COMMITTEE ON
SCIENCE, SPACE AND TECHNOLOGY
CHAIRMAN FRANK LUCAS

**SUBCOMMITTEE ON ENERGY**

**HEARING CHARTER**

***"From Theory to Reality: The Limitless Potential of Fusion Energy"***

**Tuesday, June 13, 2023**
**2:00 p.m.**
**2318 Rayburn House Office Building**

**Purpose**
The purpose of this hearing is to explore the current status of fusion energy research and development in the United States, with a focus on private sector innovation, Department of Energy (DOE) programs and facilities, and international research partnerships. This hearing will also provide an opportunity to review DOE's progress in carrying out fusion energy program direction recently enacted in the CHIPS and Science Act and the Energy Act of 2020.

**Witnesses**
- **Dr. Kathryn McCarthy,** Director, U.S. ITER Project Office
- **Dr. David Kirtley,** CEO, Helion Energy
- **Dr. Wayne Solomon,** Vice President, Magnetic Fusion Energy, General Atomics
- **Mr. Andrew Holland,** CEO, Fusion Industry Association
- **Dr. Scott Hsu,** Senior Advisor and Lead Fusion Coordinator, U.S. Department of Energy

**Overarching Questions**
- How is the Department of Energy coordinating with industry and academia to accelerate the development and deployment of fusion energy to the electric grid?
- What hurdles are still hampering industry from being able to fully progress to the point of commercialized fusion energy?
- What research areas still need to be prioritized to allow for a more rapid expansion of the fusion industry?

## BACKGROUND

The pursuit of a fusion-based reactor represents our attempt to replicate the power of a star on earth. By definition, a star is plasma held together by its own gravity, and in its core, these gravitational forces create very high pressures and temperatures.[1] Our sun has an internal temperature of 27 million degrees Fahrenheit and a core pressure equal to approximately 340 billion times the earth's atmospheric pressure.[2,3] Under these extreme conditions, hydrogen atoms in the sun's core are compressed and ultimately fused together, a process that releases a very large amount of energy in the form of gamma ray photons and neutrinos.[4] This fusion energy travels to the sun's surface and is the source of its luminosity.[5]

For decades, scientists and engineers have pushed the boundaries of experimental physics to duplicate this reaction and harness it as an energy source. The potential benefits to society from a fusion reactor are beyond calculation; the fuel is abundant and widely accessible, the carbon footprint is negligible, and its associated nuclear waste and nonproliferation concerns are minimal.[6,7] Despite these incentives and despite recent landmark achievements in the field, fusion energy science remains one the most challenging areas of experimental physics today.

A key benchmark for the achievement of nuclear fusion in a terrestrial reactor is called "ignition." This is defined as the point at which the products of the fusion reaction are sufficient to maintain the temperature of the plasma and the reaction itself without external power input.[8] In other words, ignition is reached when the reaction generates more energy than it consumes.

Generally, these conditions required to sustain this reaction are described as: temperature (T), plasma density (n), and confinement time (t). Over the past 50 years, (n) and (T) have been reasonably well defined.[9] A central remaining challenge in fusion energy science is the third quantity: (t).[10] This refers to the residence time of the fusion products inside the plasma of reacting ions.[11] In order to generate a substantial amount of power, time is needed to allow fusion reactions to occur.[12] Inside our sun, gravitational confinement is sufficient to fulfill this requirement. On earth, other mechanisms of confinement are required.

The two mainstream mechanisms for confinement are inertial and magnetic.[13] Inertial fusion applies

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[1] Sharp, Tim. "What is the Sun Made Of?" *SPACE.COM*, 3 Nov. 2017, https://www.space.com/17170-what-is-the-sun-made-of.html.

[2] National Aeronautics and Space Administration. "*The Solar Interior*." *NASA.GOV*, 1 Oct. 2015, https://solarscience.msfc.nasa.gov/interior.shtml.

[3] Treybick, Marina. "Pressure At The Center Of The Sun." *The Physics Factbook*, 1997. https://hypertextbook.com/facts/1997/MarinaTreybick.shtml.

[4] Tim Sharp, *What is the Sun Made Of?*, SPACE.COM, Nov. 3, 2017, *available at* https://www.space.com/17170-what-is-the-sun-made-of.html.

[5] Bahcall, John N. "How the Sun Shines." *NOBEL MEDIA AB*, 29 June 2000. https://www.nobelprize.org/nobel_prizes/themes/physics/fusion/index.html.

[6] U.S. Department of Energy, *Fusion Energy Sciences*, ENERGY.GOV, https://science.energy.gov/fes/.

[7] Princeton Plasma Physics Laboratory, *Fusion Power Fact Sheet*, PPPL.GOV, https://www.pppl.gov/sites/pppl/files/publication/file/FUS_PWR_FACTSHEET.

[8] Lawrence Livermore National Laboratory, *Fusion and Ignition*, LLNL.GOV, https://lasers.llnl.gov/science/ignition.

[9] EUROFusion. "Lawson's Three Criteria." *EURO-FUSION.ORG*, 25 Feb. 2013. https://www.euro-fusion.org/2013/02/triple-product/.

[10] Harack, Benjamin. "Derivation of Lawson Criterion for D-T." *Vision Of Earth*, Nov. 2010. https://www.visionofearth.org/wp-content/uploads/2010/11/LawsonCriterion.pdf.

[11] EUROFusion, *Lawson's Three Criteria*, EURO-FUSION.ORG, Feb. 25, 2013, *available at* https://www.euro-fusion.org/2013/02/triple-product/

[12] TAE Technologies. "Technology Overview." *TAE.COM*, https://tae.com/technology-overview/.

[13] General Atomics. "What is Fusion?" *GAT.COM*, http://fusioned.gat.com/what_is_fusion.html.

a rapid pulse of energy to a small sample of fusion fuel, causing this fuel to implode and heat to very high temperatures and compress to very high densities simultaneously.[14] Magnetic fusion reactors confine plasma with magnetic fields generated by running an electric current through the plasma itself. There are a wide variety of fusion reactor approaches, including combinations of these two mechanisms. For example, magnetic fusion reactors use several different architectures to approach adequate confinement: the tokamak, spherical torus, and stellarator are examples of geometries that are currently utilized by the fusion research community.[15]

With these mechanisms, fusion power has been generated in a laboratory setting for several seconds, but the creation of a burning plasma that has reached ignition had never been successfully accomplished until just late last year at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL).[16]

Due to the vast complexity of these experiments, fusion energy science is a heavily interdisciplinary endeavor. The push for construction of a successful fusion reactor, while a worthwhile endeavor on its own, can also lead to technological and scientific advancement in several fields, including plasma science in astronomy, superconducting magnet research, complex cryogenic systems, vacuum technologies, robotics, and high-performance computing.[17]

**Department of Energy Fusion Research Programs and Facilities**

Department of Energy (DOE) supports fusion energy science research primarily through the Fusion Energy Sciences (FES) program within its Office of Science. The mission of FES is "to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundation for fusion energy." In addition, the FES mission includes the development of a competitive fusion power industry in the U.S."[18] DOE stewards three main fusion facilities: the NIF at LLNL, the National Spherical Torus Experiment – Upgrade (NSTX-U) at Princeton Plasma Physics Laboratory (PPPL), and DIII-D at General Atomics. DOE also partners with the International Thermonuclear Experimental Reactor (ITER), a leading international fusion construction project.

Fusion energy sciences has greatly benefitted from public-private partnerships given the high risk, high reward nature of the technology. The Advanced Research Projects Agency – Energy (ARPA-E), has supported fusion projects over the last few years through two programs: Breakthroughs Enabling Thermonuclear-fusion Energy (BETHE) and Galvanizing Advances in Market-Aligned Fusion for an Overabundance of Watts (GAMOW). BETHE seeks to provide funding to high maturity, but low-cost fusion options while GAMOW prioritizes projects of enabling technologies and advanced materials, which are necessary for commercial fusion systems.[19, 20]

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[14] *Id.*
[15] Princeton Plasma Physics Laboratory, *Fusion Power Fact Sheet*, PPPL.GOV, https://www.pppl.gov/sites/pppl/files/publication/file/FUS_PWR_FACTSHEET.pdf
[16] *https://www.llnl.gov/news/lawrence-livermore-national-laboratory-achieves-fusion-ignition*
[17] Lawrence Livermore National Laboratory, *Fusion and Ignition*, LLNL.GOV, https://lasers.llnl.gov/science/ignition
[18] Department of Energy. Fiscal Year 2024 Budget Request: Science. Volume 5, March 13, 2023. https://www.energy.gov/sites/default/files/2023-03/doe-fy-2024-budget-vol-5-science-v3.pdf
[19] "Galvanizing Advances in Market-Aligned Fusion for an Overabundance of Watts." *ARPA E,* 2 Sept. 2020, arpa-e.energy.gov/technologies/programs/gamow.
[20] "BETHE Highlights." *ARPA E*, arpa-e.energy.gov/highlights/1056. Accessed 7 June 2023.

Recently, Congress reauthorized FES in the Energy Act of 2020 and the CHIPS and Science Act of 2022. Through the Energy Act of 2020, Congress authorized two public-private partnership programs, the Innovation Network for Fusion Energy (INFUSE) and the Milestone Based Development Fusion program. Launched in FY2019, the INFUSE program provides industry access to the national laboratories and universities who have expertise and world leading facilities in fusion energy sciences. This relationship will support the advancement of novel approaches to fusion through material sciences, modeling and simulation, advanced computing, and diagnostics. The DOE closed its INFUSE Request for Assistance (RFA) for FY2023 in March 2023. To date, the program has 72 awards totaling $14.7 million.

Similarly, the Fusion Milestone Development is a milestone program that will award companies that meet technical and commercialization targets, which will accelerate the development of a fusion power plant. The Department of Energy closed its up-to-$50 million Funding Opportunity Announcement (FOA) in December of 2022. On May 31, the DOE announced that it will award $46 million to eight companies including: Commonwealth Fusion Systems, Focused Energy Inc., Princeton Stellarators Inc., Realta Fusion Inc., Tokamak Energy Inc., Type One Energy Group, Xcimer Energy Inc, and Zap Energy Inc.

In addition, the Energy Act of 2020 authorized DOE to conduct a research and development program specifically around technologies that can advance inertial fusion activities. The Department announced in May of 2023 the Inertial Fusion Energy Science and Technology Accelerated Research (IFE-STAR) FOA that will look to provide sustained research for the inertial fusion program. The CHIPS and Science Act built on these authorizations to establish a High-Performance Computing for Fusion Innovation Center and High-Performance Computation Collaboration Research program. This legislation also authorized the Matter in Extreme Conditions (MEC) Petawatt upgrade for the Linac Coherent Light Source II (LCLS-II) facility at SLAC National Laboratory and a Major Item of Equipment (MIE) for the Material Plasma Exposure eXperiment at Oak Ridge National Laboratory.

Over the last few years, FES has seen a steady increase in funding. The President's fiscal year (FY) 2024 Budget Request includes $1.01 billion for FES activities, a topline consistent with CHIPS and Science funding levels, and a 32.4% increase from FY 2023. The President's FY 2024 Budget Request also includes funding for new FES activities such as dedicated fusion R&D centers focused on blanket/fuel cycle, advanced simulations, structural/plasma facing materials, as well as enabling technologies to support public-private fusion power plant efforts.[21]

<u>Lawrence Livermore National Laboratory</u>

At LLNL, NIF uses the world's largest and highest-energy laser to pursue ignition in the lab through inertial fusion.[22] NIF is also used to simulate temperatures and pressures like those that exist inside nuclear weapons and provides critical science for DOE's nuclear stockpile stewardship mission. On December 5, 2023, NIF achieved fusion ignition. The experiment yielded an output of 3.15 megajoules from 2.05 megajoules of input energy. This is the first fusion experiment to achieve this

[21] *Id.*
[22] Lawrence Livermore National Laboratory. "About NIF & Photon Science." *LLNL.GOV*, https://lasers.llnl.gov/about.

milestone.[23]

Princeton Plasma Physics Laboratory

PPPL is one of the leading research centers for magnetic fusion energy and basic plasma physics research. It is home to NSTX-U, a large magnetic spherical tokamak designed to serve as a testbed for researchers to test novel techniques and approaches for understanding the viability of spherical torus designs. PPPL is also focused on training and developing the next generation of the fusion workforce, including both new scientists and technical skilled workers through apprenticeship programs. The development of a fusion power plant relies on engineering and building techniques. Currently, PPPL accepts up to 14 people into a four-year program where students learn skills in electrical and mechanical engineering, welding, and HVAC. [24]

General Atomics

Operated by General Atomics, DIII-D is a DOE user facility located in San Diego; it is the largest magnetic tokamak in the U.S. Through DIII-D, General Atomics partners with over 100 institutions and supports a research team of more than 600 participants. DIII-D's design can adjust to changes to its interior and plasma configurations and provides researchers with unique capabilities to test innovative experiments DIII-D.[25] General Atomics also supports U.S. contributions to the ITER project, through delivery of key in-kind contributions. Recently, General Atomics signed a memorandum of understanding (MOU) with a U.K. company, Tokamak Energy, to collaborate on High Temperature Superconducting (HTS) technologies.[26]

Other Facilities

The Department of Energy has two additional facilities that focus on fundamental research in material sciences, which is a critical component to the viability of a fusion energy reactor. LCLS-II, an Office of Science user facility at SLAC National Laboratory, is a world leader in laser technology providing researchers the ability to study atoms and molecules in extraordinary detail. The MEC Petawatt Upgrade instrument for LCLS-II helps researchers study plasma and matter in extreme environments. Through the CHIPS and Science Act, Congress authorized these upgrades to allow for greater research to be conducted into materials and plasma science. Included in the President's FY2024 Budget, the upgrade will increase the power to the petawatt level allowing researchers to answer fundamental questions relating to nonlinear optics of plasmas and magnetized high energy density plasma physics.[27] In addition, the FY2024 Budget provides funding for the Major Item of Equipment project for the Material Plasma Exposure eXperiment project located at Oak Ridge National Laboratory. Set to begin assembly in the fall 2023, this facility will allow researchers to study the effect of plasma on materials. This experiment will be instrumental in developing materials

[23] "DOE National Laboratory Makes History by Achieving Fusion Ignition." *Energy.Gov*, 13 Dec. 2022, www.energy.gov/articles/doe-national-laboratory-makes-history-achieving-fusion-ignition.

[24] "PPPL Apprenticeship Program to Train Highly-Skilled Technicians Is a National Model." *Princeton University*, 22 Dec. 2022, www.princeton.edu/news/2022/12/22/pppl-apprenticeship-program-train-highly-skilled-technicians-national-model.

[25] "DIII-D National Fusion Facility." *General Atomics*, www.ga.com/magnetic-fusion/diii-d. Accessed 7 June 2023.

[26] "General Atomics and Tokamak Energy Announce Collaboration Regarding High Temperature Superconducting Magnet Technologies." *General Atomics*, 30 May 2023, www.ga.com/ga-and-tokamak-energy-announce-collaboration-regarding-high-temperature-superconducting-magnet-technologies.

[27] Dyer, Gilliss, and Fry, Alan. *Matter in Extreme Conditions Upgrade (Conceptual Design Report)*. United States: N. p., 2021. Web. doi:10.2172/1866100.

that can withstand plasma like temperatures.[28]

The International Thermonuclear Experiment Reactor (ITER)

Widely considered the leading research initiative in fusion science, the ITER project is a collaboration to design, build, and operate a first-of-a-kind research facility to achieve and maintain a burning plasma with a peak output of 500 MW of thermal power driven by 50 MW of input power.[29] It is a major international scientific collaboration between the European Union, Japan, South Korea, China, India, the Russian Federation, and the United States to design, build, and operate what will be the world's largest magnetic fusion tokamak reactor.[30]

Located in southern France, ITER's status as an unparalleled fusion facility is due in large part to its sheer size; it will house ten times the plasma volume of the next largest machine operating today.[31] Since the amount of fusion energy that a tokamak is capable of generating is directly proportional to the number of reacting atoms in the plasma it contains, this larger volume means a greater potential for experimental success and scientific discovery. Lessons learned from ITER can help inform the development of next generation fusion power plants.[32]

In 2003, President George W. Bush announced the United States' intention to join ITER describing it as "an ambitious international research project to harness the promise of fusion energy."[33] Under the Energy Policy Act of 2005, Congress authorized the Secretary of Energy to negotiate an agreement for U.S. participation in ITER ("the ITER Agreement" or "the Agreement"), which entered into force in 2007.[34,35] DOE fulfills its obligations under the ITER agreement by supplying personnel, delivering predetermined hardware components, and providing cash contributions to the ITER Organization for the United States' share of common expenses.[36]

Under the Agreement, the European Union is obligated to pay for 45.46 percent of the construction costs, while the United States as a non-host member is obligated to contribute 9.09 percent of construction costs. The U.S. also supports ITER by providing key components. The U.S. is responsible for 100% of the critical central solenoid magnet along with other sections such as the Tokamak cooling water systems, electron cyclotron heating transmission lines, toroidal field conductor, and tokamak blanket/shield. As a member of the ITER organization, the U.S. will have full access to the ITER reactor to carry out experiments and draw knowledge from the cutting-edge research capabilities that will be offered from this first-of-a-kind facility.

ITER has received steady support from Congress with the Energy Act of 2020 and the CHIPS and

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[28] Rapp, Juergen, et al. "The Development of the Material Plasma Exposure Experiment MPEX." *The Development of the Material Plasma Exposure eXperiment MPEX (Conference) | OSTI.GOV*, 1 Jan. 2016, www.osti.gov/biblio/1337482.
[29] ITER, *About*, ITER.ORG, https://www.iter.org/proj/inafewlines
[30] ITER. "What is a Tokamak?" *ITER.ORG*, https://www.iter.org/mach/tokamak.
[31] ITER, *About*, ITER.ORG, https://www.iter.org/proj/inafewlines
[32] ITER, *About*, ITER.ORG, https://www.iter.org/proj/inafewlines
[33] Bush, George W. "ITER: International Research Project Statement." *White House Archives*, 30 Jan. 2003, http://georgewbush-whitehouse.archives.gov/news/releases/2003/01/20030130-18.html.
[34] "Text - H.R.6 - 109th Congress (2005-2006): Energy Policy Act of 2005." *Congress.gov*, Library of Congress, 8 August 2005, https://www.congress.gov/bill/109th-congress/house-bill/6/text.
[35] U.S. Department of Energy. "Fusion Energy Sciences: Research." *ENERGY.GOV*, http://science.energy.gov/fes/research/.
[36] U.S. ITER. "About US ITER." *USITER.ORG*, https://www.usiter.org/about/index.shtml.

Science Act in 2022 authorizing funding for the project. In the Inflation Reduction Act, it was appropriated $256 million and the President's, FY2024 Budget Request includes $240 million to support U.S. contributions to ITER.[37]

Public-Private Partnerships

Over the past few years, the U.S. fusion energy industry has greatly expanded. Out of the 37 fusion companies that make up the Fusion Industry Association, the U.S. has 23 members.[38] Many of these companies have been spun out of both academia and the national laboratories, which creates cross-cutting research collaborations. The private sector has taken notice of these trends and has made large investments in the growing industry. Over time, the industry has raised more than $5 billion from private investors, of which more than $2.8 billion was secured last year.[39] Last month, Microsoft announced that it entered into a first-of-a-kind power purchase agreement with Washington State based fusion energy company, Helion Energy, starting in 2028.[40]

**Regulatory Developments:**

On April 14, the Nuclear Regulatory Commission (NRC) announced that it would regulate fusion under the existing byproduct materials framework in 10. C.F.R. Part 30. Directed by the Nuclear Energy Innovation and Modernization Act, this law required the NRC to develop a regulatory framework for Fusion by 2027.[41] Before this decision, the independent agency developed three options, which included utilization facility (Part 50), byproduct materials (Part 30), and a hybrid option of the two. This decision to use the byproduct materials framework has been generally welcomed by industry.[42]

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[37] Department of Energy. Fiscal Year 2024 Budget Request: Science. Volume 5, March 13, 2023. https://www.energy.gov/sites/default/files/2023-03/doe-fy-2024-budget-vol-5-science-v3.pdf

[38] *Fusion Industry Association*, 30 May 2023, www.fusionindustryassociation.org/.

[39] *Id.*

[40] Gardner, Timothy. "Microsoft Signs Power Purchase Deal with Nuclear Fusion Company Helion." *Reuters*, 10 May 2023, www.reuters.com/technology/microsoft-buy-power-nuclear-fusion-company-helion-2023-05-10/.

[41] "S.512 - 115th Congress (2017-2018): Nuclear Energy Innovation and Modernization Act." *Congress.gov*, Library of Congress, 14 January 2019, https://www.congress.gov/bill/115th-congress/senate-bill/512.

[42] Sailer, Sandy. "NRC Decision Separates Fusion Energy Regulation from Nuclear Fission." *Fusion Industry Association*, 12 May 2023, www.fusionindustryassociation.org/nrc-decision-separates-fusion-energy-regulation-from-nuclear-fission/.