.S. Science and Technology ecosystem and aligns with a recommendation in the FESAC LRP. In addition, this initiative expands targeted efforts, including a RENEW graduate fellowship, to broaden participation and advance justice, equity, diversity, and inclusion in SC-sponsored research.

Funding for Accelerated, Inclusive Research (FAIR)

This activity supports the FAIR initiative, which will provide focused investment on enhancing research on clean energy, climate, and related topics at HBCUs, minority-serving institutions (MSIs) and emerging research institutions (ERIs).

Accelerate Innovations in Emerging Technologies (Accelerate)

This activity supports the Accelerate initiative, which will support cross-cutting scientific research to accelerate the transition of science advances to energy technologies.

Established Program to Stimulate Competitive Research (EPSCoR)

This activity provides support for the DOE EPSCoR program that funds research in states and territories with historically lower levels of Federal academic research funding. In FY 2024, the EPSCoR program will focus on EPSCoR State-National Laboratory Partnership awards to promote single principal investigator and small group interactions with the unique capabilities of the DOE national laboratory system and continued support of early career awards.

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

Fusion Energy Sciences
Discovery Plasma Science

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Discovery Plasma Science	**$82,100**	**$91,750**	**+$9,650**
Plasma Science and Technology	$46,000	$39,000	-$7,000
General Plasma Science	*$19,000*	*$20,000*	*+$1,000*
Funding supports core research at the frontiers of basic and low temperature plasma science, as well as operations of and user-led experiments on collaborative research facilities.		The Request will continue to support core research at the frontiers of basic and low-temperature plasma science, as well as external collaborations and operations of collaborative research facilities.	Funding will enhance core research in general plasma science.
High Energy Density Laboratory Plasmas	*$27,000*	*$19,000*	*-$8,000*
Funding supports basic and translational science, MEC and LaserNetUS operations and user support, and the SC-NNSA joint program.		The Request will continue to support basic and translational science, MEC and LaserNetUS operations and user support, and the SC-NNSA joint program.	Funding will support highest-priority activities.
Measurement Innovation	$2,915	$2,000	-$915
Funding supports the development of innovative and transformative diagnostics.		The Request will continue to support the development of innovative and transformative diagnostics.	Funding will support highest-priority activities.
Quantum Information Science	$10,000	$10,000	$ —
Funding supports priority research opportunities identified in the 2018 Roundtable Workshop Report. It also continues to support the SC QIS Research Centers.		The Request will continue to support core research awards selected in FY 2023. It will also continue to support the SC QIS Research Centers.	No change.

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Advanced Microelectronics	$5,000	$15,000	+$10,000
Funding supports high priority research and the continuation of laboratory awards made through a competitive lab call and review in FY 2021.		The Request will support priority research opportunities identified in the FY 2022 microelectronics workshop. New Microelectronics Science Research Centers are established, as authorized under the Micro Act.	Funding will support new microelectronics research centers.
Other FES Research	$4,185	$2,500	-$1,685
Funding supports programmatic activities such as the FES Postdoctoral Research Program, the FES Fusion and Plasma Science Outreach programs, USBPO, peer reviews for FES solicitations and project activities, and FESAC.		The Request will continue to support programmatic activities such as the FES Postdoctoral Research Program, the FES Fusion and Plasma Science Outreach programs, USBPO, peer reviews for FES solicitations and project activities, and FESAC.	Funding will support highest-priority activities.
Reaching a New Energy Sciences Workforce (RENEW)	$6,000	$11,250	+$5,250
Funding supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions under-represented in the U.S. S&T ecosystem and aligns with a recommendation in the FESAC LRP.		The Request will continue to support targeted efforts to increase participation and retention of individuals from underrepresented groups in FES research activities, including a RENEW graduate fellowship.	This increase will broaden RENEW activities within the FES research portfolio.
Funding for Accelerated, Inclusive Research (FAIR)	$2,000	$4,000	+$2,000
Funding supports the Funding for Accelerated, Inclusive Research (FAIR) initiative, which provides focused investment on enhancing research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice communities.		The Request will continue to support the Funding for Accelerated, Inclusive Research (FAIR) initiative efforts to increase participation and retention of individuals from underrepresented groups in FES research activities.	The funding will enhance support of the FAIR initiative within the FES research portfolio.

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Accelerate Innovations in Emerging Technologies	$4,000	$6,000	+$2,000
Funding supports the Accelerate initiative, which supports scientific research to accelerate the transition of science advances to energy technologies.		The Request will continue to support scientific research to accelerate the transition of science advances to energy technologies.	The funding will enhance support of the Accelerate initiative within the FES research portfolio.
Established Program to Stimulate Competitive Research (EPSCoR)	$2,000	$2,000	$ —
FY 2023 EPSCoR funding emphasizes Implementation Awards to larger multiple investigator teams. Investment continues in early career research faculty from EPSCoR-designated jurisdictions and in co-investment with other programs for awards to eligible institutions.		The Request will support EPSCoR State-National Laboratory Partnership awards and early career awards.	No change.

Note:

- *Funding for the subprogram above, includes 3.65 percent of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs, excluding facility operations.*

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.

20-SC-61 Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC

The National Academies of Sciences, Engineering, and Medicine (NASEM) 2017 report "Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light"[d] 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 will provide a collaborative user facility that utilizes the LCLS-II light source and is focused on High-Energy-Density Science that will address this NASEM recommendation as well as maintain U.S. leadership in this important field of study. The project received Critical Decision-1 (CD-1), "Approve Alternative Selection and Cost Range," on October 4, 2021. The FY 2024 Request of $10,000,000 will support preliminary design activities. The estimated total project cost range is $264,000,000 to $461,000,000.

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

The ITER facility, currently under construction in Saint Paul-lez-Durance, France, is more than 75 percent complete to First Plasma. ITER is designed to provide fusion power output approaching reactor levels of hundreds of megawatts, sustained as a burning plasma for hundreds of seconds. ITER is a necessary next step toward developing a carbon-free fusion energy pilot plant and will help keep the U.S. competitive internationally. Construction of ITER is a collaboration among the U.S., European Union, Russia, Japan, India, Korea, and China, governed under an international agreement (the "ITER Joint Implementing Agreement"). As a co-owner of ITER, the U.S. contributes in-kind hardware components and financial contributions for the ITER Organization (IO) management and overhead (e.g., design integration, nuclear licensing, quality control, safety, overall project management, and installation and assembly of the components provided by the U.S. and other Members). The U.S. also has over 50 nationals employed by the IO and working at the site.

An independent review of CD-2, "Approve Performance Baseline," for the U.S. Contributions to ITER—First Plasma subproject (SP-1) was completed in November 2016 and then subsequently approved by the Project Management Executive on January 13, 2017, with a total project cost of $2,500,000,000. Responding to Congressional direction in the FY 2021 Appropriations Act, the project aims to baseline the entire project, which will include a rebaseline of SP-1 scope, baseline of Post-First Plasma (SP-2) scope, and financial contributions for the project to CD-4, "Approve Project Completion", by September 2023. SP-1 scope is currently 70 percent complete and will include the delivery of the completed Central Solenoid Magnet System, Steady-state Electrical Network, and Disruption Mitigations System. SP-1 also contains a portion of design and fabrication for the remaining nine systems Scope associated with SP-2 will deliver the balance of completed work to include the Tritium Exhaust Processing System, Ion Cyclotron Heating and Electron Cyclotron Heating Systems, diagnostics, and roughing pumps.

The FY 2024 Request of $240,000,000 will support the continued systems design, fabrication, and delivery of in-kind hardware, and financial contributions for IO construction operations. The estimated total project cost range is $4,700,000,000 to $6,500,000,000, which includes all U.S. in-kind hardware and financial construction contributions through the completion of the ITER project. Upon baselining in calendar year 2023, the range will no longer exist, and reporting will be to the approved Total Project Cost (TPC). ITER Organization will be providing an updated baseline to the ITER council in the FY 2024 timeframe. U.S. Contributions to ITER are estimated to remain within the TPC of $6,500,000.

The U.S. in-kind contribution represents 9.09 percent (1/11th) of the overall ITER project but will provide access to 100 percent of the science and engineering associated with what will be the largest magnetically confined burning plasma experiment ever created. The U.S. involvement in ITER will help to advance the promise of carbon-free, inherently safe, and abundant fusion energy.

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

Fusion Energy Sciences
Construction

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request	Explanation of Major Changes FY 2024 Request vs FY 2023 Enacted
Construction	**$253,000**	**$250,000**	**-$3,000**
20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC	$11,000	$10,000	-$1,000
Funding supports design activities and preparation for developing a project performance baseline.		The Request will continue to support design activities and preparation for developing a project performance baseline.	Funding will support critical preparation activities for developing the performance baseline.
14-SC-60, U.S. Contributions to ITER (Historical)	$242,000	$240,000	-$2,000
Funding supports continued design and fabrication of in-kind hardware systems and requested construction financial contributions.		The Request will support continued design and fabrication of in-kind hardware systems and requested construction financial contributions.	Funding will support design and fabrication of in-kind hardware and fulfill the U.S. obligations for financial contributions to the ITER Organization.

Fusion Energy Sciences
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2022 Enacted	FY 2022 IRA Supp.	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted
Capital Operating Expenses							
Capital Equipment	N/A	N/A	34,963	14,000	22,443	41,500	+19,057
Minor Construction Activities							
General Plant Projects	N/A	N/A	1,500	–	1,500	1,000	-500
Total, Capital Operating Expenses	**N/A**	**N/A**	**36,463**	**14,000**	**23,943**	**42,500**	**+18,557**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2022 Enacted	FY 2022 IRA Supp.	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted
Capital Equipment							
Major Items of Equipment							
Burning Plasma Science: Long Pulse							
Material Plasma Exposure eXperiment (MPEX)	185,803	62,080	25,000	14,000	14,000	25,000	+11,000
Total, MIEs	N/A	N/A	25,000	14,000	14,000	25,000	+11,000
Total, Non-MIE Capital Equipment	N/A	N/A	9,963	–	8,443	16,500	+8,057
Total, Capital Equipment	**N/A**	**N/A**	**34,963**	**14,000**	**22,443**	**41,500**	**+19,057**

Notes:
- *The Capital Equipment table includes MIEs located at a DOE facility with a Total Estimated Cost (TEC) > $5M and MIEs not located at a DOE facility with a TEC >$2M.*
- *In FY 2021, additional funding of $7,996,000 above the Enacted level was provided for the MPEX MIE. The adjusted TEC Total is $108,575,000.*

Fusion Energy Sciences
Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2022 Enacted	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted
General Plant Projects (GPP)						
Total GPPs less than $5M	N/A	N/A	–	1,500	1,000	-500
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**–**	**1,500**	**1,000**	**-500**
Total, Minor Construction Activities	**N/A**	**N/A**	**–**	**1,500**	**1,000**	**-500**

Note:

- *GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or addition to roads, and general area improvements. AIP activities less than $5M include minor construction at an existing accelerator facility.*

Major Items of Equipment Description(s)

<u>Burning Plasma Science: Long Pulse MIEs:</u>

Material Plasma Exposure eXperiment (MPEX)

FES is developing a first-of-a-kind, world-leading experimental capability to explore solutions to the plasma-materials interactions challenge. This device, known as MPEX, will be located at ORNL and will enable dedicated studies of reactor-relevant plasma-material interactions at a scale not previously accessible to the fusion program. The overall goal of this project is to create a new class of fusion materials science enabling the study of the combined effects of fusion-relevant heat, particle, and neutron fluxes for the first time anywhere in the world. The project received CD-2/3 "Approve Performance Baseline/Start of Construction" on August 22, 2022, with a TPC of $201,000,000. The FY 2024 Request will allow the project to execute the approved performance baseline and continuation of approved long-lead procurements. MPEX scope includes the design, fabrication, installation, and commissioning of the MPEX linear plasma device, as well as associated facility and infrastructure modifications and reconfiguration.

Fusion Energy Sciences
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2022 Enacted	FY 2022 IRA Supp.	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted
20-SC-61, Matter in Extreme Conditions (MEC) Upgrade							
Total Estimated Cost (TEC)	448,700	23,487	11,000	10,000	11,000	10,000	-1,000
Other Project Cost (OPC)	12,300	6,900	–	–	–	–	–
Total Project Cost (TPC)	**461,000**	**30,387**	**11,000**	**10,000**	**11,000**	**10,000**	**-1,000**
14-SC-60, U.S. Contributions to ITER							
Total Estimated Cost (TEC)	6,429,698	1,855,617	242,000	256,000	242,000	240,000	-2,000
Other Project Cost (OPC)	70,302	70,302	–	–	–	–	–
Total Project Cost (TPC)	**6,500,000**	**1,925,919**	**242,000**	**256,000**	**242,000**	**240,000**	**-2,000**
Total, Construction							
Total Estimated Cost (TEC)	**N/A**	**N/A**	**253,000**	**266,000**	**253,000**	**250,000**	**-3,000**
Other Project Cost (OPC)	**N/A**	**N/A**	**–**	**–**	**–**	**–**	**–**
Total Project Cost (TPC)	**N/A**	**N/A**	**253,000**	**266,000**	**253,000**	**250,000**	**-3,000**

Note:
- *In FY 2021, funding was reduced to $800,000 for MEC OPC. The adjusted TPC with FY 2021 Current funding is $461,000,000.*

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.

(dollars in thousands)

	FY 2022 Enacted	FY 2022 Current	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted
Scientific User Facilities - Type A					
DIII-D National Fusion Facility	**120,390**	**116,643**	**130,000**	**133,600**	**+3,600**
Number of Users	515	666	700	700	–
Achieved Operating Hours	–	818	–	–	–
Planned Operating Hours	800	818	800	560	-240
Unscheduled Down Time Hours	–	226	–	–	–
National Spherical Torus Experiment-Upgrade	**96,000**	**89,551**	**104,000**	**89,350**	**-14,650**
Number of Users	351	307	300	373	+73
Total, Facilities	**216,390**	**206,194**	**234,000**	**222,950**	**-11,050**
Number of Users	866	973	1,000	1,073	+73
Achieved Operating Hours	–	818	–	–	–
Planned Operating Hours	800	818	800	560	-240
Unscheduled Down Time Hours	–	226	–	–	–

Note:
- *Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.*

Fusion Energy Sciences
Scientific Employment

	FY 2022 Enacted	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted
Number of Permanent Ph.Ds (FTEs)	916	1,025	1,492	+467
Number of Postdoctoral Associates (FTEs)	113	126	184	+58
Number of Graduate Students (FTEs)	305	341	497	+156
Number of Other Scientific Employment (FTEs)	1,365	1,530	2,224	+694
Total Scientific Employment (FTEs)	**2,699**	**3,022**	**4,397**	**+1,375**

Note:
- *Other Scientific Employment (FTEs) includes technicians, engineers, computer professionals and other support staff.*

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

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

Summary

The FY 2024 Request for the Matter in Extreme Conditions (MEC) Petawatt Upgrade project is $10,000,000 of Total Estimated Cost (TEC) funding. The project has a preliminary estimated Total Project Cost (TPC) range of $264,000,000 to $461,000,000. Currently, this cost range encompasses the most feasible preliminary alternatives.

The future MEC Petawatt user facility will be a premier research facility to conduct experiments in the field of High Energy Density Plasmas. It will utilize the Linac Coherent Light Source II (LCLS-II) X-Ray Free-Electron Laser (XFEL) beam at SLAC to probe and characterize plasmas and extreme states of matter.

Significant Changes

The MEC Petawatt Upgrade project was initiated in FY 2019. The project achieved CD-1, "Approve Alternative Selection and Cost Range," on October 4, 2021, and initiated the TEC-funded preliminary design phase.

FY 2022 IRA funding will be utilized to advance the project design as well as replan the path forward to CD-2/3 approval.

FY 2023 and FY 2024 funding will be used to advance the project design and develop the cost and schedule basis in support of baselining efforts planned for end of FY 2024.

A Level III 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 2024	1/4/19	3/9/21	10/4/21	1Q FY 2025	Q1 FY 2025	1Q FY 2025	TBD	1Q FY 2030

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, Total	TPC
FY 2023	23,487	425,213	448,700	12,300	12,300	461,000
FY 2024	55,487	393,213	448,700	12,300	12,300	461,000

Note:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

2. Project Scope and Justification

Scope

The scope of the MEC Petawatt Upgrade project includes the development of a user facility that couples long-pulse (1 Kilojoule or higher) and short-pulse (1 petawatt or higher) drive lasers to an X-ray source, as well as a second target chamber that will accommodate laser-only fusion and material science experiments. The lasers will be placed in a dedicated MEC experimental hall (located at the end of the LCLS-II Far Experimental Hall), composed of an access tunnel, experimental hall, control room, 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, which is currently not available in the U.S. The National Academies of Sciences, Engineering, and Medicine (NASEM) 2017 study titled "Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light[e]" found that about 80 percent to 90 percent of the high-intensity laser systems are overseas, and all the highest-power lasers currently under construction or already built are overseas as well. The report made 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 NASEM report focuses on high-intensity, pulsed petawatt-class lasers (1 petawatt is 10^{15} watts). Such laser beams can drive nuclear reactions, heat matter to mimic conditions found in stars, and create electron-positron plasmas. In addition to discovery-driven science, petawatt-class lasers can generate particle beams with potential applications in medicine, intense neutron and gamma ray beams for homeland security applications, directed energy for defense applications, and radiation for extreme ultraviolet lithography.

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 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. 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. The upgrade includes the petawatt laser beam and the long-pulse laser beam. The latter is required to compress matter to densities relevant to planetary science and fusion plasmas.

FES is pursuing development of a new world-class petawatt laser capability to meet the FES mission and address the recommendations from the NASEM report.

The project will be conducted utilizing the project management principles described in DOE Order 413.3B*, Program and Project Management for the Acquisition of Capital Assets*.

Key Performance Parameters (KPPs)

The KPPs are preliminary and may change during design phase 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 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 the conceptual design phase, and the KPPs reflect the types of parameters being considered and are notional at this stage.

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

Performance Measure	Threshold	Objective
Optical Laser Systems		
▪ High repetition rate short pulse laser	▪ 30 Joules of energy ▪ 300 fs pulse length ▪ 1 Hz frequency	▪ 150 Joules of energy ▪ 150 fs pulse length ▪ 10 Hz frequency
▪ High energy long pulse laser	▪ 200 Joules of energy on target ▪ 10 ns pulse length 1 shot per 60 minutes	▪ 1000 Joules of energy on target ▪ 10 ns pulse length 1 shot per 30 minutes
X-ray Beam Delivery		
▪ Photon energy	▪ 5-25 keV energy delivered to target center	▪ 5-45 keV of energy delivered to target center

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Total Estimated Cost (TEC)				
Design (TEC)				
Prior Years	23,487	23,487	–	–
FY 2022	11,000	11,000	23,487	–
FY 2022 - IRA Supp.	10,000	10,000	–	–
FY 2023	11,000	11,000	11,000	10,000
FY 2024	10,000	10,000	10,000	–
Total, Design (TEC)	**65,487**	**65,487**	**44,487**	**10,000**
Construction (TEC)				
Outyears	383,213	383,213	394,213	–
Total, Construction (TEC)	**383,213**	**383,213**	**394,213**	**–**
Total Estimated Cost (TEC)				
Prior Years	23,487	23,487	–	–
FY 2022	11,000	11,000	23,487	–
FY 2022 - IRA Supp.	10,000	10,000	–	–
FY 2023	11,000	11,000	11,000	10,000
FY 2024	10,000	10,000	10,000	–
Outyears	383,213	383,213	394,213	–
Total, TEC	**448,700**	**448,700**	**438,700**	**10,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Other Project Cost (OPC)				
Prior Years	6,900	6,900	6,088	–
FY 2022	–	–	812	–
Outyears	5,400	5,400	5,400	–
Total, OPC	**12,300**	**12,300**	**12,300**	**–**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Total Project Cost (TPC)				
Prior Years	30,387	30,387	6,088	–
FY 2022	11,000	11,000	24,299	–
FY 2022 - IRA Supp.	10,000	10,000	–	–
FY 2023	11,000	11,000	11,000	10,000
FY 2024	10,000	10,000	10,000	–
Outyears	388,613	388,613	399,613	–
Total, TPC	**461,000**	**461,000**	**451,000**	**10,000**

Note:

- *This project has not received CD-2 approval; therefore, funding 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	42,587	14,787	**N/A**
Design - Contingency	22,900	8,700	**N/A**
Total, Design (TEC)	**65,487**	**23,487**	**N/A**
Construction	129,093	129,093	**N/A**
Equipment	138,076	138,076	**N/A**
Construction - Contingency	116,044	158,044	**N/A**
Total, Construction (TEC)	**383,213**	**425,213**	**N/A**
Total, TEC	**448,700**	**448,700**	**N/A**
Contingency, TEC	*138,944*	*166,744*	***N/A***
Other Project Cost (OPC)			
R&D	350	350	**N/A**
Conceptual Planning	4,650	4,650	**N/A**
Conceptual Design	1,900	1,900	**N/A**
Other OPC Costs	3,800	3,800	**N/A**
OPC - Contingency	1,600	1,600	**N/A**
Total, Except D&D (OPC)	**12,300**	**12,300**	**N/A**
Total, OPC	**12,300**	**12,300**	**N/A**
Contingency, OPC	*1,600*	*1,600*	***N/A***
Total, TPC	**461,000**	**461,000**	**N/A**
Total, Contingency (TEC+OPC)	***140,544***	***168,344***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2022	FY 2022 IRA Supp.	FY 2023	FY 2024	Outyears	Total
FY 2023	TEC	23,487	5,000	—	1,000	—	419,213	448,700
	OPC	6,900	—	—	—	—	5,400	12,300
	TPC	30,387	5,000	—	1,000	—	424,613	461,000
FY 2024	TEC	23,487	11,000	10,000	11,000	10,000	383,213	448,700
	OPC	6,900	—	—	—	—	5,400	12,300
	TPC	30,387	11,000	10,000	11,000	10,000	388,613	461,000

Note:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	1Q FY 2030
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, Maintenance and Repair	21,200	TBD	931,000	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	TBD
Area of D&D in this project at SLAC	TBD
Area at SLAC 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

FES is proposing that the MEC-U project be acquired by Stanford University under the SLAC Management and Operations (M&O) Contract (DE-AC02-76-SF00515) for DOE. The acquisition of large research facilities is within the scope of the DOE contract for the management and operations of SLAC and consistent with the general expectation of the responsibilities of DOE M&O contractors.

SLAC does not currently possess all the necessary core competencies to design, procure and build the laser systems. To address this, SLAC will collaborate with Lawrence Livermore National Laboratory (LLNL) and University of Rochester—Laboratory for Laser Energetics (LLE) as partners through signed Memorandum of Agreements to perform significant portions of the MEC-U laser systems scope of work. Memorandum Purchase Orders will be used to define work scopes and budgets with LLNL as funds become available. Any work accomplished through LLE will be completed using the standard DOE format university agreements. Procurements authorized by the partner institutions will utilize the approved DOE purchasing systems.

14-SC-60 U.S. Contributions to ITER
Project is for Design and Construction

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

Summary

The FY 2024 Request for the U.S. ITER project is $240,000,000 of Total Estimated Cost (TEC) funding. The Total Project Cost (TPC) for the U.S. Contributions to ITER (U.S. ITER) project is $6,500,000,000, including $2,500,000,000 for Subproject-1 (SP-1), First Plasma Hardware for U.S. ITER and $900,500,000 estimated for construction cash contribution to the ITER Organization (IO). In FY 2023, the entire U.S. ITER project will be baselined, with a top-end cost range of $6,500,000,000, and includes SP-1 and SP-2 scope, as well as the total construction cash contribution. Sections of this Construction Project Data Sheet (CPDS) have been tailored accordingly to reflect the unique nature of the U.S. ITER project. Research results from the ITER project are expected to contribute to the development of a U.S. fusion pilot plant, as well as other future fusion energy plants. Fusion energy is expected to provide a carbon-free, inherently safe energy source that will be a significant contributor to ameliorating climate change.

Significant Changes

The U.S. ITER project was initiated in FY 2006. On January 13, 2017, U.S. ITER SP-1 achieved both Critical Decision (CD)-2, “Approve Performance Baseline,” and CD-3, “Approve Start of Construction.” CD-4, “Project Completion,” for SP-1 is currently planned for December 2028.

The Inflation Reduction Act provided $256,000,000 to the U.S. ITER project. $66,000,000 was utilized to provide for Cash Contributions to fulfill U.S. agreements to the ITER Organization (IO). The remaining $190,000,000 will be used to significantly enhance the design and fabrication performance of project scope in FY 2023–2024 to include the full funding of the Central Solenoid agent and the Tokomak Cooling Water System (within SP-1).

In response to Congressional direction articulated in the Consolidated Appropriations Act 2021 to baseline the entire project, the full requirement to complete the U.S. Contributions to ITER project will be baselined in FY 2023.

In FY 2022, the U.S. completed efforts to reinitiate full power testing of the Central Solenoid (CS) magnet modules, as well as continuing in the design, fabrication, and delivery of additional In-kind hardware system components.

In FY 2023, the U.S. is scheduled to deliver the third and fourth (of seven) Central Solenoid magnet modules, as well as continuing the design, fabrication and delivery of additional in-kind hardware system components. The U.S. ITER project will have obligated more than $1,700,000,000 through the end of FY 2023, of which more than 80 percent is to U.S. industry, universities, and DOE laboratories. In addition, the U.S. will baseline the entire U.S. ITER project, including re-baselining SP-1 and the baselining of SP-2 per direction from Congress in the Consolidated Appropriations Act, 2021 and as a result of the IO rebaselining for the overall project due to COVID and first-of-a-kind component delivery delays, material specification and fabrication issues as well as quality challenges.

The FY 2024 Request of $240,000,000 will support the continued design and fabrication of “in-kind” hardware systems and construction financial (cash) contributions to the ITER Organization. This includes continued fabrication and delivery of the CS magnet system.

A Federal Project Director with level I certification has been assigned to this Project and is currently pursuing higher-level certification.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	CD-3	CD-4
FY 2024	7/5/05	–	1/25/08	1/13/17	1/13/17	1Q FY 2028

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-1R	CD-3B	CD-4A
FY 2024	1/13/17	1/13/17	1/13/17	1/13/17	1Q FY 2028

CD-3B - Approval of the project starting construction under the 2017 approved baseline.
CD-4A - Completion of SP-1 and as such encompasses both CD-3A and CD-3B.

Project Cost History

At the time of CD-1 approval in January 2008, the preliminary cost range was $1,450,000,000 to $2,200,000,000. Until 2016, however, it was not possible to confidently baseline the project due to delays early 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 IO at that time) affected the project cost and schedule. Shortly after the arrival of the new Director General in March 2015, the overall 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 $4,000,000,000 to $6,500,000,000 would likely encompass the final TPC (includes SP-1, SP-2, and Cash Contributions). In preparation for baselining SP-1, based on the results of an Independent Project Review, 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-1 Revised (CD-1R) range of $4,700,000,000 to $6,500,000,000.

FY 2023 reflects only SP-1 and associated cash contributions. Beginning in FY 2024, the entire U.S. ITER Project will be baselined per Congressional direction in the Consolidated Appropriations Act, 2021. The TPC for the entire project is projected to be $6,500,000,000.

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

Fiscal Year	TEC, Design	TEC, Construction	TEC, Cash Contributions	TEC, Total	OPC, Except D&D	OPC, Total	TPC
FY 2023	483,126	1,946,572	—	3,330,198	70,302	70,302	3,400,500
FY 2024	439,243	4,663,877	1,067,081	6,429,698	70,302	70,302	6,500,000

2. Project Scope and Justification

ITER, currently one of the largest science experiments in the world, is a major fusion research facility under construction in St. Paul-lez-Durance, France by an international partnership of seven Members or domestic agencies, specifically, the U.S., China, the European Union, India, Korea, Japan, and the Russian Federation. ITER is co-owned and co-governed by the seven Members. The U.S. The Energy Policy Act of 2005 (EPAct 2005), Section 972(c)(5)(C) authorized U.S. participation in ITER. The Agreement on the Establishment of the ITER International Fusion Energy Organization for the Joint Implementation of the ITER Project (Joint Implementation Agreement or JIA), signed on November 21, 2006, provides the legal framework for the four phases of the program: construction, operation, deactivation, and decommissioning. The JIA is a Congressional-Executive Hybrid Agreement that is considered "treaty-like." The other six Members entered the project by treaty. The IO is a designated 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:

- In-kind Hardware systems (13 in total), built under the responsibility of the U.S., and then shipped to the ITER site for IO assembly, installation, and operation. Included in this element is cash provided in-lieu of U.S. In-kind component contributions to adjust for certain reallocations of hardware contributions between the U.S. and the IO.
- Funding to the IO to support common expenses, including ITER research and development (R&D), design and construction integration, overall project management, nuclear licensing, IO staff and infrastructure, IO-provided hardware, on-site assembly/installation/testing of all ITER components, installation, safety, quality control and operation.
- Other project costs, including R&D (other than mentioned above) and conceptual design-related activities.

The U.S. is to contribute the agreed-upon in-kind hardware to ITER, the technical components of which are currently split between SP-1 (First Plasma) and SP-2 (Post-First Plasma) subprojects.

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 planned experimental outcomes expected from ITER. The first 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 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 will provide a sustained burning plasma for long term experimentation which is a necessary step toward developing a fusion pilot plant.

Although not classified as a Capital Asset, the U.S. ITER project is being conducted following project management principles of DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets,* to the greatest extent possible.

Key Performance Parameters (KPPs)

The U.S. Contributions to the ITER Project will not deliver an integrated operating facility, but rather in-kind hardware contributions, which represent a portion of the international ITER facility. 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.

3. **Financial Schedule**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Total Estimated Cost (TEC)				
Design (TEC)				
Prior Years	439,243	439,243	439,243	–
Total, Design (TEC)	**439,243**	**439,243**	**439,243**	**–**
Construction (TEC)				
Prior Years	1,096,877	1,096,899	820,795	–
FY 2022	181,000	181,000	170,330	–
FY 2022 - IRA Supp.	190,000	190,000	–	–
FY 2023	172,000	172,000	172,000	190,000
FY 2024	170,000	170,000	170,000	–
Outyears	2,854,000	2,854,000	3,086,805	–
Total, Construction (TEC)	**4,663,877**	**4,663,899**	**4,419,930**	**190,000**
Cash Contributions (TEC)				
Prior Years	60,000	60,000	60,000	–
FY 2022	61,000	61,000	61,000	–
FY 2022 - IRA Supp.	66,000	66,000	–	66,000
FY 2023	70,000	70,000	70,000	–
FY 2024	70,000	70,000	70,000	–
Outyears	740,081	740,131	794,100	–
Total, Cash Contributions (TEC)	**1,067,081**	**1,067,131**	**1,055,100**	**66,000**
Total Estimated Cost (TEC)				
Prior Years	1,855,617	1,855,639	1,579,535	–
FY 2022	242,000	242,000	231,330	–
FY 2022 - IRA Supp.	256,000	256,000	–	66,000
FY 2023	242,000	242,000	242,000	190,000
FY 2024	240,000	240,000	240,000	–
Outyears	3,594,081	3,594,131	3,880,905	–
Total, TEC	**6,429,698**	**6,429,770**	**6,173,770**	**256,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Other Project Cost (OPC)				
Prior Years	70,302	70,230	70,230	–
Total, OPC	**70,302**	**70,230**	**70,230**	**–**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Total Project Cost (TPC)				
Prior Years	1,925,919	1,925,869	1,649,765	–
FY 2022	242,000	242,000	231,330	–
FY 2022 - IRA Supp.	256,000	256,000	–	66,000
FY 2023	242,000	242,000	242,000	190,000
FY 2024	240,000	240,000	240,000	–
Outyears	3,594,081	3,594,131	3,880,905	–
Total, TPC	**6,500,000**	**6,500,000**	**6,244,000**	**256,000**

Notes:
- *SP-2 is expected to be baselined in FY 2023 and when combined with SP-1 and cash contributions, will bring the entire project TPC to within the CD-1 (R) cost range of $4,700,000,000–$6,500,000,000.*
- *All Appropriations to date for the U.S. Contributions to ITER project include both funding for SP-1 and funding for Cash Contributions.*
- *Obligations and costs through FY 2022 reflect actuals; obligations and costs for FY 2023 and the outyears are estimates.*

4. Details of Project Cost Estimate

The overall U.S. Contributions to ITER project has an approved revised CD-1 Cost Range (CD-1R). DOE chose to divide the project hardware scope into two distinct subprojects (First Plasma SP-1, and Post-First Plasma or SP-2) so that an initial portion of the project that was mature enough to baseline could be accomplished. The baseline for SP-1 ($2,500,000,000) was approved in January 2017. Re-baselining of the entire U.S. ITER project (including SP-1, SP-2, and construction cash contribution to the IO) is planned for FY 2023.

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	439,243	483,126	573,660
Design - Contingency	N/A	N/A	122,365
Total, Design (TEC)	**439,243**	**483,126**	**696,025**
Construction	3,720,360	1,696,355	**N/A**
Equipment	N/A	N/A	1,362,521
Construction - Contingency	943,517	250,217	371,152
Total, Construction (TEC)	**4,663,877**	**1,946,572**	**1,733,673**
Cash Contributions	1,017,000	900,500	**N/A**
Cash Contributions Contingency	309,578	N/A	**N/A**
Total, Cash Contributions (TEC)	**1,326,578**	**N/A**	**N/A**
Total, TEC	**6,429,698**	**3,330,198**	**2,429,698**
Contingency, TEC	*1,253,095*	*250,217*	*493,517*
Other Project Cost (OPC)			
OPC, Except D&D	70,302	70,302	70,302
Total, Except D&D (OPC)	**70,302**	**70,302**	**70,302**
Total, OPC	**70,302**	**70,302**	**70,302**
Contingency, OPC	***N/A***	*N/A*	***N/A***
Total, TPC	**6,500,000**	**3,400,500**	**2,500,000**
Total, Contingency (TEC+OPC)	***1,253,095***	***250,217***	***493,517***

Notes:

- *In the table above, the previous total estimate includes cash contributions estimate to align with the TPC budget request. The Baseline information represents only the SP-1 project.*
- *In the table above, the "Original Validated Baseline" reflects SP-1 only.*
- *Current total estimated design reflects work done prior to CD-2/3. SP-2 design work is accounted for in TEC Construction as part of SP-1 scope approved at CD-2/3.*

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2022	FY 2022 IRA Supp.	FY 2023	FY 2024	Outyears	Total
FY 2023	TEC	1,855,617	221,000	—	240,000	—	1,013,581	3,330,198
	OPC	70,302	—	—	—	—	—	70,302
	TPC	1,925,919	221,000	—	240,000	—	1,013,581	3,400,500
FY 2024	TEC	1,855,617	242,000	256,000	242,000	240,000	3,594,081	6,429,698
	OPC	70,302	—	—	—	—	—	70,302
	TPC	1,925,919	242,000	256,000	242,000	240,000	3,594,081	6,500,000

6. Related Operations and Maintenance Funding Requirements

The U.S. Contributions to ITER operations phase is to begin with initial integrated commissioning activities with an assumed useful life of 30 to 35 years. The fiscal year in which commissioning activities begin depends on the international ITER project schedule, which currently indicates 2025. As a result of COVID-19 and other known delays, the overall ITER project is being re-baselined to update cost and schedule estimates that have an anticipated First Plasma date of December 2028.

Start of Operation or Beneficial Occupancy	2035
Expected Useful Life	35 years
Expected Future Start of D&D of this capital asset	2070

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 phase is assumed to begin no earlier than 30 years after the start of operations. The deactivation phase is also assumed to begin no earlier than 30 years after operations begin and will continue for a period of five years. The U.S. is responsible for 13 percent of the total decommissioning and deactivation cost; this requirement will be collected and escrowed out of research Operations funding.

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 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, to use 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 use best value, competitive source-selection procedures to the maximum extent possible, including foreign firms on the tender/bid list when necessary. 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.