The Global State of Fusion Development

August 2022 Briefing Note

American Security Project

Fusion Fast Facts

- Fusion occurs when two nuclei combine to form a new nucleus, releasing tremendous amounts of energy. The process occurs in Earth's Sun, which is why some fusion research projects are called "artificial suns."
- Fusion energy has no carbon emissions, making it an ideal component of a clean energy transition and enhancing energy efficiency and energy security.
- Fusion occurs in nature and produces minimal amounts of low-level, short-lived radioactive waste compared to fission's high level waste.
- Fusion does not rely on a chain reaction, so there is no chance of a nuclear meltdown.
- While magnetic Tokamaks are the leading plasma confinement "concepts for future fusion power," there are a variety of options for commercial fusion.

Mainstream Fusion Approaches

There are three main approaches researchers use to create sustained fusion reactions:

- **Magnetic Confinement Fusion** (MCF) uses high-powered magnetic fields to create plasma.
- **Inertial Confinement Fusion** (ICF), uses lasers to heat and compress targets filled with nuclear fuel. The U.S. National Ignition Facility (NIF) at Lawrence Livermore National Laboratory houses the world's largest and highest energy laser.
- **Magnetized Target Fusion** (MTF) combines features of MCF and ICF to create fusion conditions in plasma.

Recent Advances

The past two years have seen several notable advances in fusion research, including:

- The achievement of plasma temperatures above 100 million degrees Celsius by private companies, a crucial milestone on the path toward commercial fusion.
- The creation of the strongest ever superconducting magnet of its type, a major step in overcoming "the greatest technological hurdle" in the advance towards net-positive magnetic confinement power.
- The first instance of "burning plasma," a requirement for a self-sustaining fusion reaction.
- Generation of the highest sustained energy pulse ever created by fusing atoms, doubling the previous record and providing key information on how future experiments will work.

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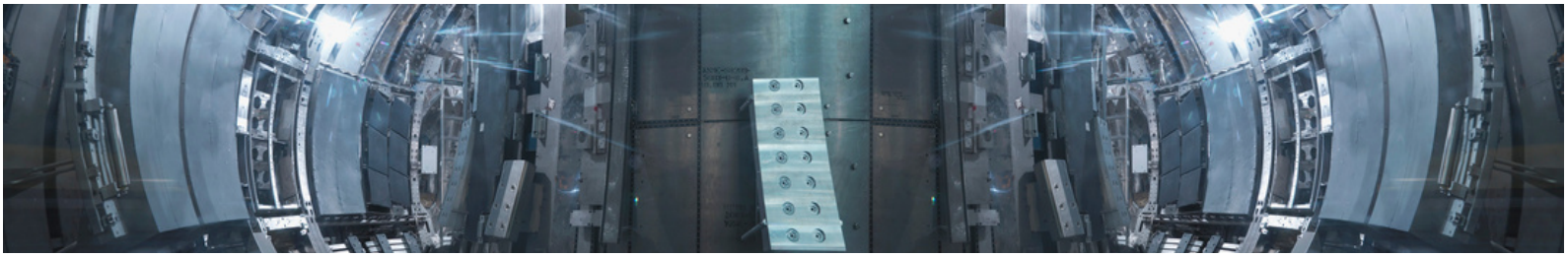

Domestic Research Landscape

The U.S. has numerous organizations, companies, and facilities actively conducting research on nuclear fusion and related technologies. The U.S. Department of Energy (DOE) Office of Science Fusion Energy Sciences Program (FES) is a key funder of U.S. government fusion efforts. FES has four strategic goals:

1. Advance the science of magnetically confined plasmas needed for a sustainable fusion energy source;
2. Support the development of the scientific understanding required to design and deploy the materials needed to support a burning plasma environment;
3. Pursue scientific opportunities and grand challenges in high energy density plasma science to better understand our universe, and to enhance national security and economic competitiveness;
4. Increase the fundamental understanding of basic plasma science.

Public Private Partnerships:

Through the Innovation Network for Fusion Energy (INFUSE), DOE FES awarded funding for 18 projects for FY22 at three national labs and eight universities, including Oak Ridge National Laboratory, the Princeton Plasma Physics Laboratory, and the Savannah River National Laboratory, to "enhance collaboration to overcome challenges in fusion energy development."

The Secretary of Energy recently named a new Senior Advisor and Lead Coordinator for Fusion, who will lead efforts across the Department of Energy to accelerate fusion, including by pursuing a new "Milestone-based" public private partnership that will directly invest in U.S.-based private fusion efforts.

Private Industry Developments

There is now around $5 billion in private investment into fusion energy, and in 2021, for the first time, more private capital went to fusion than public capital.

- **Commonwealth Fusion Systems (CFS)**, a Massachusetts-based company, is building an experimental tokamak to produce more energy than it consumes by mid-decade in Devens, Massachusetts.
- **General Fusion**, a Canadian company, aims to use MTF as a way to create commercially available fusion. They are building a fusion demonstration plant in Culham in the United Kingdom.
- **Helion Energy, Inc.**, a Washington-based fusion startup, expects to achieve net positive electricity in their pulsed device by 2024.
- **TAE Technologies**, a California-based fusion energy company, previously proved that its reactor design could sustain plasma long enough and hot enough for fusion energy, and is aiming to see commercialization by 2030.

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International Fusion Research

- **China**
  - China is investing heavily in research-related tokamak reactors and inertial confinement fusion.
  - China built the world's first fully superconducting tokamak, the Experimental Advanced Superconducting Tokamak (EAST), which produced a nuclear fusion reaction for more than 17 minutes. EAST reactor technology is also being used to support the development of the ITER nuclear reactor. China is investing heavily in fusion research in an effort to address its energy security. The Shanghai Superintense Ultrafast Laser Facility (SULF) is under construction and "aims to provide advanced research technique[s] for material and life sciences."
  - The national research institutes, such as the Research Centre of Laser Fusion (RCLF), the Institute of Applied Physics and Computational Mathematics (IAPCM), the National Laboratory on High Power Laser and Physics (NLHPLP), as well as many universities and other institutions are participating in the inertial confinement fusion (ICF) program.
- **Europe**
  - European fusion laboratories collaborate through a consortium called EUROfusion, the European Consortium for Development of Fusion Energy. Established in 2014, EUROfusion coordinates physics and technology research and development in the member institutions as well as European industry. Consortium members are located across 30 institutes in 28 countries, with activities guided by the European Roadmap to Fusion Energy.
  - The Extreme Light Infrastructure (ELI) is "the world's largest and most advanced high-power laser infrastructure." It manages several research facilities through the ELI European Research Infrastructure Consortium, including the Extreme Light Infrastructure Nuclear Physics (ELI-NP) project, an advanced research facility which conducts experimental, interdisciplinary research on high-power lasers and nuclear physics.
- **Japan**
  - A Cabinet office was established in Japan in 2022 to develop a strategy for nuclear fusion, with the goal of achieving a prototype reactor by mid-century.
  - In Japan, small and midsize companies are working on making components for nuclear fusion reactors with government support.
  - A Japanese startup, Kyoto Fusioneering Ltd., is building the world's first "integrated testing facility," to allow for the testing of power components designed convert fusion energy into electricity.

International Fusion Research

- **Russia**
  - The Kurchatov Institute in Moscow built the world's first tokamak over sixty years ago and currently focuses on the study and development of fusion and other nuclear energy related projects. In 2021, a modified version of the institute's previous tokamak, T-15MD, is the "first new fusion installation at the institute in 20 years."

- **South Korea**
  - South Korea has established a specialized research institute for fusion-power-oriented R&D through the creation of the Korean Institute of Fusion Energy (KFE). KFE operates the Korea Superconducting Tokamak Advanced Research (KSTAR) reactor which ran at one million degrees and maintained super-hot plasma for 30 seconds in 2021, which is recognized as a key milestone on the road to usable fusion.

- **United Kingdom**
  - The Culham Centre for Fusion Energy (CCFE) in Oxfordshire is the fusion research arm of the UK Atomic Energy Authority. Fusion research in the UK started in the later 1940s, and the Culham facility officially opened in 1965. There are two primary programs at CCFR, one centered on the Mega Amp Spherical Tokamak (MAST) Upgrade device and the Joint European Torus, a joint program between the European Commission and the United Kingdom Atomic Energy Authority.

  - Tokamak Energy in the UK is a private company developing a spherical tokamak and conducting research on HTS magnets.

  - Last year, the United Kingdom committed £220 million to the planning of the Spherical Tokamak for Energy Production (STEP), a plan for a commercially viable fusion power station.

ITER

International fusion research is a rare area of widespread international collaboration, and is "one of the most complex scientific and engineering projects in the world." Since its launch in 1985, the ITER project has had thousands of engineers and scientists from member countries contributing to the development and deployment of fusion technology. Members include: China, the European Union, India, Japan, South Korea, Russia, and the United States. Located in southern France, the ITER Project is currently in main assembly phase 1 and is approximately 77% complete to creating its first plasma. The ITER reactor is projecting its first plasma to occur in December 2025, and while it will not produce electricity, it will take fusion to the point where industrial applications can be designed.