

Building Bridges

Update from Fusion Energy Sciences

FESAC Virtual Meeting, September 30, 2024

Jean Paul Allain

Associate Director of the Office of Science
for Fusion Energy Sciences

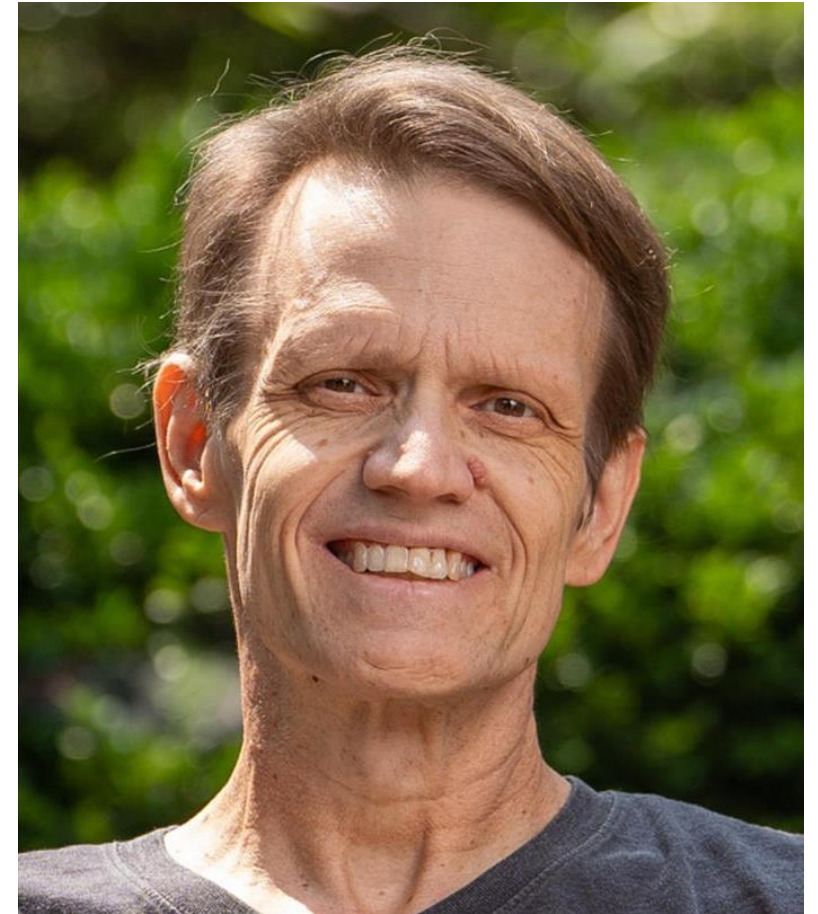


U.S. DEPARTMENT OF
ENERGY

Office of
Science

Bill Dorland (1965-2024)

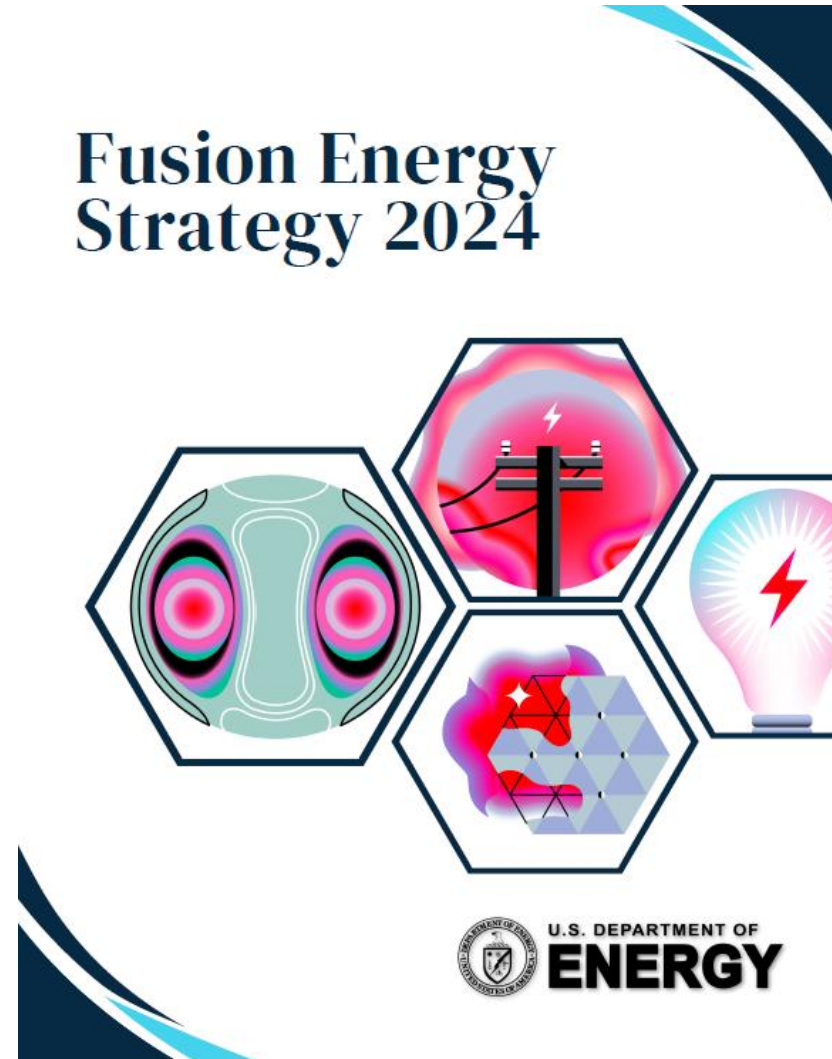
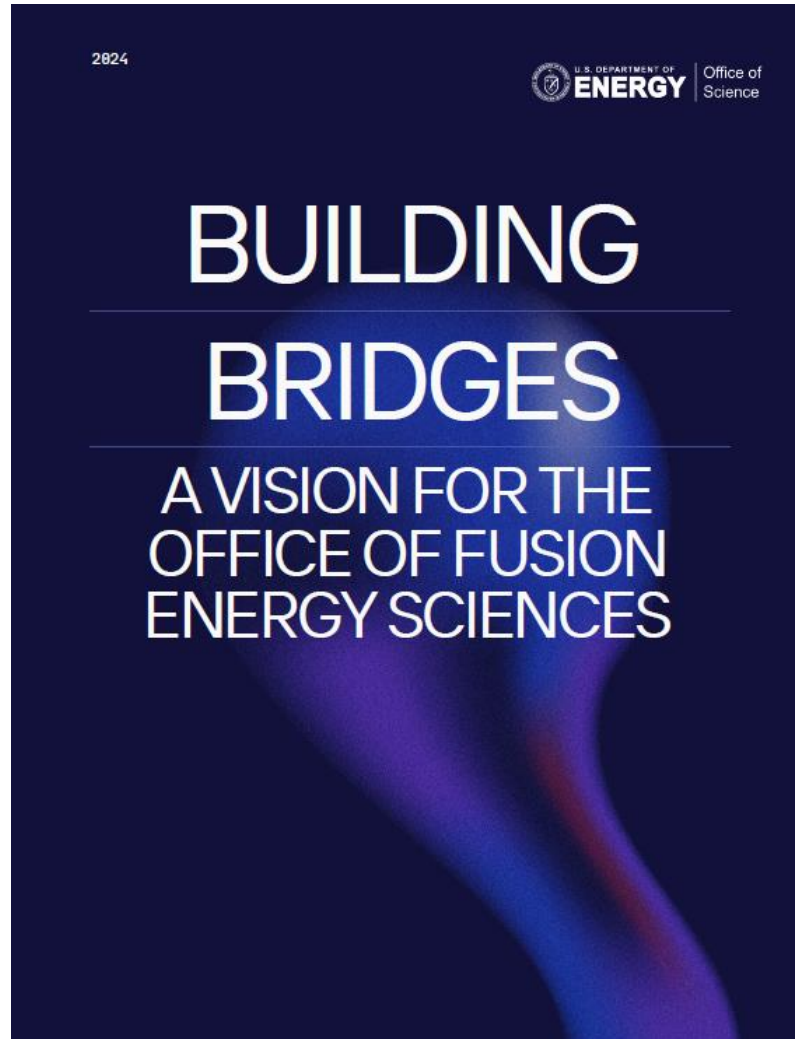
- Our community lost a beloved colleague last week.
- Bill Dorland made seminal contributions in plasma physics, especially in the area of plasma turbulence where he led the development of continuum gyrokinetic codes.
- Bill was a Professor of Physics at the University of Maryland and a former Honors College director. He served the fusion community in a multitude of roles, including as the first PPPL Associate Lab Director for computational sciences from 2020-2023.
- The FES-supported multi-institutional Center for Multiscale Plasma Dynamics that he co-led from 2004-2009, played a significant workforce development role with many of its early career scientists becoming leaders in the field.
- He was recognized with many prestigious awards, including the 2009 DOE Ernest Orlando Lawrence Award, and, most recently, shared the 2024 APS James Clerk Maxwell Prize for Plasma Physics.
- A celebration of Bill's life will be held at the upcoming APS-DPP meeting (October 7-11, Atlanta, GA)



Outline: FES Updates

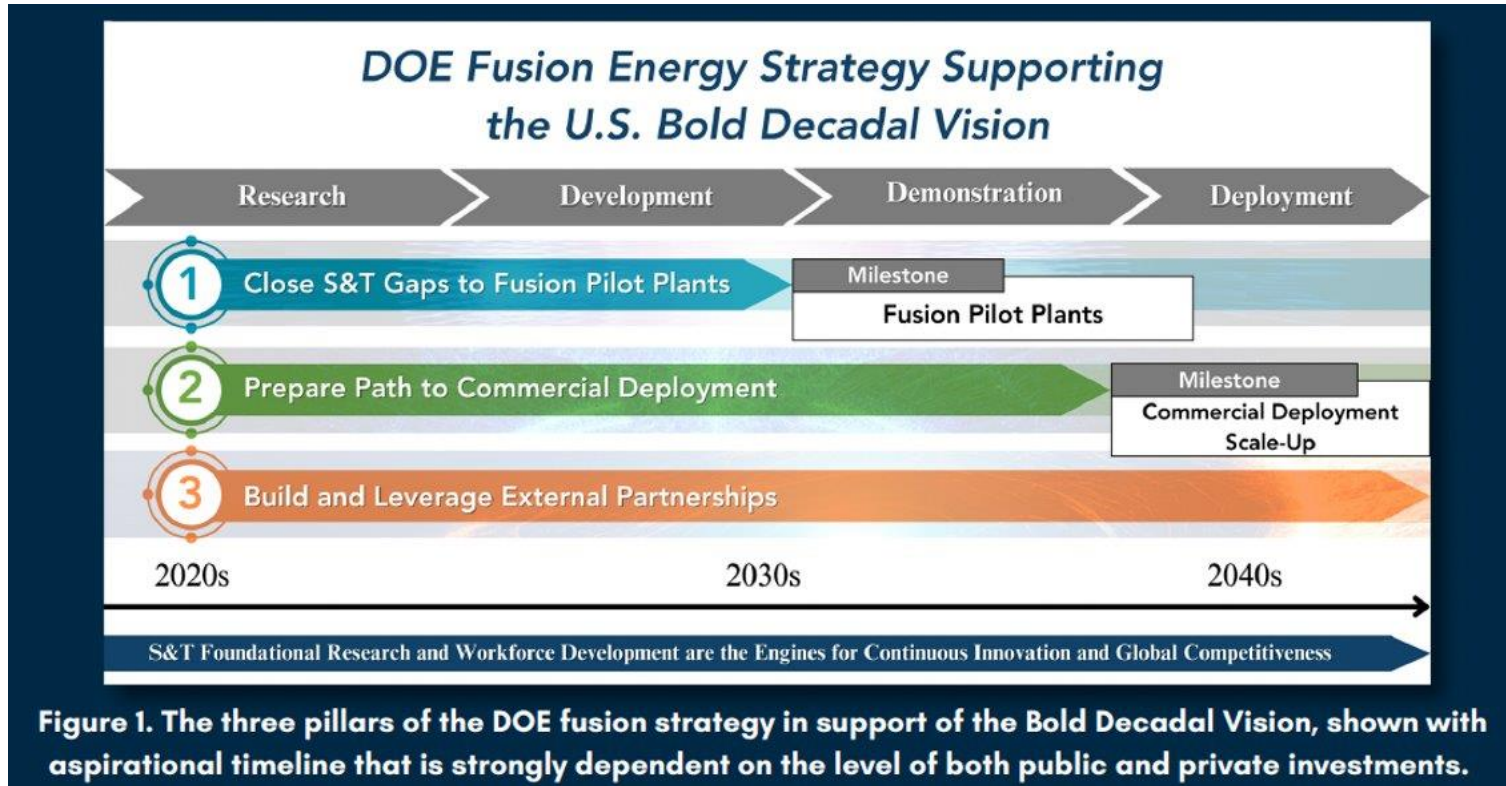
- Building Bridges Vision and U.S. Fusion Strategy
- Re-org and alignment progress
- International Partnerships
- Updates on PPP activities
- Summary and Future Outlook
- National Fusion Science & Technology Roadmap Process (this afternoon)

Two documents released at WH Bold Decadal Vision II Event



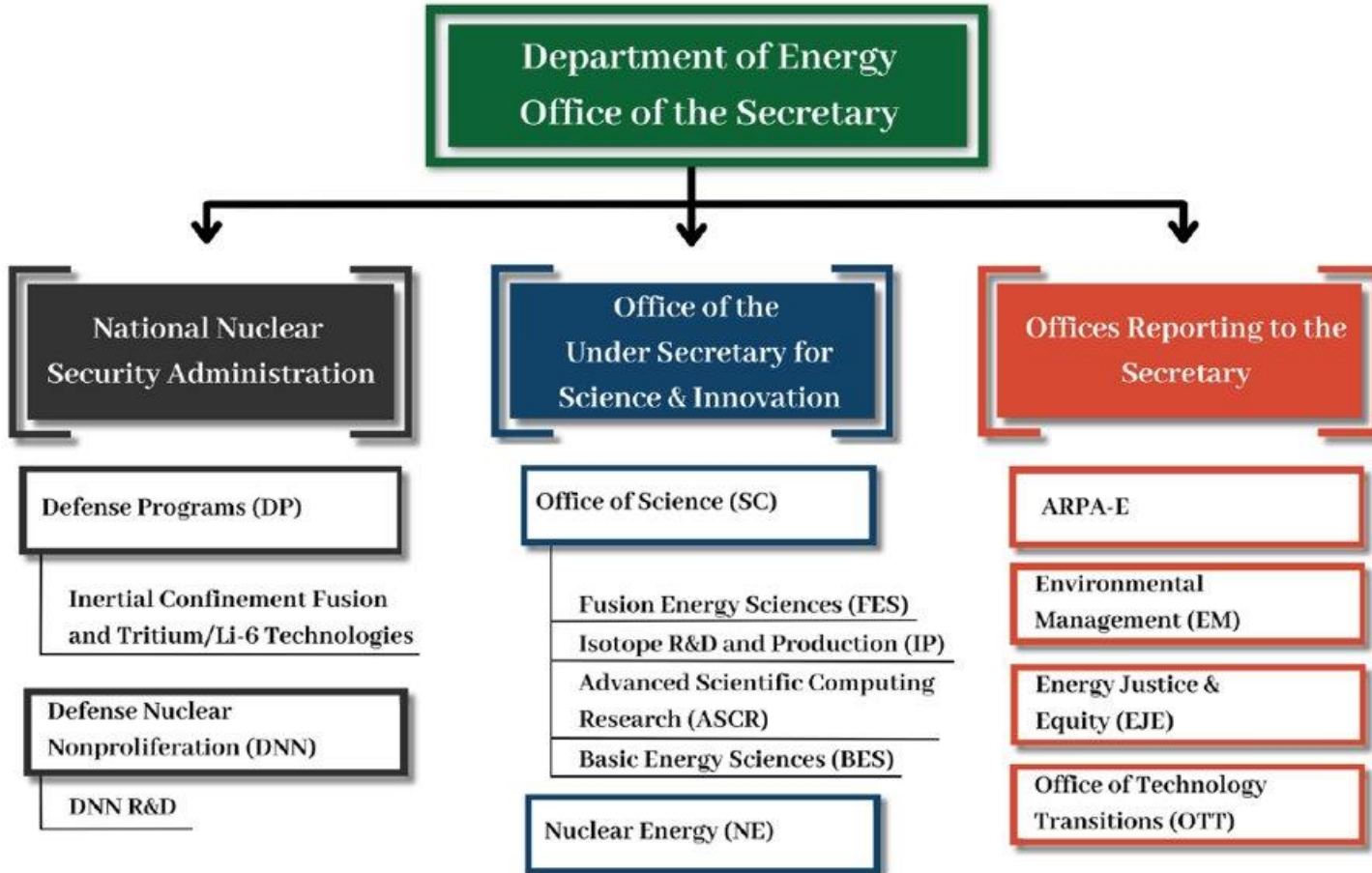
<https://www.energy.gov/fusion-energy>

US Fusion Strategy: BDV and SC FES Building Bridges



- SC FES supports ALL Pillars of the US Fusion Strategy
- R&D continues beyond demonstration
- Focus on de-risk of technologies and closure of physics gaps
- Tools
 - Fusion S&T Roadmap
 - FIRE Collaboratives
 - Milestone Program
 - Public-Private Consortium Framework for Fusion Energy

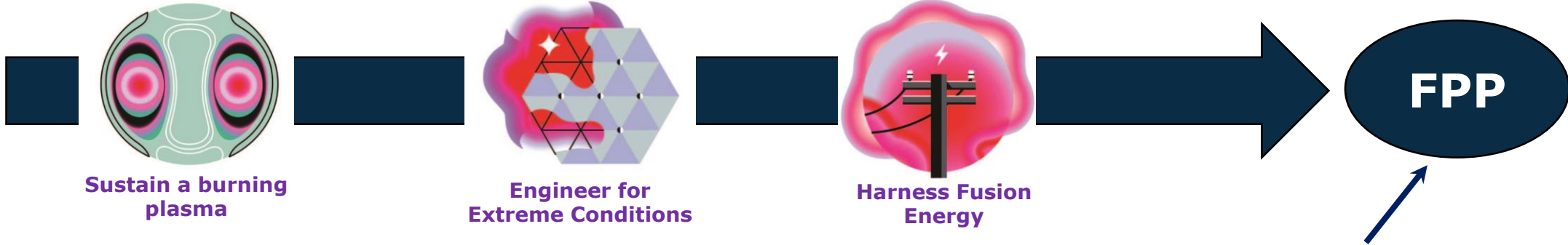
Bringing it all together: a unified U.S. Fusion Strategy



- Cross-cut in Fusion led by Scott Hsu and co-chaired by SC FES and ARPA-E
- FES engages DOE equities at different levels
 - Policy: Fusion Cross-cut
 - Implementation: partnerships
- DOE Equities support U.S. Fusion Strategy
 - Collaborative initiatives underway between FES and multiple DOE equities including: NNSA, ARPA-E, NE, SC-IP, SC-BES, SC-ASCR, OTT

The Road to Fusion Energy is through *combined* private sector “pull” and public sector “push” - with key gaps to address

Build LRP
FM&T Gap
Facilities



A Fusion S&T Roadmap with metrics to track progress

Input from industry

- **Focus** on LRP science and technology gaps as a “bridge” to realize a viable path towards fusion energy (“interim stage”)
- Input from industry is integrated in FS&T Roadmap
- FS&T Roadmap guides priorities and partnerships
- FS&T Roadmap is updated regularly to meet industry and R&D needs/gaps with clear timelines

Fusion and Plasma Research: reflects S&T gaps guided by the FESAC Long Range Plan

Theory and Simulation	Fusion Materials and Internal Components	Sustain a Burning Plasma	Closing the Fusion Cycle	Discovery Plasma Science and Technology
<ul style="list-style-type: none"> • Multi-scale modeling • Advanced Computing and Simulation • AIML in control systems 	<ul style="list-style-type: none"> • Fusion Nuclear Materials • PFCs • Actuators • Adv. Manufacturing • MPEX 	<ul style="list-style-type: none"> • Compact Toroidal Concepts • Toroidal Long Pulse • Liquid Metals • Stellarators • IFE • FRC, Mirror, MIF 	<ul style="list-style-type: none"> • Nuclear Science • Blanket Tech • Fuel Cycle • Balance-of-Plant • RAMI and Waste streams • Enabling Technologies 	<ul style="list-style-type: none"> • Foundational Plasmas and Astrophysics • Plasma Tech. • HEDLP, MEC-U • QIS • Microelectronics

Cross-threads: Fusion Science & Technology Facilities, FIRE Collaboratives, Public-Private Partnerships, Fusion Workforce Pathways, ITER

FESAC
Sam Barish
Sandy Newton

Fusion Energy Sciences
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Gene Nardella, Chief of Staff, Fusion Tech Lead
Senior Strategy Advisor (Vacant)
Sam Barish (Physical Scientist)
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Theory, Simulation & AIML

High Energy Density Science

Emergent Confinement Concepts

Inertial Fusion Energy

Toroidal Long Pulse

General Plasma Science

Compact Toroidal Concepts

Quantum Information Science

Fusion Nuclear Science

Fusion Workforce Pathways

Public Private Partnerships

SBIR/STTR

Private Facility Research

Measurement Innovation

Fusion Materials and Internal Components

Enabling Fusion Technologies

Plasma Technology

MEC-U Project

MPEX MIE

Strategic Facilities

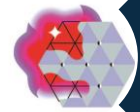
ITER Organization Governance

US Contributions to ITER Project

NSTX-U Recovery Project

Working Draft Version

Key Tech to de-risk (TRL ~ 0-4 push to 7)



Fusion Materials



Fuel Cycle (tritium) &
Blanket



Enabling Tech (magnets,
laser systems, heating)

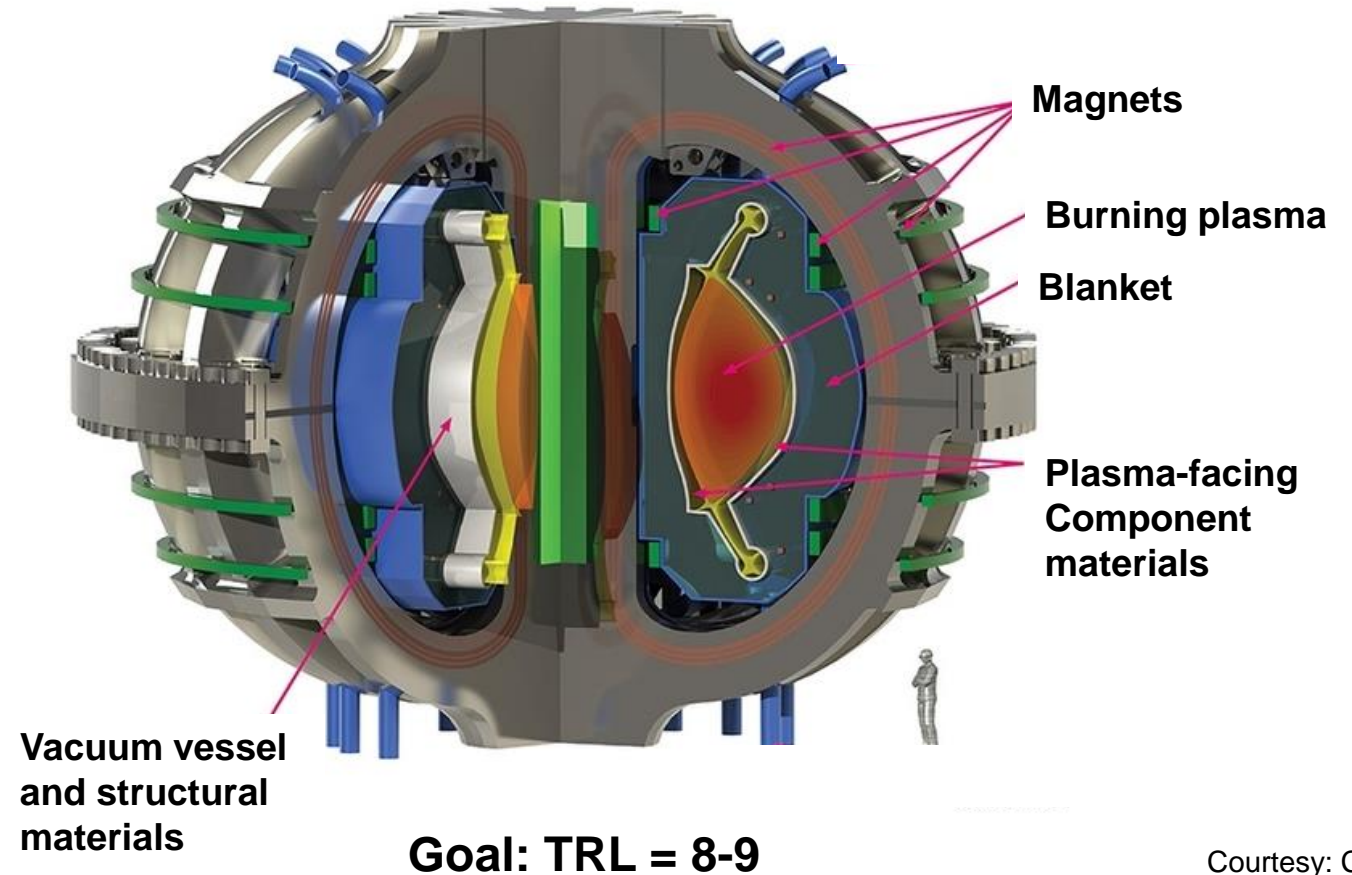


Integration



Sustain a Burning Plasma

Fusion Power Plant (three approaches: MCF, MIF, IFE)

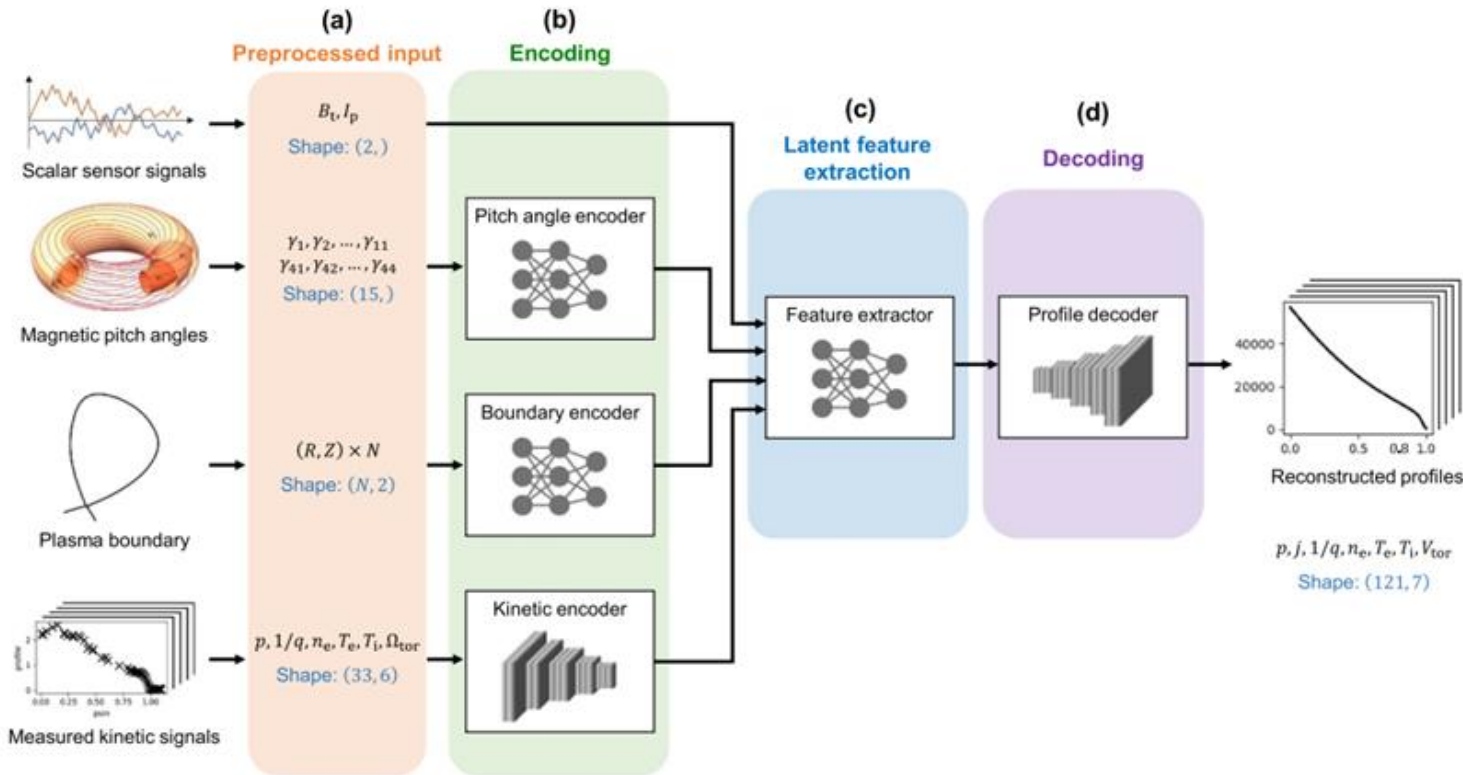


Courtesy: CFS

SC FES Mission: *Establish the foundational understanding of fusion and plasma science in enabling development of a fusion power industry (Energy Act of 2020)*

Theory and Simulation

\$53.3M USD, FY24



Machine learning and automated analysis bridges capability gap to enable real-time plasma state estimation and adaptive control

Theory

- Supports efforts at universities, national laboratories, and private industry focused on the fundamental theory of fusion plasmas.

SciDAC (Scientific Discovery through Advanced Computing)

- Whole-Facility Modeling capability to enable FPP design activities.
- FS&T gaps in plasma turbulence, stellarator optimization, and IFE physics and frameworks for integrated physics and engineering simulations.

FIRE Collaborative on Advanced Simulations

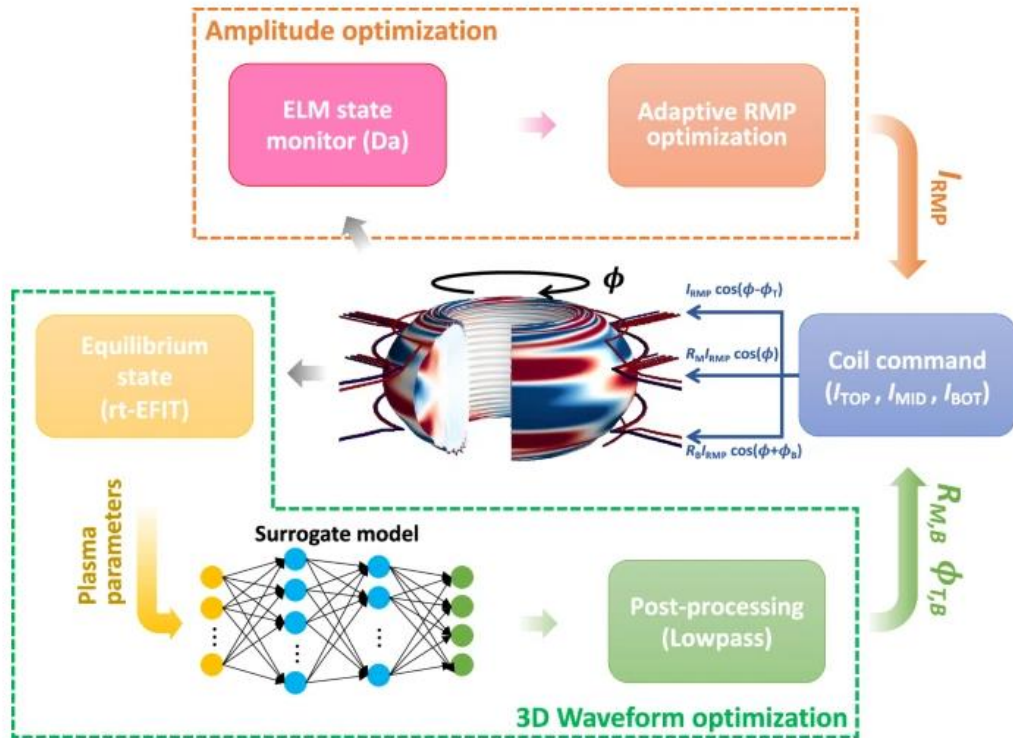
- Advanced Simulation for Design and Optimization
- Coordinated groups with Fusion Industry

AI/ML

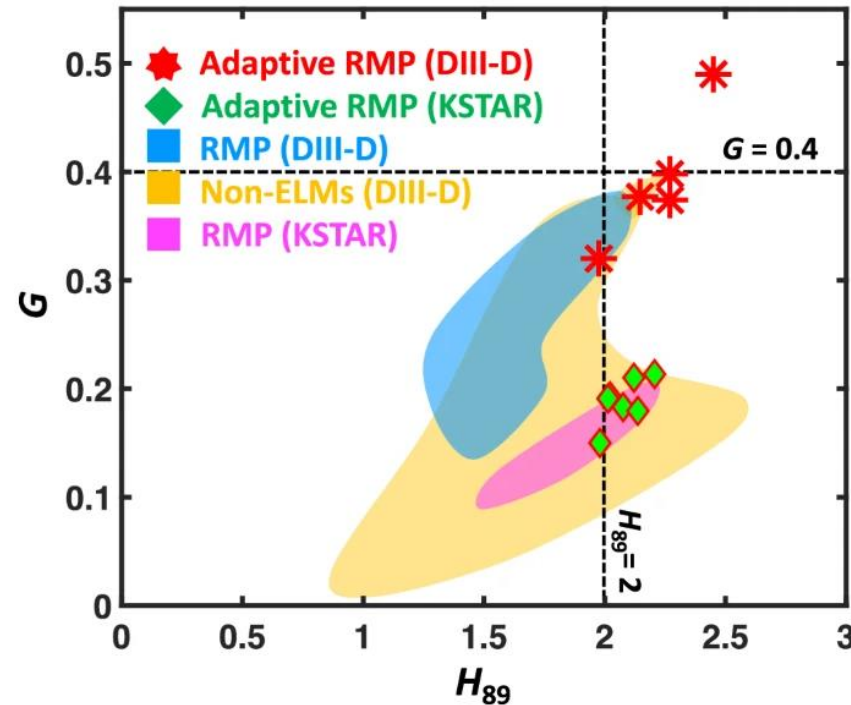
- Develop advanced algorithms and handle large datasets from both experimental efforts and HPC simulations.
- Elucidate foundational scientific models using physics-informed neural networks.

Long-Pulse Tokamak: international collaborations

Explores new and unique plasma regimes that can be achieved with long-pulse, superconducting tokamak facilities abroad, amplifying impact and reach of domestic program elements



Schematic diagram of integrated RMP optimization scheme in KSTAR with ML-surrogate model (ML-3D) with 3D-coil variables (I_{RMP} , I_{TOP} , I_{MID} , I_{BOT} , $R_{M,B}$, and $\phi_{T,B}$).



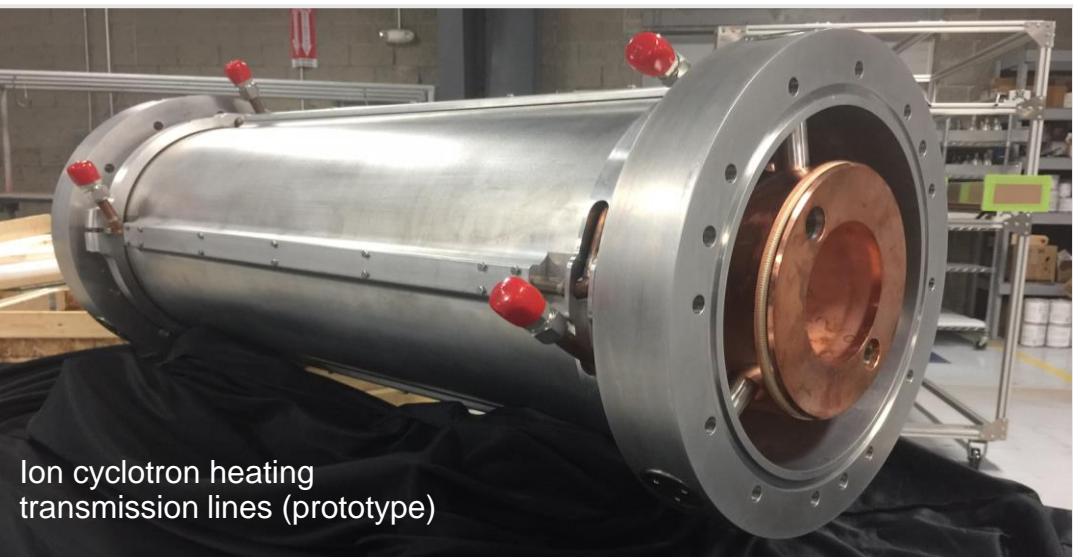
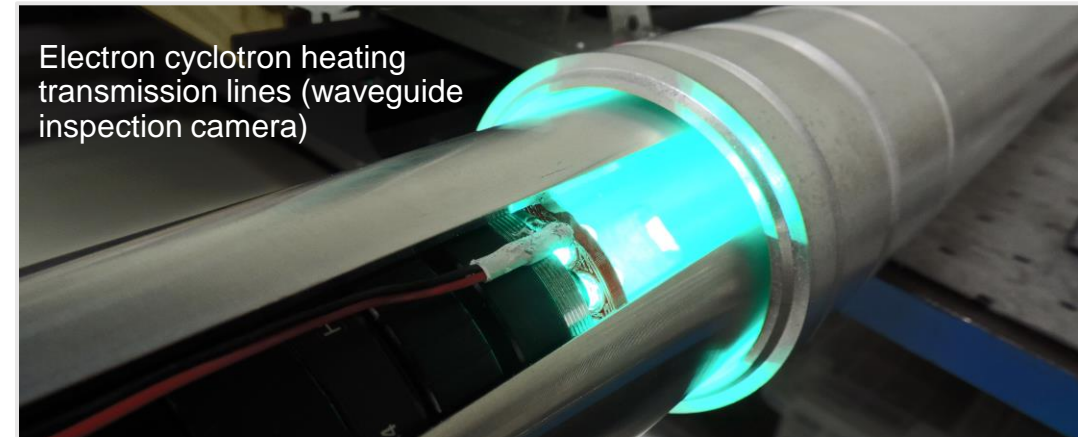
Normalized energy confinement time (H_{89}) versus a fusion gain figure of merit (G) in ELM-free state. Adaptive control used to exceed ITER levels (dashed lines) in both DIII-D and KSTAR

S.K. Kim et al., Nature Communications 15, 3990 (2024)

US ITER advances multiple essential areas of fusion technology

More than 8,000 ITER-related publications to date

- Tools and strategies for plasma control and performance
- Superconducting magnet technologies
 - Radiation transport analysis
 - High-power plasma heating
 - Continuous plasma fueling
 - Fusion materials
 - Fusion power handling
 - Tritium processing
- Vacuum technology advancement
 - Remote handling technology
- Diagnostics for extreme environments



U.S. Contributions to ITER Project



Central solenoid magnet assembly is underway inside the Assembly Hall. From left: magnet test load, module stack, and fourth module for stack

Hardware Systems completed:

- ◆ Steady State Electrical Network
- ◆ Toroidal Field Conductor
- ◆ CS (Central Solenoid) Magnets Assembly Tooling
- ◆ Insert Coils



The third module has been centered on the central solenoid assembly stack.

FY 2025 Planned Accomplishments:

- ◆ Deliver the final Central Solenoid module to the ITER site and complete the CS system
- ◆ Continue to design, fabricate, and deliver other In-Kind Hardware systems

Actively identifying opportunities to close S&T gaps defined by LRP science drivers



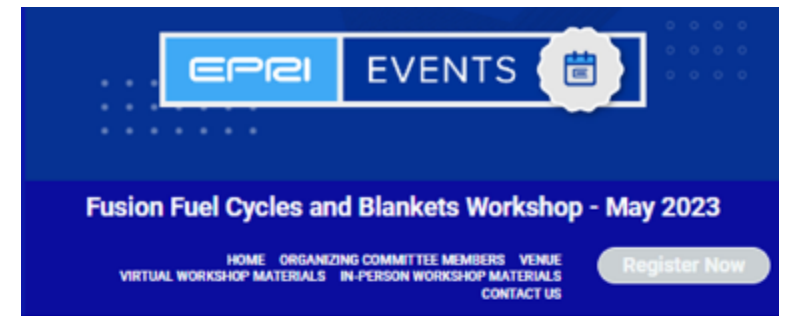
- De-risking gaps by building infrastructure at all scales
- Partnerships with industry and international collaborators
 - Identify opportunities on FM&T and closing key physics gaps
- Bridging to industry: PPP elements in FES
- Bridging to ITER R&D and technology development

FCP process update

- FESAC FCP is one several steps in the process to prioritize facility project construction in the Office of Science
- Input from the FESAC FCP will be combined with other input including FESAC IB, FESAC DP, FESAC LRP, and other reports to help define prioritization in the context of our Fusion S&T Roadmap
- **Key Factors:**
 - Need for a technology readiness assessment of FM&T gaps
 - Coordinate with international partners of access to existing, or joint funding of new, FM&T facilities
 - Align priorities from FS&T Roadmap with industry needs and global fusion energy development activities

Fusion Technology Community Workshops

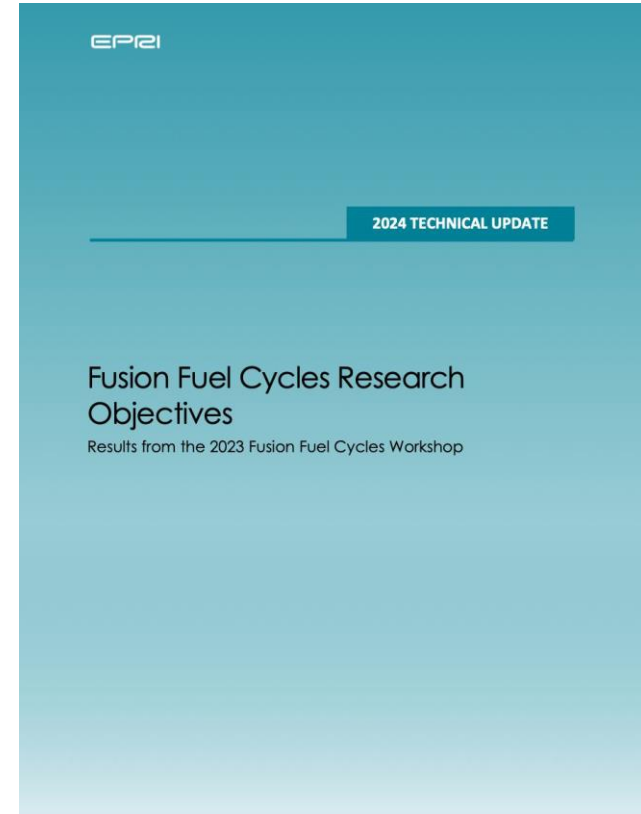
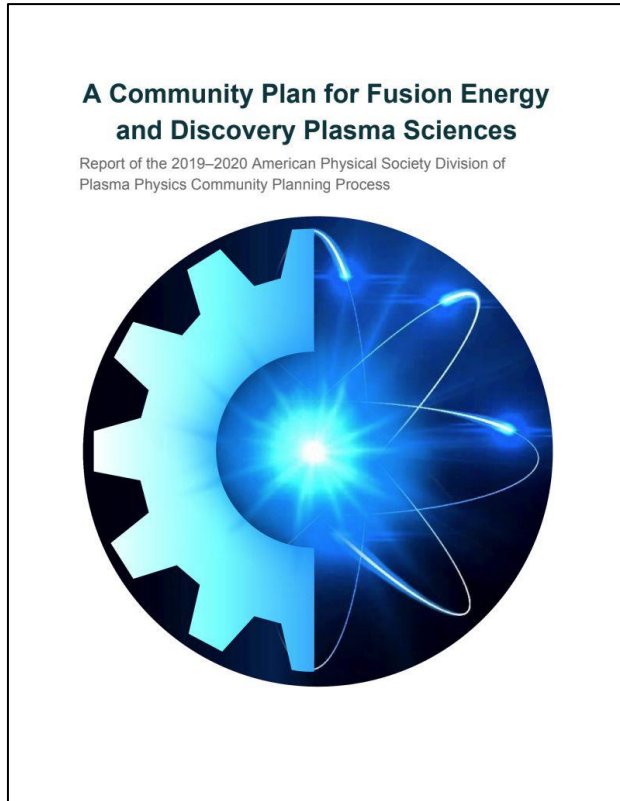
- ◆ IFE BRN | June 2022
 - Identified scientific/technology PROs
- ◆ Fusion Non-proliferation | Hosted by PPPL in January 2023 and SRNL in January 2024
- ◆ Fusion Neutronics | Hosted by ORNL in January 2023
- ◆ Fusion Magnet R&D | Hosted by PPPL in March 2023
- ◆ Fusion Blanket and Fuel Cycle | Hosted by EPRI in May 2023
 - Follow-on: [Blanket and Fuel Cycle Page](#) and a workshop roadmap report
- ◆ Fusion Materials | Hosted by EPRI in November 2023
- ◆ Measurement Innovation BRN | Held in January 2024
- ◆ Private Research Facility BRN | Held in February 2024



Organizing Committee Members



Integrating community-based workshops in 2022-2024 with prior and current FESAC reports to help define technology readiness



Measurement Innovation

- The program objective is to develop new innovative diagnostics needed by the FES program including the private sector
- The FESAC Long Range Plan (LRP) called out for the support of diagnostics in all the areas of the program.
- The MI program addresses primarily the Fusion Technology & Science Drivers: “Sustain a Burning Plasma” and “Engineer for Extreme Conditions”
- A BRN workshop was held in January 2024 to identify Priority Research Opportunities as determined by the FES community; A report will be delivered in Fall 2024
- The report will inform future solicitations for new diagnostics in all FES areas, as called for in the LRP and bridge to industry

Measurement Innovation
Basic Research Needs Workshop
January 9-11, 2024



Dr. Luis Delgado-Aparicio (PPPL), Chair
Sean Regan (LLE), co-Chair

FES Public Private Partnership Elements

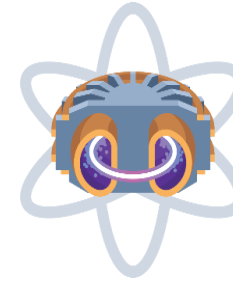


- **INFUSE (Innovation Network for Fusion Energy)**
 - Leverage National Laboratory and university infrastructure/capabilities for industry use
- **Milestone-Based Fusion Development Program**
 - Fusion companies partner with national labs and universities to provide viable FPP designs and technology roadmaps
- **Upcoming programs and initiatives**
 - Create a new bridge between the public and private sectors in fusion science and technology with the **FIRE Collaboratives**
 - To provide the public sector an opportunity to leverage strategic private sector infrastructure: **Private Facility Research (PFR)**
 - Innovative PPP program to design and/or build small to midscale infrastructure to de-risk low-TRL fusion technologies (**Public-Private Consortium Framework**)
 - A **Fusion Technology Manufacturing Network** is also being designed to complement the PPCF



Innovation Network for Fusion Energy (INFUSE)

- ◆ The purpose of INFUSE is to connect private-sector fusion companies to the expertise & facilities of DOE's national laboratories and U.S. academic institutions.
 - ◆ INFUSE projects seek to overcome critical scientific and technological hurdles of fusion energy.
- ◆ To date, INFUSE has made **107** awards, totaling **\$24.2M**.
 - ◆ INFUSE has supported **34** private companies in partnering with **10** DOE labs and **12** U.S. Universities.
 - ◆ Private companies incorporated in the U.S. are eligible and the private company must provide *at least* 20% cost share



INFUSE

Innovation Network
for Fusion Energy

INFUSE Topic Areas:

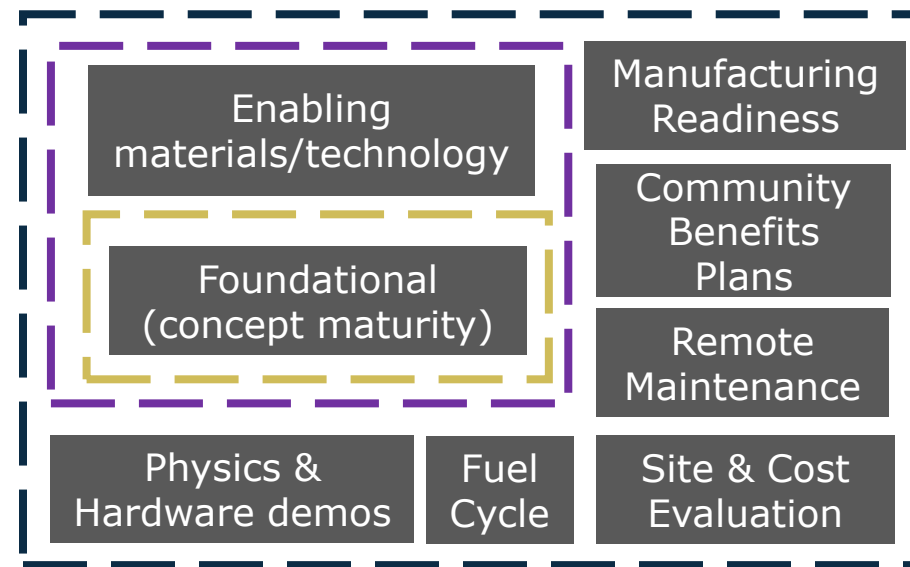
- Enabling technologies
- Materials
- Diagnostics
- Modeling and simulation
- Unique fusion experimental capabilities
- Activities to support eventual fusion commercialization

Milestone-Based Fusion Development Program in FES

- **FES Milestone** program supports fusion developer startup companies establish viable fusion pilot plant (FPP) designs



Milestone Work Scopes



Milestone companies
officially signed in early June
2024

Private Facility Research (PFR) Program

PFR program purpose:

- ◆ Sponsor publicly funded researchers to conduct open scientific studies on private facilities for public benefit
- ◆ Will include fusion, plasma technology, and other relevant private sector capabilities
- ◆ Will establish balance between private goals and public science and technology research

The model works:

- ◆ **2020 - present:** A pilot project involving the privately built ST40 facility, Tokamak Energy, PPPL, and ORNL took place
- ◆ This project **achieved a world record 100M degree temperature for the 1st time** in a spherical tokamak (ST), enhancing the relevance of an ST FPP
- ◆ PPPL has delivered 4 peer reviewed papers so far and ORNL will submit its first paper shortly

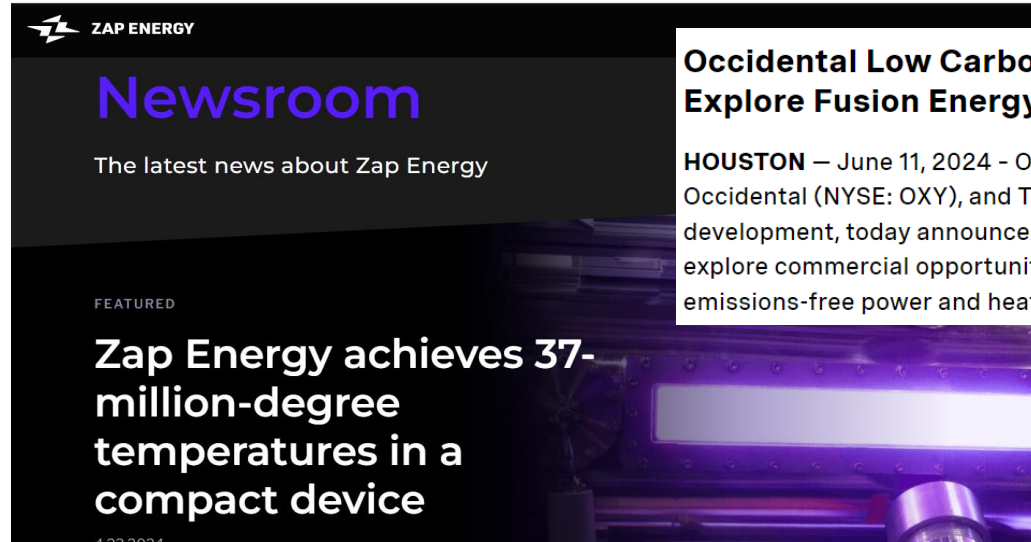


FY 2025 pilot program builds on previous model project success & opens research opportunities to compete across all private devices and facilities in the U.S. and the world

Growth in public-private strategic partnerships supporting RD&D activities in the U.S. fusion ecosystem

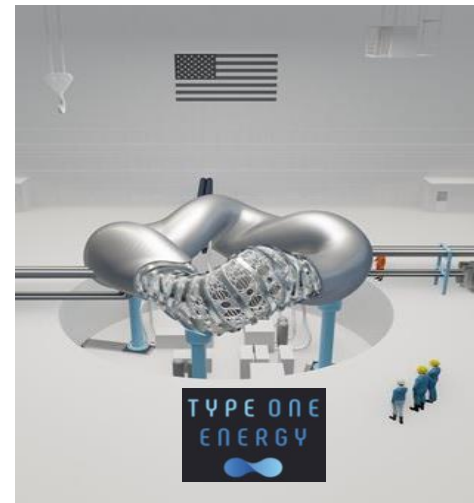
Recent developments

- Exciting results from Zap Energy and Realta Fusion
- Engagement between fusion applications and non-fusion markets
- Type One Energy announced \$200M+ public-private investment with TN, TVA and ORNL, of their next-step facility, *Infinity One*



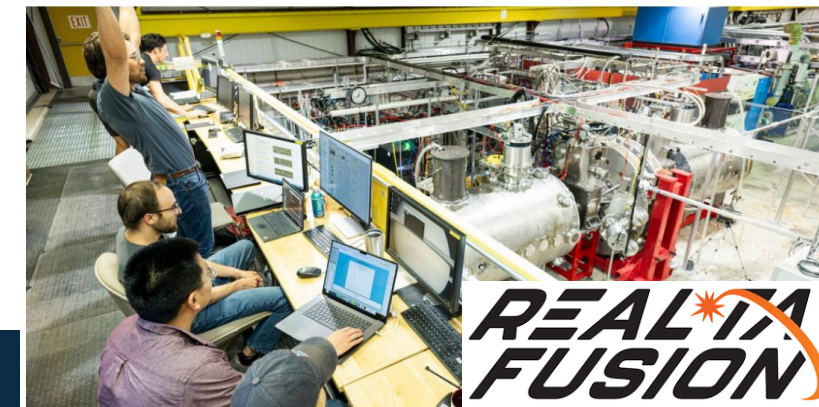
Occidental Low Carbon Ventures and TAE Technologies Explore Fusion Energy for Direct Air Capture Facilities

HOUSTON – June 11, 2024 - Oxy Low Carbon Ventures (OLCV), a subsidiary of Occidental (NYSE: OXY), and TAE Technologies, a global leader in fusion energy development, today announced they have signed a memorandum of understanding to explore commercial opportunities that use TAE's fusion technology to provide emissions-free power and heat for Direct Air Capture (DAC) facilities.

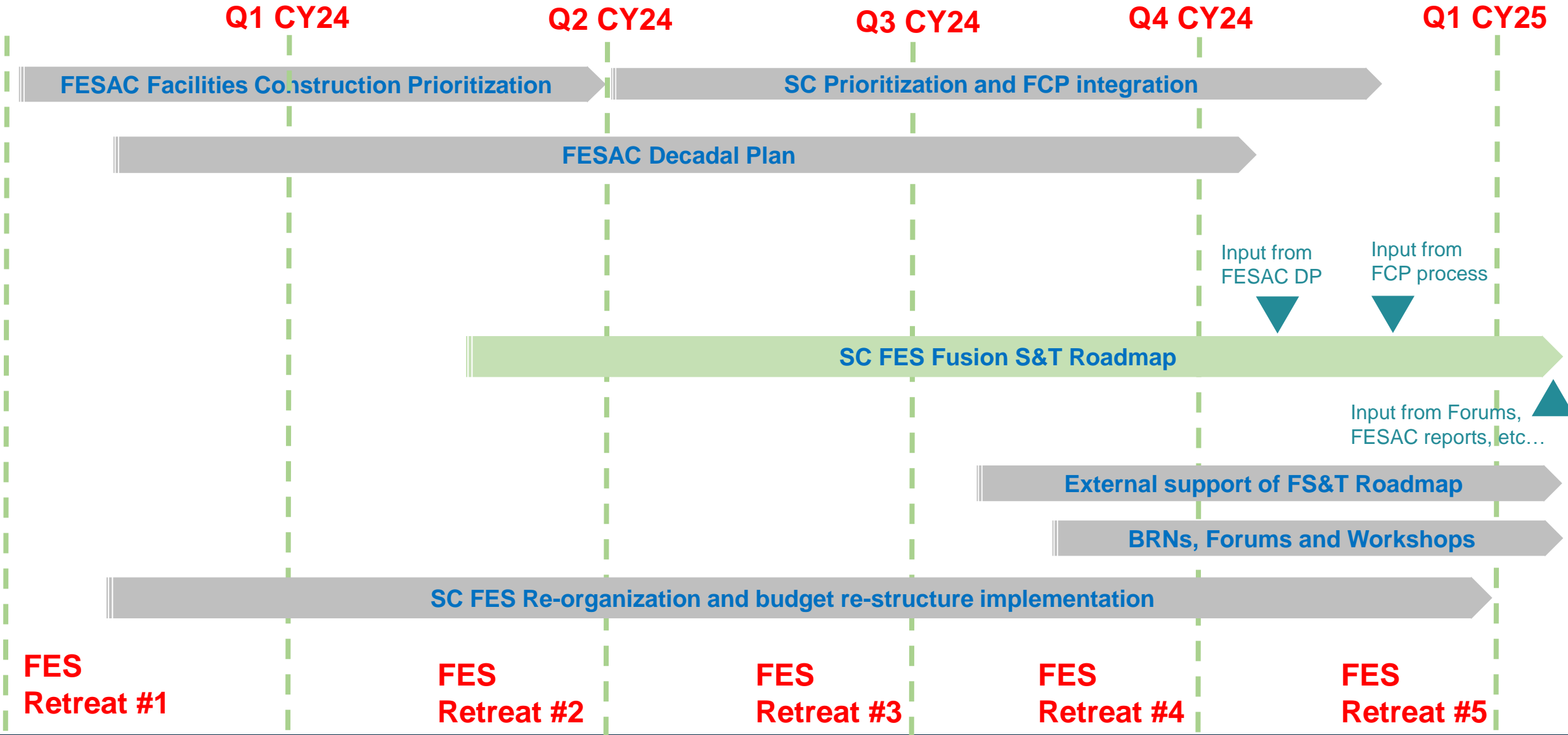


WHAM: Realta gets first plasma with 17 Tesla magnets in mirror fusion test

Thu, Jul 25, 2024, 8:01AM | Nuclear News



Timeline for FES re-structure and National FS&T Roadmap process



Summary and Future Outlook: US DOE FES



Strategic Input

- FESAC LRP/ CPP
- Bold Decadal Vision
NASEM21/NASEM19
- FESAC FCP
- FESAC Decadal Plan
- Community and BRN Workshops
- FS&T Forums

Re-alignment

- FES Budget Re-structure
- FES Re-organization
- New FES Staffing
- FES Vision: Building Bridges

Impact Drivers

- FS&T Roadmap (by: **CY25 Q2**)
- International and Public-Private Partnerships
- Milestone, PFR and FIRE Programs
- Public-Private Consortium Framework for Fusion Energy
- U.S. Fusion Energy Strategy

*The U.S. DOE FES is in a process of transition building a **National Fusion Science & Technology Roadmap** that will guide strategic partnerships towards viable paths to fusion energy*

**Thanks for your
attention!**



**Feliz Mes de la Herencia
Hispana**