Federal Energy RD&D: Fusion Energy Sciences

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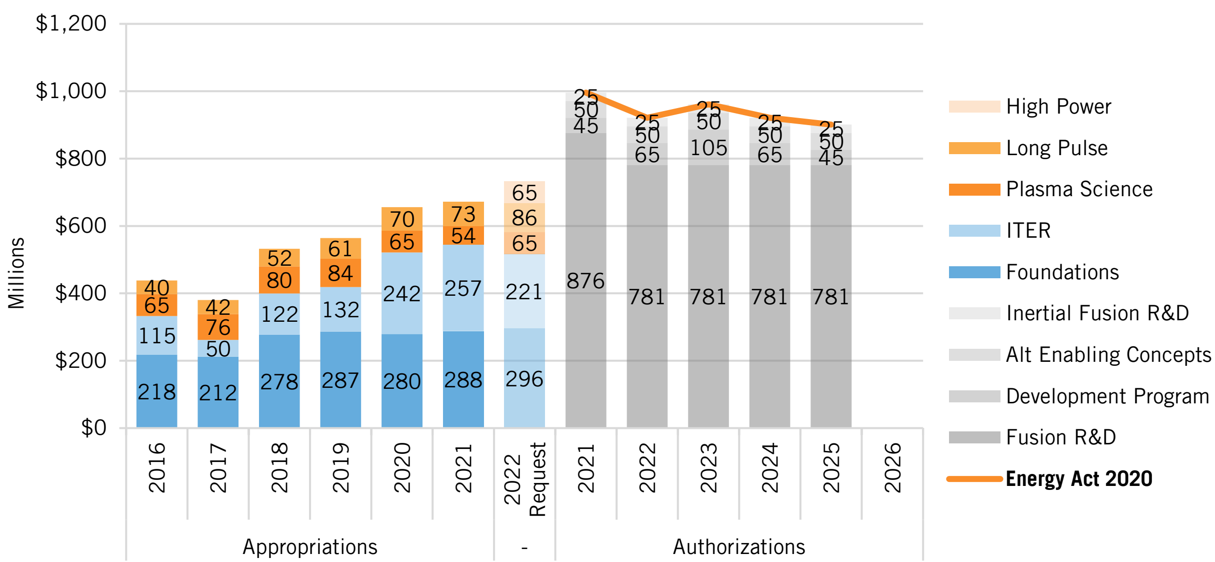
The mission of the Fusion Energy Sciences (FES) program is to build the scientific foundation needed to develop a fusion energy source by expanding the fundamental understanding of the physics behind plasmas (i.e., matter at very high temperatures and densities).[1] Comprising 99 percent of the visible universe, plasmas are at the heart of the fusion process that powers the stars.[2] The promise of fusion—an energy system that could generate massive amounts of power using fuel obtained from seawater and earth-abundant materials, with very little pollution—is enormous. However, controllable fusion technology is still at a very early stage of development.

Figure 1: Fusion research has seen a boost in recent years, both in domestic research and in U.S. contributions to the International Thermonuclear Experimental Reactor (ITER).[3]



What's at Stake

Fusion research, development, and demonstration (RD&D) has the potential to contribute to U.S. energy security by making available a robust clean energy technology that relies on widely available and virtually inexhaustible fuel sources. However, the technological advances needed to realize safe, low-cost fusion are still nascent, so basic research into plasma physics—including plasma confinement and plasma-materials interactions—remains essential to advancing toward the goal of fusion energy.

DOE explains explained fusion energy as follows:

> Fusion is a nuclear reaction where two small atoms like hydrogen combine to form a larger atom like helium, and produce an enormous amount of energy as a byproduct. In controlled thermonuclear fusion, these reactions are facilitated by heating and confining fusion fuel in the form of a plasma, which is created when a gas absorbs enough energy to separate the electrons from the nuclei, making it susceptible to electric and magnetic fields. It requires a great deal of energy to attain the temperatures and pressures required for fusion, and confining plasmas to sustain these conditions is a monumental technical challenge. Most mainstream fusion research currently focuses on one of two approaches to confining plasmas: magnetic confinement, which uses magnetic fields and lower-than-air ion densities, and inertial confinement, which uses heating and compression and involves greater-than-solid densities.[4]

Because its science is so wide-ranging, plasma research could spin off a number of applications for other technologies. Advances developed in the quest for fusion energy have already led to the creation of other technologies that provide considerable economic and societal impact, including applications in lighting, semiconductor manufacturing, medical and health science and technology, materials, and waste management.[5] Robust plasma-research funding may therefore be necessary to prevent the United States from losing out on future benefits in these and other industries.

The FES program in the DOE Office of Science has primarily pursued magnetic confinement fusion approaches. Research facilities include DIII-D, the largest magnetic fusion user facility in the United States; and the National Spherical Torus Experiment, the most powerful spherical tokamak user facility in the world. The program also supports enabling research and development (R&D) in high-temperature superconducting magnet technology and plasma fueling and heating technologies, as well as long-pulse tokamak research and materials research that seeks to understand how plasmas interact with materials that might be used in future fusion facilities.[6] The National Nuclear Security Administration (NNSA), a semiautonomous agency within DOE responsible for stewardship of the nation's stockpile of nuclear weapons, also supports research in inertial confinement fusion, using lasers at its National Ignition Facility.[7]

DOE also participates in the International Thermonuclear Experimental Reactor (ITER), a collaboration among seven governments (China, the European Union, India, Japan, the Republic of Korea, Russia, and the United States) to demonstrate the scientific and technological feasibility of fusion energy for electricity generation. ITER is the only mature burning-plasma experiment in the world, with a goal of completing the first assembly phase in 2025 and second testing phase from 2025 to 2035.[8] The National Academies of Sciences, Engineering, and Medicine (NASEM) has found that no single country has the expertise or capacity to conduct a fusion experiment at this scale.[9] As a member of ITER, the United States has committed to provide 9 percent of the construction costs in return for full access to all ITER technology and scientific data, which represents a significant opportunity for U.S. universities, laboratories, and industries to both design and construct parts and propose and conduct experiments.[10]

In 2020, DOE launched a new pilot program, Innovation Network for Fusion Energy (INFUSE), which aims to accelerate progress in fusion energy by establishing research partnerships with the private sector. Modeled after the successful Gateway for Accelerated Innovation in Nuclear (GAIN) Energy Voucher program, the INFUSE program provides private-sector fusion companies with access to the expertise and facilities of DOE's national laboratories.[11] INFUSE is motivated in part by recent research suggesting compact fusion technologies could be developed and commercialized on a much smaller scale than large, capital-intensive projects such as ITER. For example, Commonwealth Fusion Systems (CFS), in collaboration with the Massachusetts Institute of Technology's Plasma Science Fusion Center, published a series of papers laying out their approach to develop a compact fusion device.[12] INFUSE provides an alternative model for supporting fusion research, by allowing innovative start-ups such as CFS to tap into national research facilities and validate their approach.

The Energy Act of 2020 provides the first reauthorization to the FES program in over a decade and entails a significant restructuring of the program. The bill authorizes funding for DOE to support fusion energy RD&D activities. The bill creates a new inertial fusion research and development (R&D) program in FES to research ion beam, laser, and pulsed power fusion systems, and authorizes $25 million annually for FY 2021 to FY 2025. Moreover, $50 million is allocated annually for FY 2021 to FY 2025 to support alternative fusion energy concepts, enabling fusion technology development, and advanced scientific computing activities. The bill includes a milestone-based development program to support R&D of technologies for the construction of new full-scale fusion systems. The program is authorized $45 million for FY 2021, $65 million for FY 2022, $105 million for FY 2023, $65 million for FY 2024, and $45 million for FY 2025.[13]

Figure 1 shows historical DOE investment in fusion energy RD&D by subprogram, for FY 2016 through FY 2021, and the FY 2022 budget request. The orange line shows authorized funding levels from the Energy Act of 2020.

Fusion Energy Sciences RD&D Activities

RD&D in fusion energy is distributed across four subprograms:[14]

- **Burning Plasma Science: Foundations** advances the predictive understanding of plasma confinement, dynamics, and interactions with surrounding materials—and conducts research in advanced tokamak and spherical-tokamak science, as well as small-scale magnetic confinement experiments.

- **Burning Plasma Science: Long Pulse** explores new scientific regimes using long-duration superconducting international machines, and addresses the development of materials and technologies required to withstand and sustain burning plasma.

- **Discovery Plasma Science** explores the fundamental properties and complex behavior of matter in the plasma state to improve the understanding required to control and manipulate plasmas for a broad range of applications.

- **ITER** is an ambitious international collaboration among seven governments (China, the European Union, India, Japan, the Republic of Korea, Russia, and the United States) to demonstrate the scientific and technological feasibility of fusion power for electricity generation. The United States contributes funding, personnel, and in-kind hardware components to the ITER facility currently under construction in France.

Key Elements of the FY 2022 Budget Proposal[15]

The budget proposal seeks $675 million for FES RD&D activities, a 0.4 percent boost from FY 2021 enacted levels. Some highlights include:

- **A 3 percent increase in Burning Plasma Science: Foundations,** including a $11 million boost for Theory and Simulation, most of which would go into Scientific Discovery through Advanced Computing (SciDAC) partnerships. Funding for research and operations at DIII-D, the largest magnetic fusion user facility in the United States, and the National Spherical Torus Experiment Upgrade (NSTX-U), the most powerful spherical tokamak user facility in the world, would continue.
- **A 19 percent increase in Burning Plasma Science: Long Pulse,** including $15 million to long-pulse tokamak research, as well as a $10.5 million increase in the fusion nuclear science and materials research that seeks to understand how plasmas interact with the materials that might be used in future fusion facilities.
- **A 19 percent increase in Discovery Plasma Science,** including a $7.3 million increase in general plasma science, which explores low-temperature plasma science and engineering.
- **A 9 percent-reduced contribution to the International Thermonuclear Experimental Reactor (ITER),** which would still allow the U.S. to meet its agreed-upon contributions to ITER. ITER is the only mature burning plasma experiment in the world, and the National Academies has found that no single country has the expertise or the capacity to conduct a fusion experiment at this scale. As a member of ITER, the United States has committed to provide 9 percent of the construction costs in return for full access to all ITER technology and scientific data, which represents a significant opportunity for U.S. universities, laboratories, and industries to both design and construct parts, and propose and conduct experiments. The requested funding will continue to support the design and fabrication of In-kind hardware systems for the First Plasma subproject.
- **A new $2 million ITER Research program** to start preparing the U.S. fusion community to take full advantage of ITER operations after First Plasma.

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ENDNOTES

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