



U.S. DEPARTMENT OF
ENERGY

Office of
Science

Fusion Energy Sciences Perspective

James W. Van Dam

Associate Director, Office of Science

Fusion Energy Sciences

42nd Fusion Power Associates Annual Meeting

December 15-16, 2021

Budget status

- ▶ **Continuing Resolution**

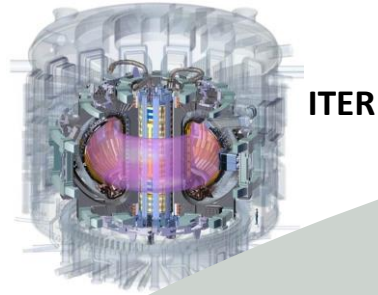
- ▶ Extended through February 18

- ▶ **Waiting for:**

- ▶ FY 2022 budget appropriation from Congress
- ▶ Build Back Better reconciliation bill
- ▶ FY 2023 budget request pass back from OMB

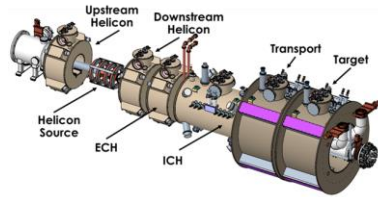
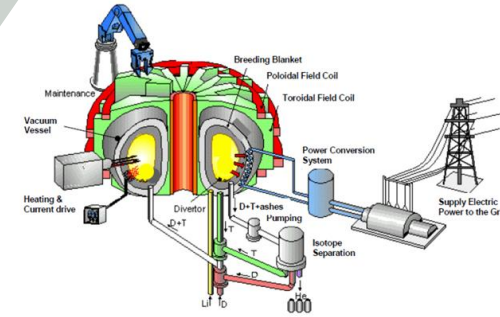
New FESAC Long-Range Plan recommends balancing the domestic program to aim at a Fusion Pilot Plant

- *Fusion nuclear science*
- *Fusion materials R&D*
- *Fusion facilities systems studies*



ITER

Electricity on the grid



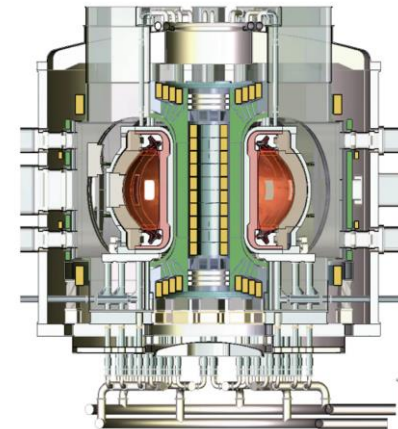
Material Plasma Exposure Experiment

Fusion Pilot Plant

ITER

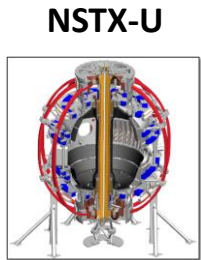
Long Pulse

Foundations

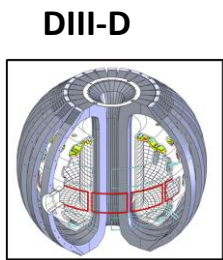


Fusion Pilot Plant

- *Advanced computing (SciDAC)*
- *Artificial intelligence*
- *Quantum information science*
- *Advanced manufacturing*
- *High-temperature superconductor magnets*
- *Public-private partnerships*

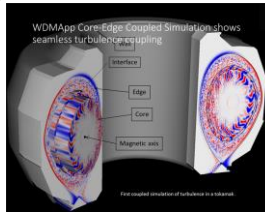


NSTX-U

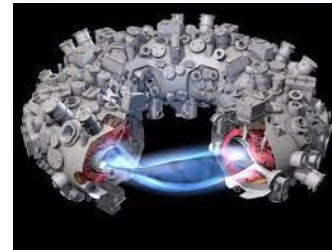


DIII-D

Fusion User Facilities



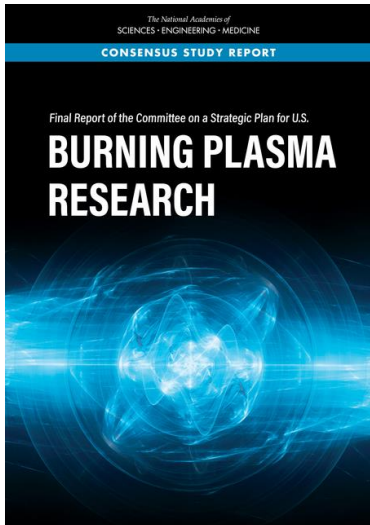
Theory & Simulation



International Collaborations

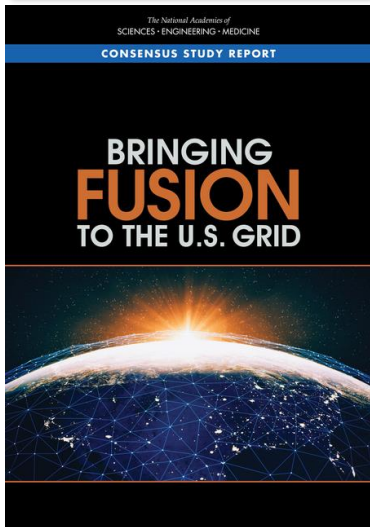
“Powering the Future: Fusion and Plasmas”
(Fusion Energy Sciences Advisory Committee, 2021)

Recent National Academy advisory reports for FES



Strategic Plan for U.S. Burning Plasma Research (2019)

- ▶ The U.S. should remain an ITER partner as the most cost-effective way to gain experience with a burning plasma at the scale of a power plant.
- ▶ The U.S. should start a national program of accompanying research and technology leading to the construction of a compact pilot plant which produces electricity from fusion at the lowest-possible capital cost.



Bringing Fusion to the U.S. Grid: Key Goals and Innovations for a U.S. Fusion Pilot Plant (2021)

- ▶ To make an impact on the transition to a low-carbon emission electrical system by 2050, the Department of Energy and the private sector should produce net electricity in a fusion pilot plant in the United States in the 2035—2040 timeframe.
- ▶ DOE should move forward now to foster the creation of national teams, including public-private partnerships, that will develop conceptual pilot plant designs and technology roadmaps that will lead to an engineering design of a pilot plant that will bring fusion to commercial viability.

Fusion at UN Climate Change Conference (COP26)

- ▶ **For the first time, fusion had a role at the conference**, with a featured panel on final day and side-event in first week.
- ▶ **November 3, 2021**: ITER presented the leading fusion energy projects from around the world.

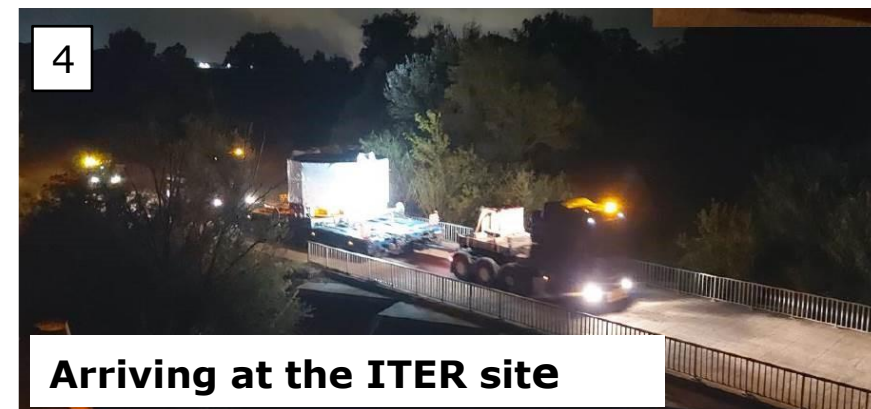
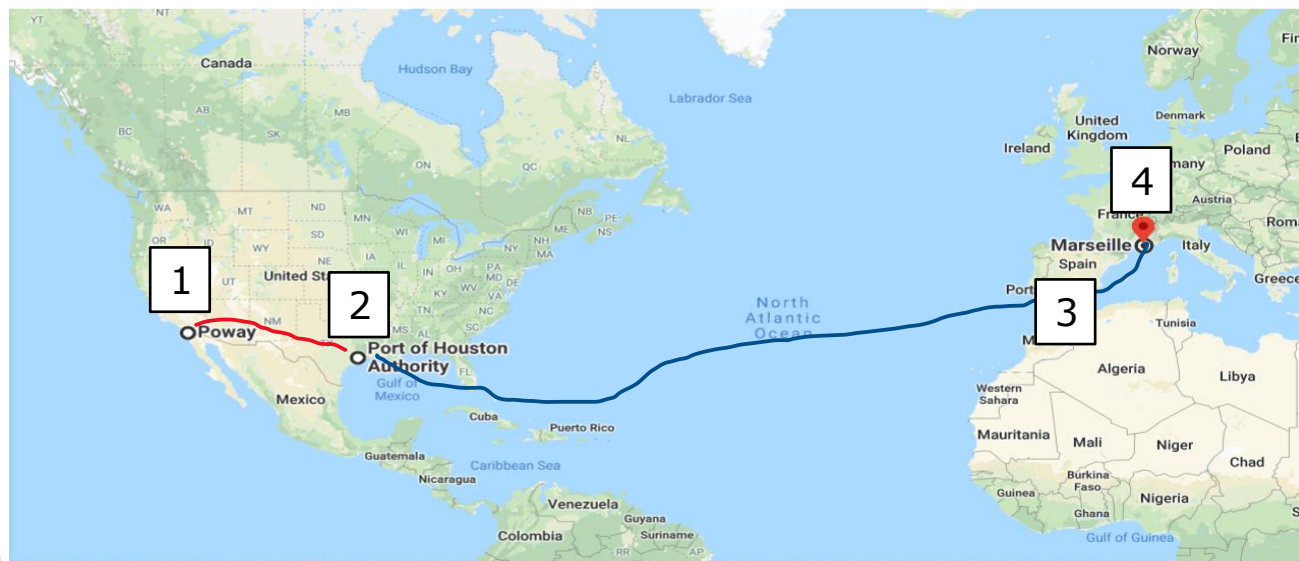


- ▶ **November 4, 2021**: ITER presented the largest experimental fusion project in human history at the COP 26 Action Hub. (This hosts representatives of businesses, investors, & foundations as well as civil society, cultural, & media figures to encourage a cross-disciplinary climate debate.



Fusion Power Associates Meeting, December 8-9, 2021

ITER central solenoid magnet modules #1 and #2 delivered



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CS magnet module #1 celebrations

General Atomics

▶ August 10, 2021



ITER Organization

▶ September 10, 2021



Virtual visits



DIID-D vent activities (Sept 24)



The very latest ...

21 October 2021
A Chinese-made correction coil is lowered carefully into position.

VR tour of ITER (Oct 21)



Secretary of Energy visit to ORNL (Sept 28)



Secretary of Energy visit to PPPL (Oct 29)

US Research Team for ITER Workshop: Basic Research Needs Workshop planned in FY 2022

- ▶ “Ensure full engagement of the US fusion community in ITER by forming an ITER research team that capitalizes on our investment to access a high-gain burning plasma.”

FESAC Long Range Plan (p. 32)

FES points of contact: Josh King and Matt Lanctot

FES is planning a Basic Research Needs workshop on the US Research Team for ITER in 2022



Dr. Charles Greenfield
(GA)
Chair



Dr. Cami Collins (ORNL)
Co-Chair

Inertial Fusion Energy: Basic Research Needs Workshop planned in FY 2022

- ▶ “Inertial fusion energy (IFE) utilizes advances in lasers, pulsed power technology, and other innovative drivers to achieve fusion at high fuel density. The enormous progress made with indirect drive at the National Ignition Facility, direct drive, magnetic drive inertial confinement fusion (ICF), and heavy ion fusion underpin the promise of IFE. An IFE program that leverages US leadership and current investments should be targeted.”

FESAC Long Range Plan (page 34)

An IFE Science and Technology Community Strategic Planning Workshop - Kickoff (pre-BRN) was held November 16

- ▶ This workshop collected input from the entire community
- ▶ For more information, contact Dr. Alex Zylstra (zylstra1@llnl.gov)

FES is planning a Basic Research Needs (BRN) Workshop for Inertial Fusion Energy in March/April 2022



**Dr. Tammy Ma
(LLNL)
Chair**



**Prof. Riccardo Betti
(UR-LLE)
Co-Chair**

FES point of contact: Kramer Akli

DIII-D is completing several facility enhancements and preparing for 20-week FY 2022 campaign

▶ DIII-D completed 18.7 weeks in FY21 with high system availability

- Hydrogen and FRONTIER science campaigns completed; Helicon system commissioned

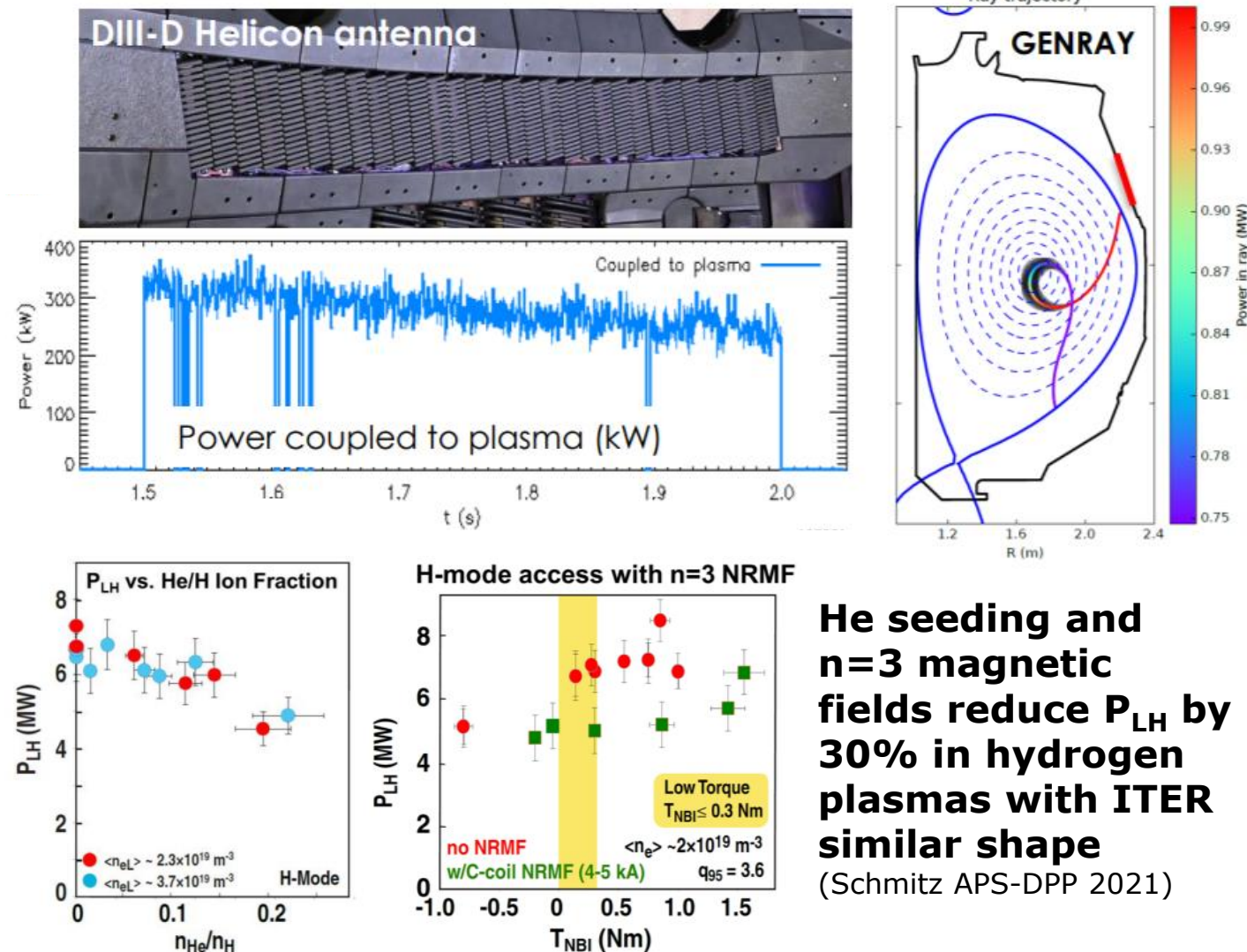
▶ A broad user base is supported

- DIII-D Research Opportunities Forum is ongoing (contact Craig Petty)
- Breakout discussions Dec. 1 to Jan. 14.
- International participation is welcomed

▶ Facility projects during 6-month vent

- New helium liquefier
- Additional gyrotrons & top launchers
- New diagnostics: Doppler-free saturation spectroscopy, helium beam, WiSP, multichord divertor spectroscopy

Bortolon, APS-DPP 2021



He seeding and n=3 magnetic fields reduce P_{LH} by 30% in hydrogen plasmas with ITER similar shape
(Schmitz APS-DPP 2021)

Status of the NSTX-U Recovery

Project Progress

- Recovery project is proceeding (~70% complete)
- Technical issue w/ TF bundle insulation may delay project
- All production plasma facing component tiles have been delivered to PPPL and are being readied for installation
- Delivery of the completed center stack casing is expected in the spring of 2022

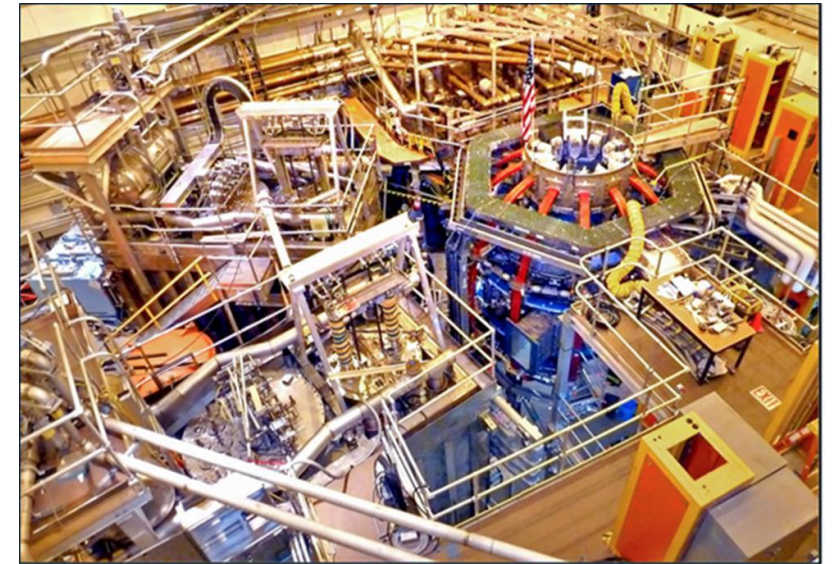
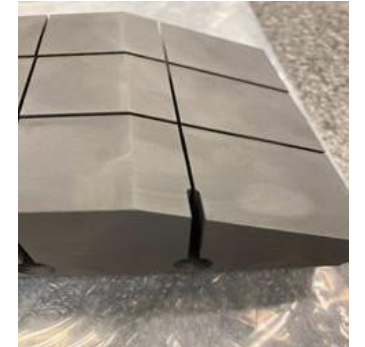
COVID-19 Impacts

- Delays from on-site personnel limitations and curtailments have adversely impacted the project schedule
- New PPE procedures, testing, and vaccination requirements
- Center stack casing vendor delays due to COVID illnesses
- A new NSTX-U Recovery cost and schedule baseline is expected to be reviewed and approved in FY22

CS Casing



PFC tile



NSTX-U Test Cell



Other FES facility projects

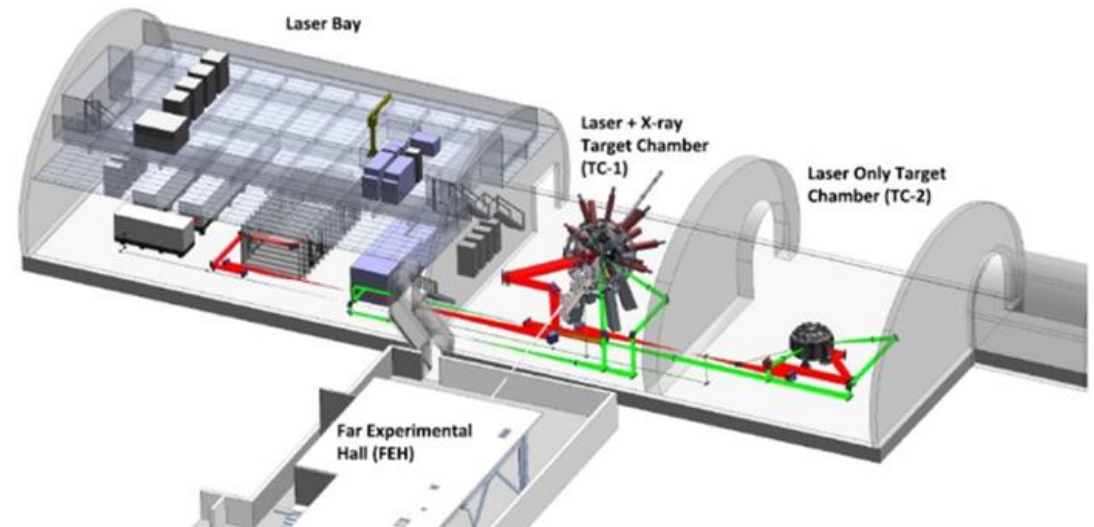
Material Plasma Exposure eXperiment (MPEX)

- ▶ New world-class plasma exposure facility for accelerated testing of fusion materials
- ▶ CD-1 (Alternative Selection & Cost Range) approval achieved January 2020
- ▶ CD-3A (Long-lead Procurement) approval achieved October 2020
- ▶ Long-lead procurements awarded for magnets, gyrotrons, and high-voltage power supplies



Matter in Extreme Conditions (MEC) Petawatt Laser Upgrade

- World-leading high-energy-density plasma science instrument
- Conceptual design was finalized in support of CD-1 (Alternative Selection & Cost Range) and approved in early October 2021



Long Pulse Tokamak: 10 multi-institutional teams continue to address gaps in tokamak physics basis using international facilities

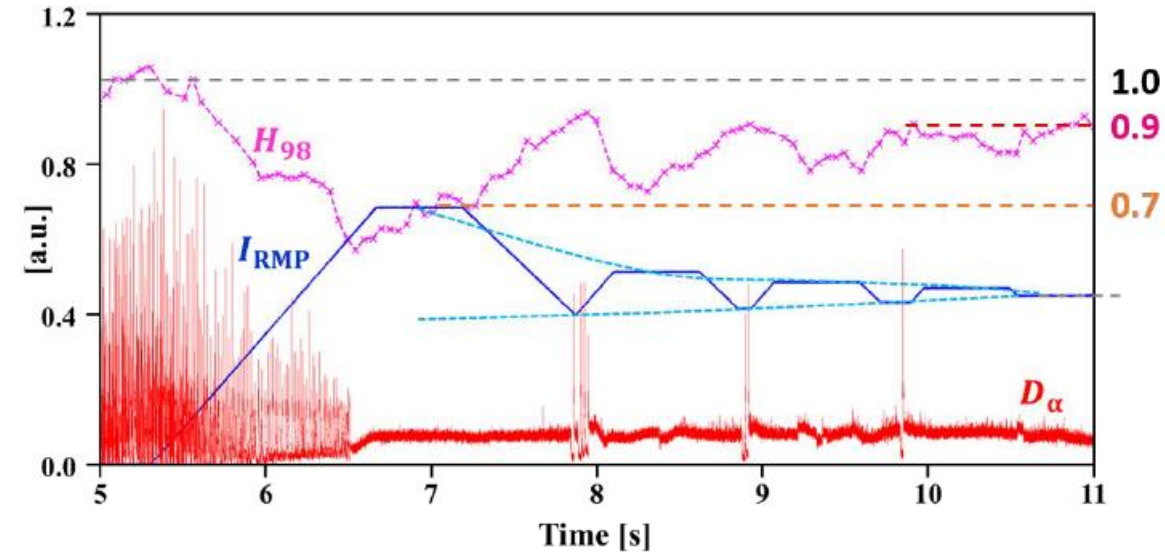
► Multi-institutional teams continue to make progress as their three-year programs conclude in 2022

- Participants from universities, nat'l labs, and industry
- Efforts are multi-disciplinary involving burning plasma scenario development, diagnostic development and exploitation, plasma control, AI/ML, integrated modeling, and model validation
- Activities complement Theory and Simulation program, especially in area of model validation and exploitation of products from SciDAC program

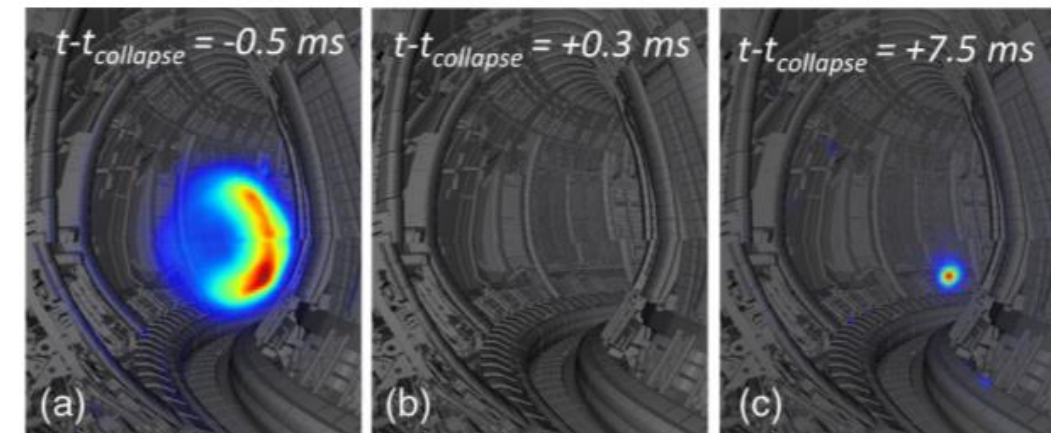
► Contact FES for news about future solicitations

- Program Manager: Matthew.Lanctot@science.doe.gov

Confinement improved 60% with adaptive ELM control in KSTAR (S.K. Kim, APS-DPP invited)

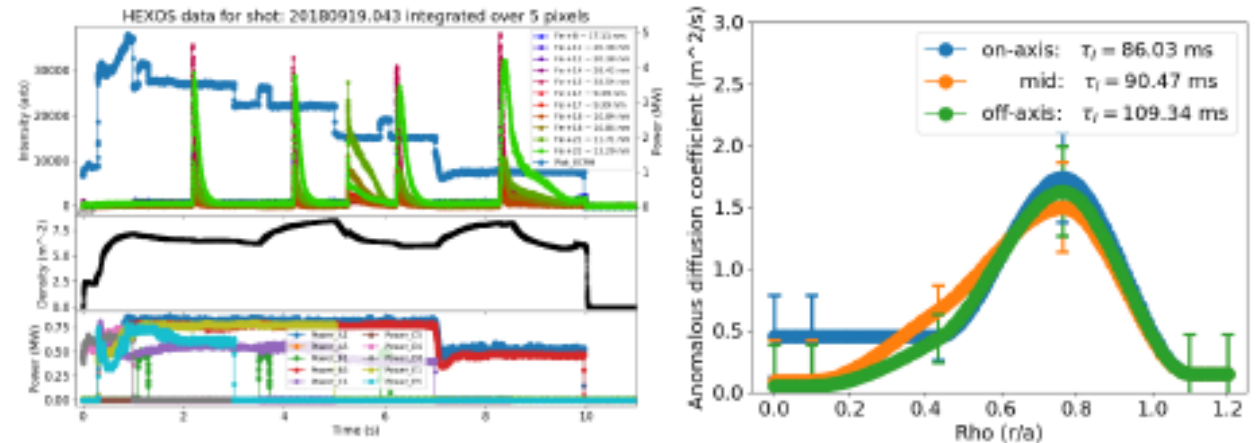


Runaway electron suppression by D2 SPI in JET

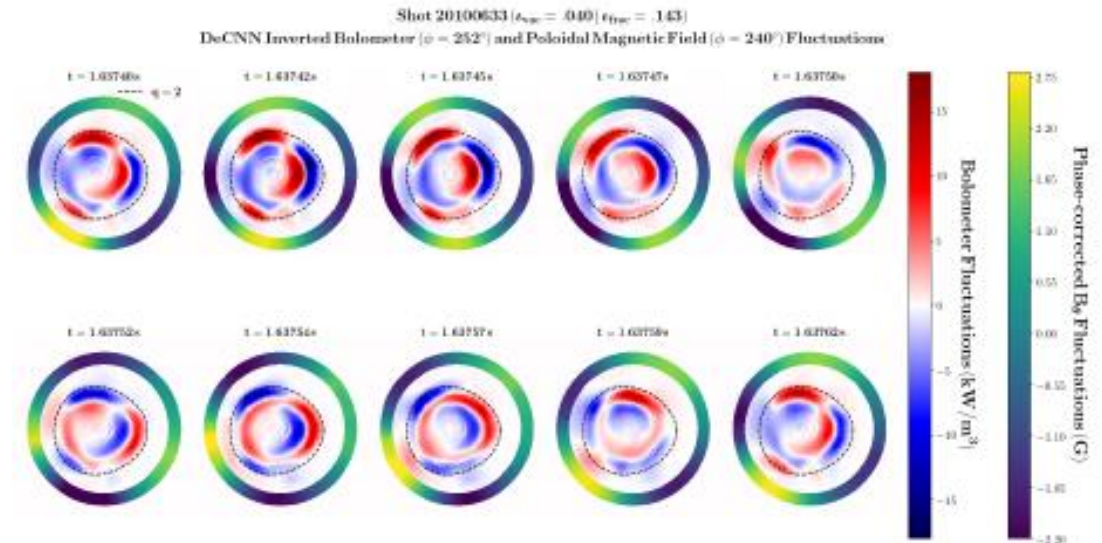


Long-Pulse & Domestic Stellarator

- An international team led by ORNL has been constructing a continuous, high-speed pellet system to fuel W7-X plasmas in quasi-steady-state conditions with significantly enhanced fueling, pumping, and heating capabilities. The system is being assembled at ORNL and is scheduled to begin full testing in the fall of 2021.
- U.S. stellarator researchers are enhancing their diagnostic systems to prepare for the next major W7-X experimental campaign in late 2022.
- The upgrade of HSX is on schedule to resume operations by December 2021. The upgrade will implement a 70 GHz gyrotron to significantly improve the ECH system and provide a factor of 2 to 3 in electron density, increased heating power, and longer pulses.



Iron impurity transport during on- to off-axis ECH in W7-X

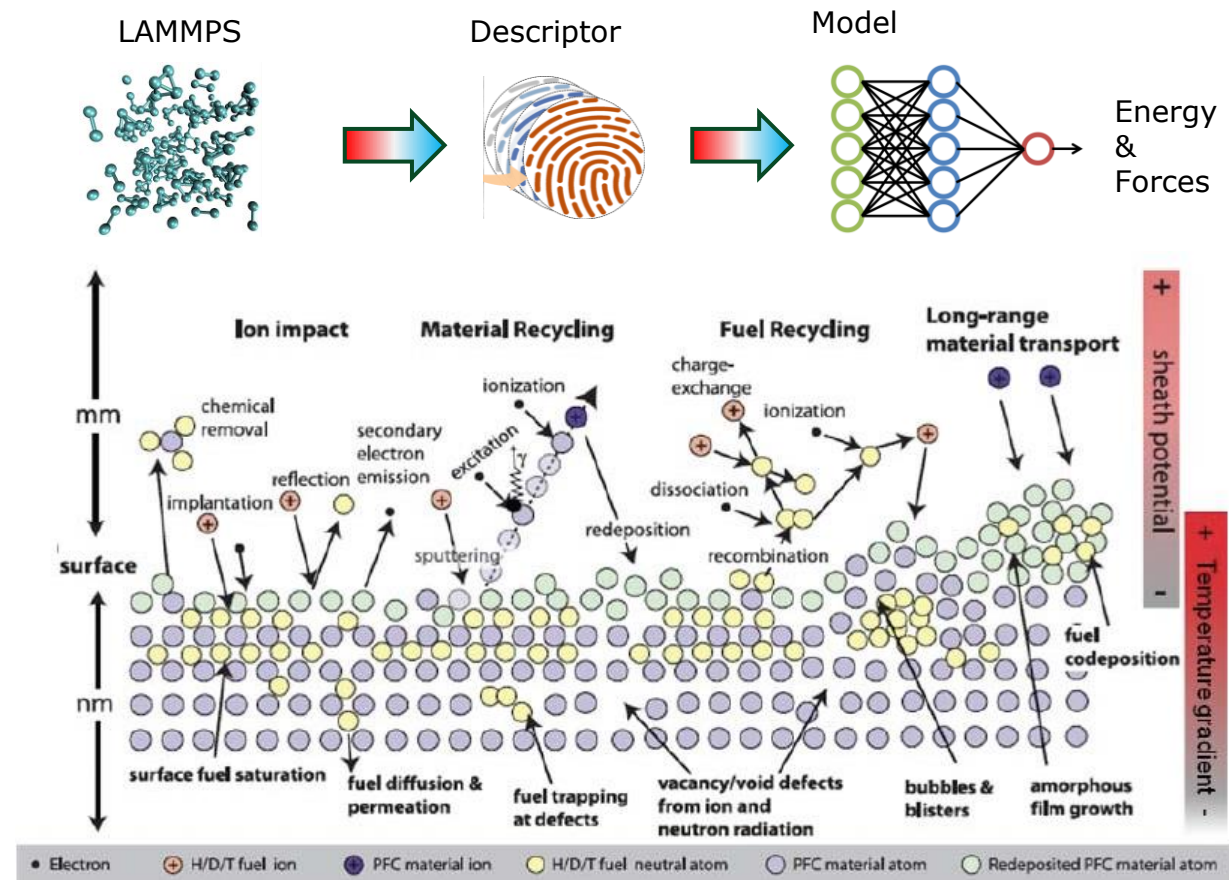


De-Convolutional Neural Network B field fluctuations in CTH

Artificial Intelligence and Machine Learning: Program was expanded in FY 2021 to include six pilot studies on high priority R&D

- ▶ **FY20 FOA:** Five teams were supported to pursue materials modeling, real-time plasma behavior prediction, plasma equilibrium reconstruction, radio frequency modeling, and optimization of experiments with high-repetition-rate lasers.
- ▶ **FY21:** Six pilot studies (3 lab; 3 non-lab) supported in the areas of randomized methods for real-time plasma control, ML models for plasma pulse design optimization and validation, data-driven stellarator optimization, surrogate models for detached divertor control, optimization of inertial confinement fusion experiments, and physics-informed neural networks for disruption prediction and avoidance.
- ▶ **SC vision for AI/ML** is to increasingly use learned models to improve experimental discovery, pursue questions semi-autonomously, merge simulation and AI, and include AI/ML as a common part of scientific activities. SC supports DOE's participation in the U.S. National Artificial Intelligence Initiative and coordinates AI activities with the Office of Science and Technology Policy.

FusMatML (Sandia, UTK, LANL) team is using AI/ML to deploy interatomic potentials for predictive atomistic simulations of materials

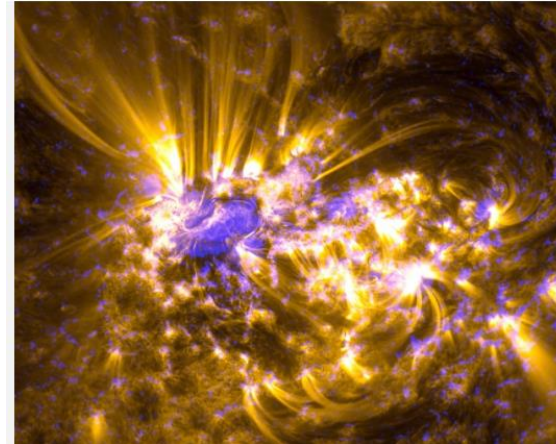


Innovation Network for Fusion Energy (INFUSE)

- **INFUSE** is now in its fourth year
- FY 2021: 2 Request for Assistance Calls, with approx. \$4.0M in research awards
- FY 2021 RFA-2 award announcements coming soon
- To date, **47** awards totaling **\$9.3M** have been made, enabling **8** DOE national labs to collaborate with **17** fusion companies
- A pilot program for **University** participation is being launched in FY 2022
- The 3rd Annual **INFUSE Workshop** will be held virtually Dec. 16 and will include discussion of this pilot program



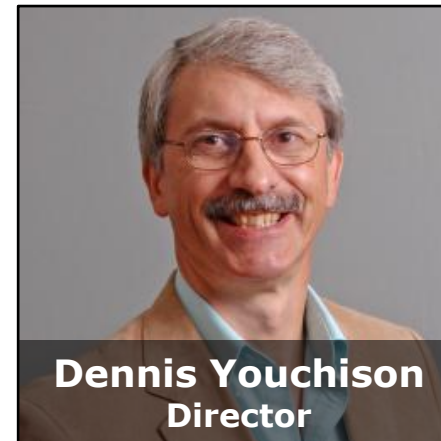
What Is INFUSE? Topic Areas ▾ Meetings ▾ Library Submission ▾



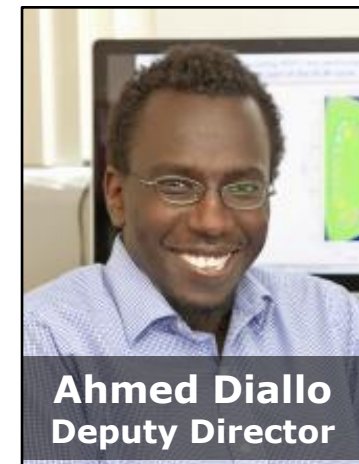
Innovation Network for Fusion Energy

The INFUSE program will accelerate fusion energy development in the private sector by reducing impediments to collaboration involving the expertise and unique resources available at DOE laboratories. This will ensure the nation's energy, environmental and security needs by resolving technical, cost, and safety issues for industry.

Read More



Dennis Youchison
Director



Ahmed Diallo
Deputy Director



US Burning Plasma Organization update



2021-2022 webinar series

- ▶ Burning plasma aspects and reactor concept based on SPARC/ARC (high field) Speaker: Dennis Whyte, MIT-PSFC, MA, USA Webinar date: 12/09, 4.30PM ET
- ▶ Burning plasma aspects and reactor concept with a Steady State Tokamak Speaker: Richard Buttery, GA, CA, USA Webinar date: 01/20/2022, 4.30PM ET
- ▶ Burning plasma aspects at ITER Speaker: Alberto Loarte, ITER Organization, Cadarache, France Webinar date: 02/10/2022, 11.30AM ET
- ▶ Burning plasma aspects and reactor concept based on the Stellarator approach Speaker: Mike Zarnstorff, PPPL, NJ, USA Webinar date: 03/03/2022, 4.30PM ET
- ▶ Burning plasma aspects and reactor concept based on the high-field mirror approach Speaker: Cary Forest, UW Madison, WI, USA Webinar date: 03/24/2022, 4.30PM ET
- ▶ Burning plasma implications on reactor technology – FESS summary Speaker: Chuck Kessel, ORNL, TN, USA Webinar date: 04/14/2022, 4.30PM EDT, Zoom info below
- ▶ Burning plasma aspects and reactor concept based on the FRC approach Speaker: Michl Binderbauer, TAE, CA, USA Webinar date: 05/05/2022, 4.30PM ET, Zoom info below
- ▶ Burning plasma achieved in inertial fusion Speaker: Alex Zylstra, LLNL, CA, USA Webinar date: 05/26/2022, 4.30PM ET, Zoom info below



Virtual Laboratory for Technology Update

- ▶ Updating each topical area
- ▶ Re-establish webinars, Jan 2022
- ▶ Create regular highlights (quarterly)
- ▶ Archiving Historical Workshops
- ▶ Institutional links from US Map

<https://vltfusion.org/>



Enabling Technologies

Radio-Frequency heating and current drive

Magnet systems

Remote Handling

Measurement and Diagnostics

Materials and High Heat Flux

Fusion materials research

Plasma facing components and plasma material interactions

Blanket, Fuel Cycle and Design

Fueling systems

Blanket research and development

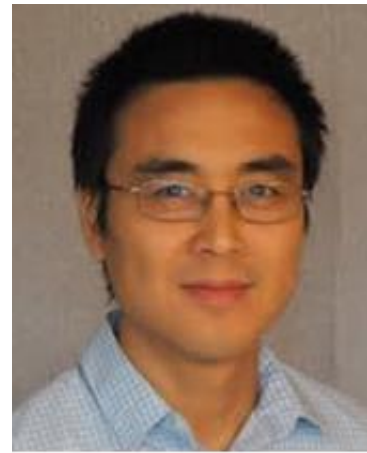
Tritium and Fuel Cycle Research

Fusion safety

Fusion energy systems studies and fusion nuclear facility design

FY 2021 Early Career Research Awards

▶ \$14M FES funds committed over 5 years for two university awards and five laboratory awards



Prof. Petros Tzeferacos
Univ Rochester
HED Magnetized Plasma Turbulence - Simulations, Experiments and Theory

Prof. Mona Ghassemi
Virginia Tech
Prediction of Breakdown in Air and Solid Dielectrics: A Complete Plasma Model from Discharge Initiation to Flashover

Dr. Mark Boyer
PPPL
Machine learning approaches for spherical tokamak scenario optimization and rt control

Dr. Andrea Schmidt
LLNL
Neutron Yield Scaling with Current in Dense Plasma Focus Z-Pinch Discharges

Dr. Daisuke Shiraki
ORNL
Precision Science and Control of Pellet Fueling for Optimizing Tokamak Plasma Scenarios

Dr. Emma McBride
SLAC
First Principles Measurements of Temperature and Transport Properties in Warm Dense Matter

Dr. Matthew Beidler
ORNL
Hybrid Kinetic-Fluid Modeling of Tokamak Disruption Mitigation

Significant investment made from the DOE Office of Science for 51 new university and 32 new lab projects

Fusion Power Associates Meeting, December 8-9, 2021

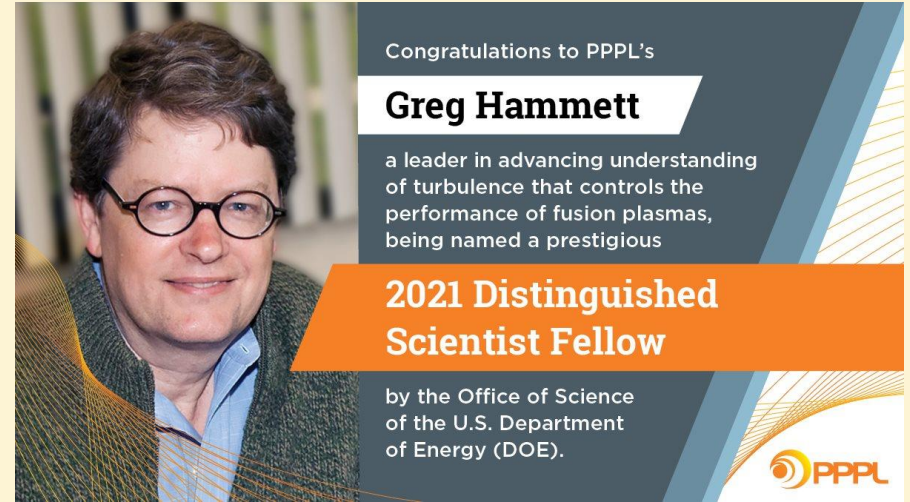
Awards



DOE Ernest O. Lawrence Award

Dustin Froula (University of Rochester)

- ▶ *"For innovative research in laser plasma physics including pioneering spatiotemporal pulse shaping techniques, focused laser plasma instability research, and novel high-resolution Thomson scattering methods that has significantly advanced the Department of Energy's mission."*



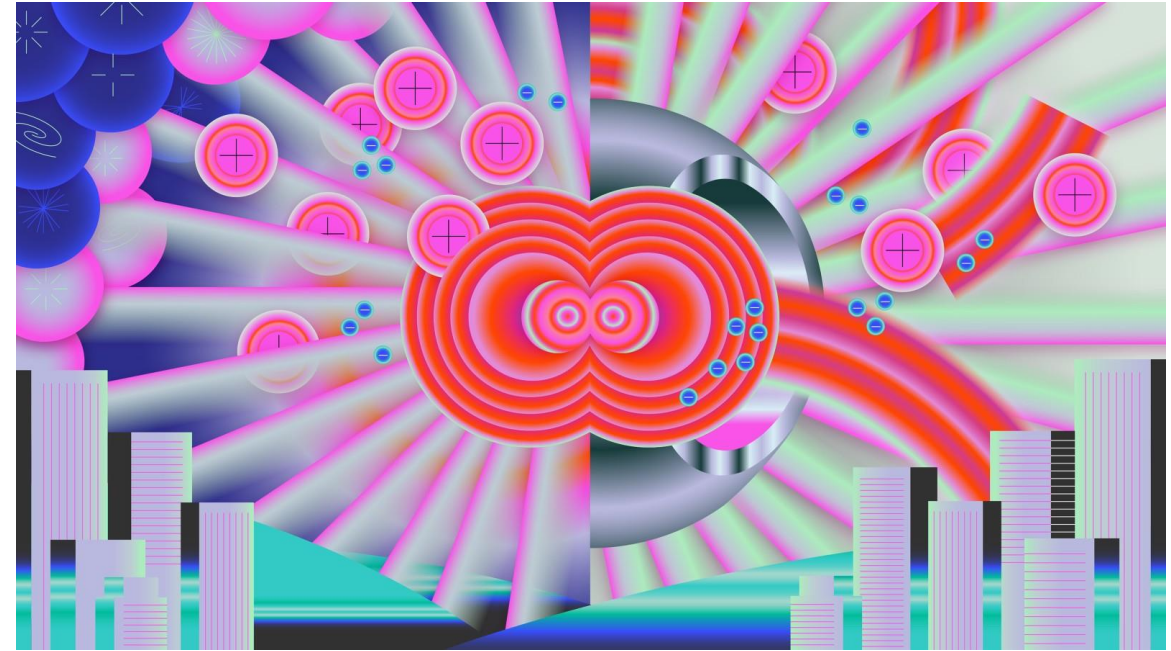
SC Distinguished Scientist Fellow Award

Greg Hammett (PPPL)

- ▶ *Honored for "leading the development of the quantitative theory and simulation of plasma turbulence in fusion and astrophysics, and for educating and mentoring a diverse group of graduate students and early career researchers."*

U.S. Fusion Energy Website

- ▶ Organized and designed by the FES community
 - ▶ Fusion Outreach Team
- ▶ Aligns with the FESAC LRP
- ▶ Provides the community and the general public
 - ▶ Introduction and general education on Fusion and Plasma Science
 - ▶ Current Fusion and Plasma Science News
 - ▶ Fusion and Plasma Science Events
 - ▶ Fusion and Plasma Science Support in government and industry
 - ▶ Student engagement and research opportunities



<https://usfusionenergy.org/>



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