

Fusion Energy Sciences Program & Facilities

Office of Science Advisory Committee (SCAC)

March 27, 2026

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U.S. DEPARTMENT
of **ENERGY**

Office of
Science

energy.gov/fusion

FES – Advancing Energy Abundance and U.S. Competitiveness

MISSION: Drive the scientific and technological foundation for a fusion energy source and support the development of a competitive U.S. fusion energy industry*

Funding: FY 2026 Enacted: \$ 806M.

- **Annual Support** for >650 Research activities
- **Modalities:** Individual, Team, and Public-Private Partnerships
 - National labs, Universities, Industry

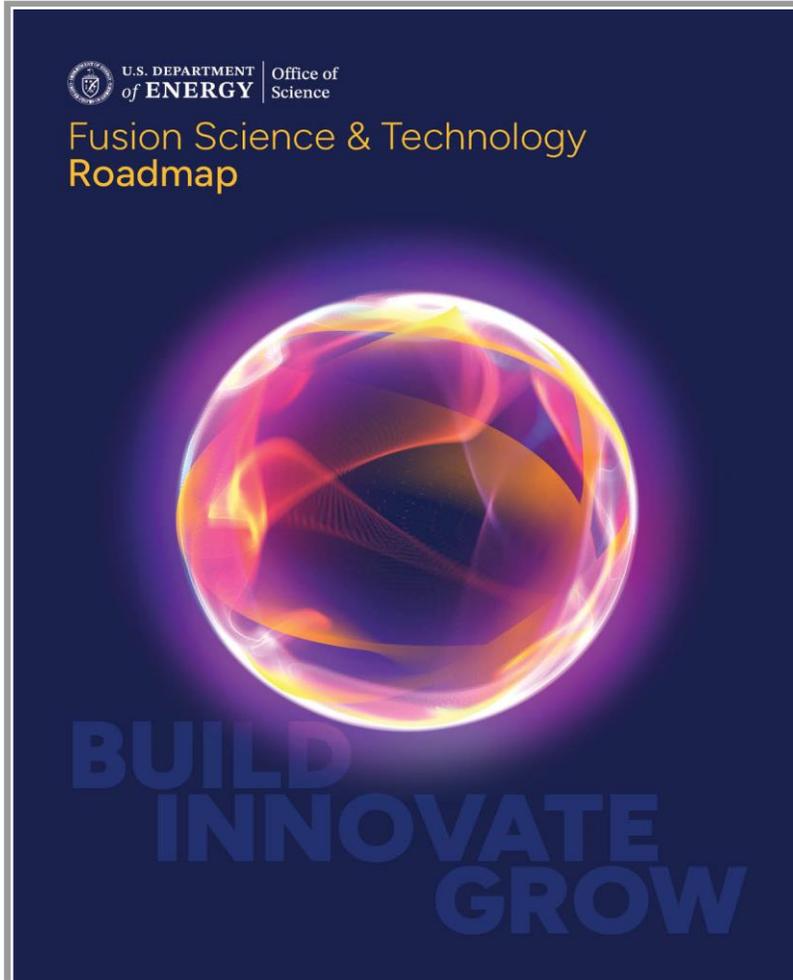
User Facilities:

- **DIII-D:** 833 users in FY 2025
- **NSTX-U:** Recovering from coil failure; Initial Operation 2027

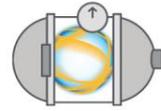
Two active Construction Projects

- **ITER:** Initial Operation: >2033
- **Material Plasma Exposure eXperiment (MPEX):** Initial Operation 2027

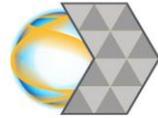
DOE released the Fusion Science and Technology Roadmap in 2025, a Comprehensive Plan to Close Remaining Gaps for Fusion Energy



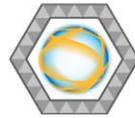
Challenge Areas



Structural
Materials Science &
Technology



Plasma-Facing
Components and
Plasma-Materials
Interactions



Advancing
Confinement
Approaches



Fuel Cycle and
Tritium Processing



Blanket Science &
Technology



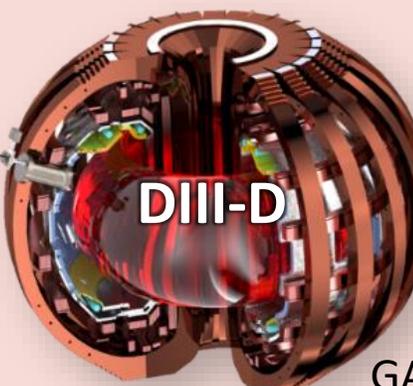
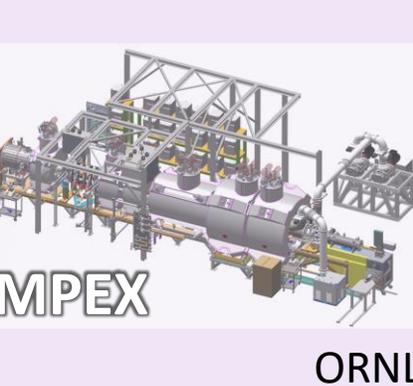
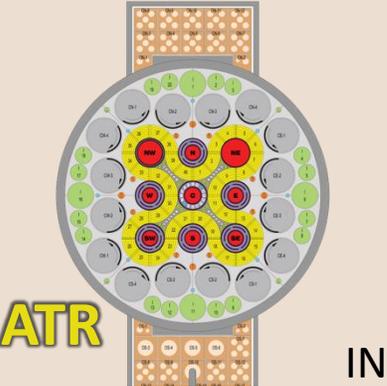
Fusion Plant
Engineering &
System Integration

Key Gaps

- Qualified fusion materials & data
- Predictive, multi-scale modeling
- Sustained burning plasma ($Q > 5$)
- Supplying, recovering, and recycling tritium
- Demonstrated blankets to breed tritium, shield neutrons, & supply heat
- Advance balance of plant (digital design, maintenance, reliability)

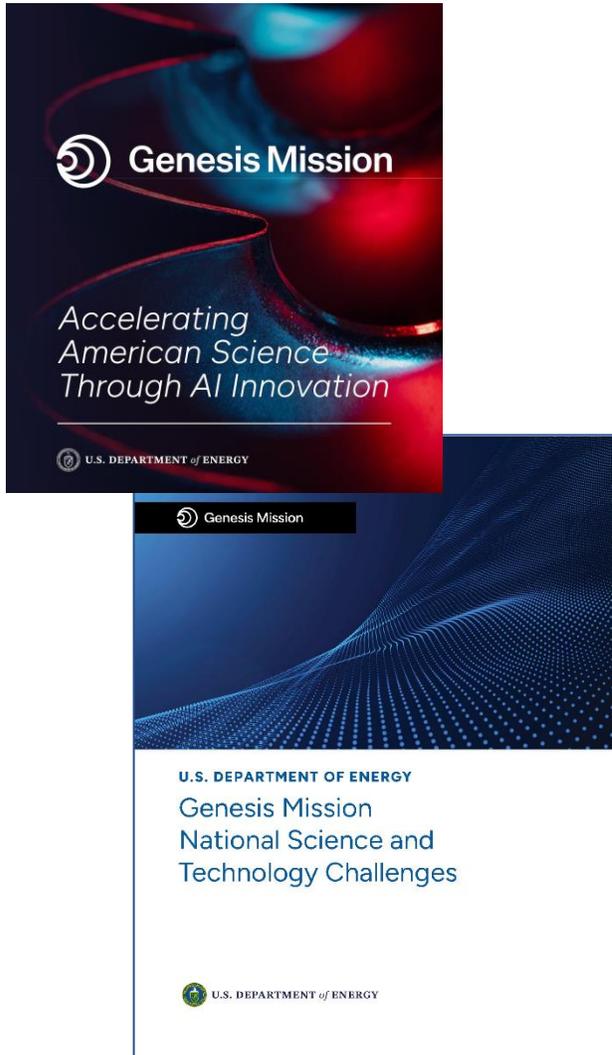
FES Supports Underpinning Science, Technology, and Facilities for the Fusion Energy Sciences R&D Community

Fusion Programs and Infrastructure

Theory and Simulation	Sustain a Burning Plasma	Fusion Materials	Fuel Cycle	Public Private Partnerships
<ul style="list-style-type: none"> • Fusion Science • High Performance Computing • Genesis and AI 	<ul style="list-style-type: none"> • Magnetic Fusion • Inertial Fusion • Measurements 	<ul style="list-style-type: none"> • Wall & Structural Materials • Neutron testing 	<ul style="list-style-type: none"> • Nuclear Science • Blanket Technology • Fuel Cycle 	<ul style="list-style-type: none"> • Milestone • INFUSE • Public-Private Consortia
 <p>PPPL</p>	 <p>GA</p>	 <p>ORNL</p>	 <p>INL</p>	

Genesis Mission Aims to Develop an Integrated AI Platform to Support Fusion Engineering and System Integration

Accelerating Delivery of Fusion Energy



- **Challenge:** Realizing fusion requires coordinated progress across six tightly coupled challenge areas defined in the FS&T Roadmap.
- **AI Solution:** An **AI-Fusion Digital Convergence Platform (DCP)** will integrate novel algorithms in high performance computing codes, foundation models for plasma and materials science, physics- and chemistry-informed neural networks, surrogate models, and digital twins for whole-facility modeling and real-time control across the six Roadmap challenge areas.
- **Justification:** DOE uniquely brings together fusion facilities, national laboratories, leadership-class computing, data stewardship, and public-private partnerships to build and operate a trusted, national-scale AI platform for the fusion ecosystem.
- **Impact:** Would accelerate delivery of fusion energy as a source of firm, scalable baseload power, strengthening energy security and competitiveness for U.S. and allies.



Ongoing Construction and Future FES Facilities

- **Future**

- U.S. Contributions to ITER (ITER) - under construction
- Material Plasma Exposure eXperiment (MPEX) - under construction
- Fusion Prototypical Neutron Source (FPNS)
- Nuclear High Heat Flux Test Facility (NHHF)
- Inertial Fusion Beamlet Testbed (Beamlet)
- Volumetric Neutron Source (VNS)
- Blanket Component Test Facility (BCTF)
- Integrated Blanket and Fuel Cycle Test Facility (IB-FCTF)
- Matter in Extreme Conditions Petawatt Upgrade (MEC-U) - paused

- **In planning**

- Small to Medium Sized Test Stands to de-risk facility alternatives

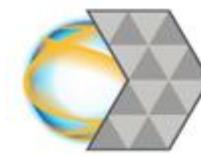
ITER Project, an International Collaboration in France

104-acre platform; 39 buildings; 1M components; 10M parts; 100,000km Nb₃Sn



- CD-4: 1QFY41
- TPC: \$6.5B
- %-complete: 55% (Feb '26)
- Operations: H 2034; DT 2039

Material Plasma Exposure eXperiment (MPEX)

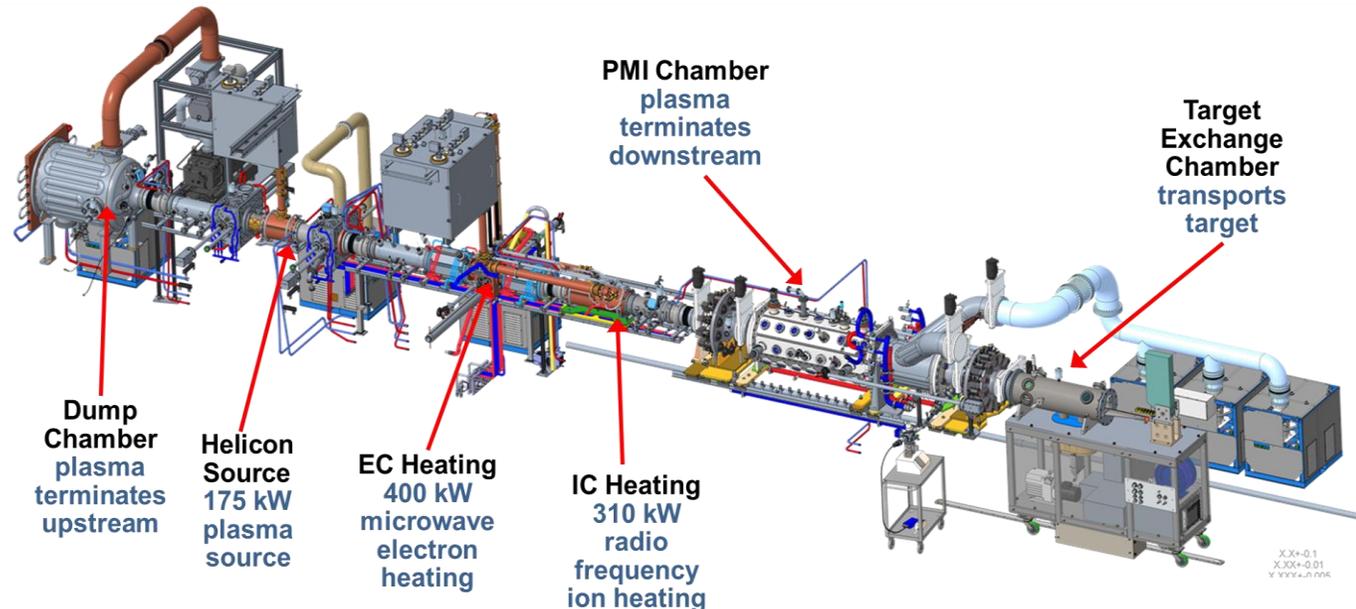


Plasma-Facing
Components and
Plasma-Materials
Interactions

Gap: Qualify materials and validate predictive models of material evolution under heat, particle, and neutron irradiation

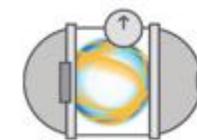
Focus Areas

- Advances the science of plasma-material interactions (PMI) and materials discovery for plasma facing components, providing critical foundational science for design and extrapolation
- Enables researchers to understand how extreme conditions affect the divertor and first wall, including power and particle exhaust effects and w/neutrons (using previously irradiated samples)



- CD-4: January 2028
- TPC: \$201M
- %-complete: 83% (Jan '26)
- Operations: 2027

Fusion Prototypical Neutron Source (FPNS)



Structural
Materials Science &
Technology

Gap: Inability to predict and control materials degradation under extreme neutron irradiation

Focus areas

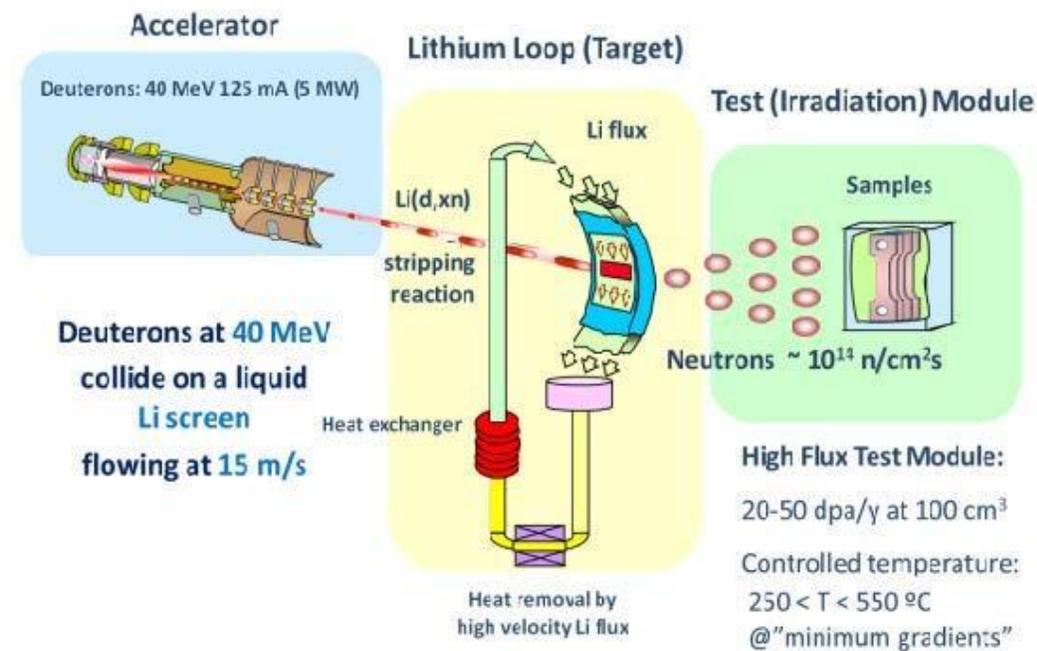
- **Survivability:** Limited understanding of irradiation-driven microstructural evolution and mechanisms driven by $>20\text{-}50$ displacements per atom (dpa)
- **Qualification:** Lack of validated performance models and materials databases to predict lifetime limits and enable systems design

FPNS facility concept is mature

2023/4 → RFI on FPNS alternatives; 16 concepts evaluated → 6 viable

Now → Mission Need and cost under review

One Concept: D-Li stripping source driven by a 40-MeV deuteron LINAC



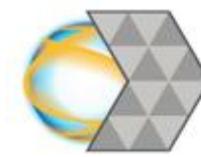
Summary

- FS&T Roadmap covers all aspects of fusion R&D, motivating facilities across six challenge areas and significantly expands blanket and fuel cycle R&D program

Facility	Challenge Area	Purpose	Status; Cost
ITER	Confinement	Burning plasma	CD-2/3; TPC: \$6.5B
Beamlet	Confinement	De-risk laser, target, etc.	Pre CD-0; Est. cost: \$0.2-0.3B
MPEX	Materials	First wall material tests	CD-2/3; TPC: \$0.2B
NHHF	Materials	Component testing	Pre CD-0; Est. cost: \$0.2B
FPNS	Materials, Blanket	14 MeV Neutron irradiation	MNS under review; Est. cost: \$0.75B
VNS	Blanket, Fuel Cycle	Component qualification	Pre CD-0; Est. cost: \$0.5-1.5B
BCTF	Blanket	Blanket component tests	Pre CD-0; Est. cost: \$0.1B
IB-FCTF	Blanket, Fuel Cycle	Integrated testing	MNS under review; Est. cost: \$0.65B
MEC-U	N/A	High-energy density science	Paused; Est. cost: \$0.35-0.45B

FES anticipates building facilities via public-private partnership to reduce federal share.

Nuclear High Heat Flux Test Facility (NHHF)

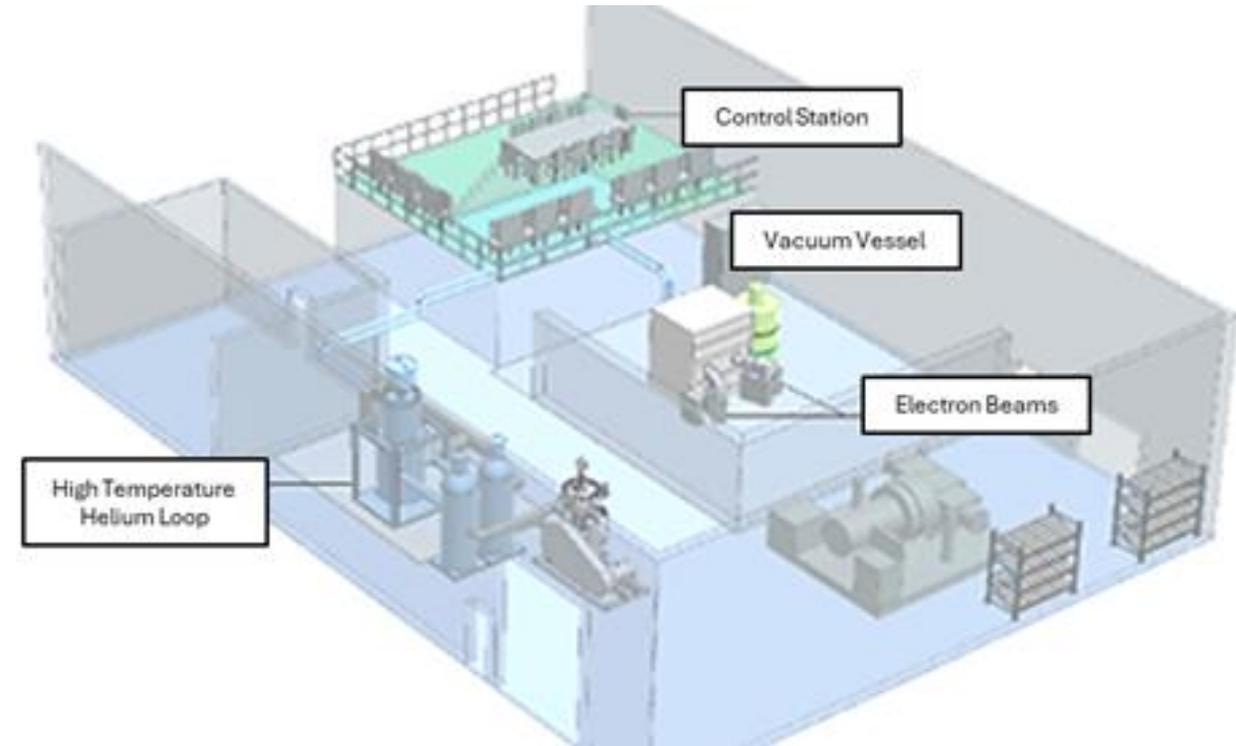


Plasma-Facing
Components and
Plasma-Materials
Interactions

Gap: expose component samples to high-density, high-temperature plasmas with in-operando measurements

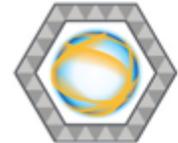
Focus areas

- **Synergistic irradiation:** Plasma, heat, and neutron irradiation of component-scale samples using hot cell technology
- **Qualification:** Expanded capability to predict lifetime limits with compounding effects on thermo-mechanical, surface, and interface properties and hydrogen isotope transport management



Could be upgrade to MPEX: higher heat flux, larger samples, transient heat loads

Inertial Fusion Beamlet Testbed (Beamlet)



Advancing
Confinement
Approaches

Gap: a full-scale, single beam, prototype laser system, to derisk IFE driver, target, and injection technology.

Two Approaches

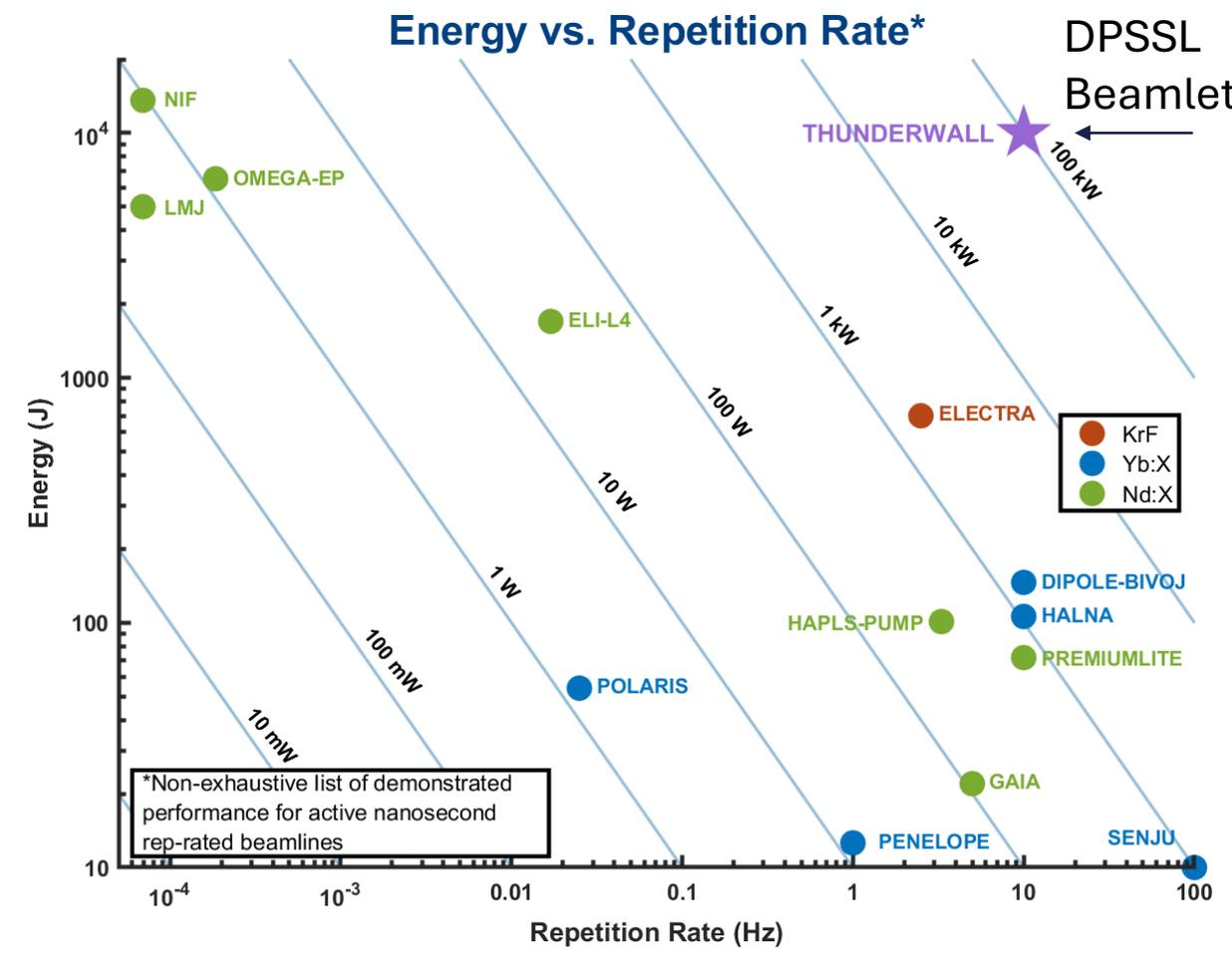
- Diode-Pumped Solid-State Laser beamlet
- Krypton fluoride excimer laser beamlet



DPSSL



KrF



Volumetric Neutron Source (VNS)

Gap: Inability to test entire components/systems necessary for fusion commercialization

Focus areas

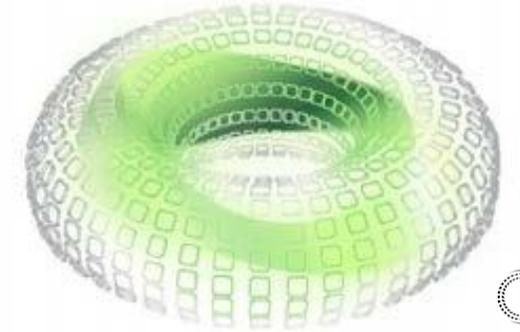
- **Qualification:** Enables performance testing and qualification of complex components, including tritium breeding blankets, in relevant configurations
- **System-level testing:** VNS to be integrated with facilities such as IB-FCTF to enable system-level testing of structural materials, blanket and fuel cycle technology to ensure deployment readiness

Features & Options

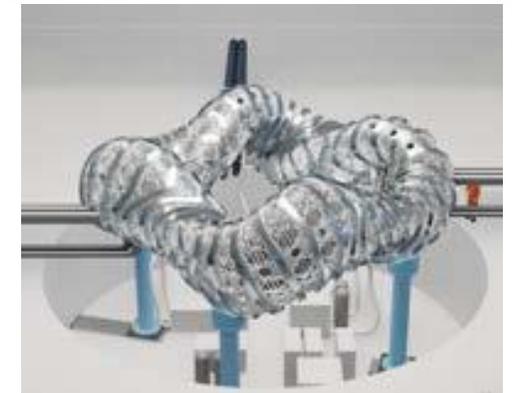
- Operated continuously for high neutron fluence (tens dpa)
- Wall surface areas $>$ several m^2
- Common approaches include driven tokamaks & stellarators



Fuel Cycle and
Tritium Processing



THEA
ENERGY



TYPE ONE
ENERGY

Emerging options: neutral beam driven stellarator using design from FES Milestone program

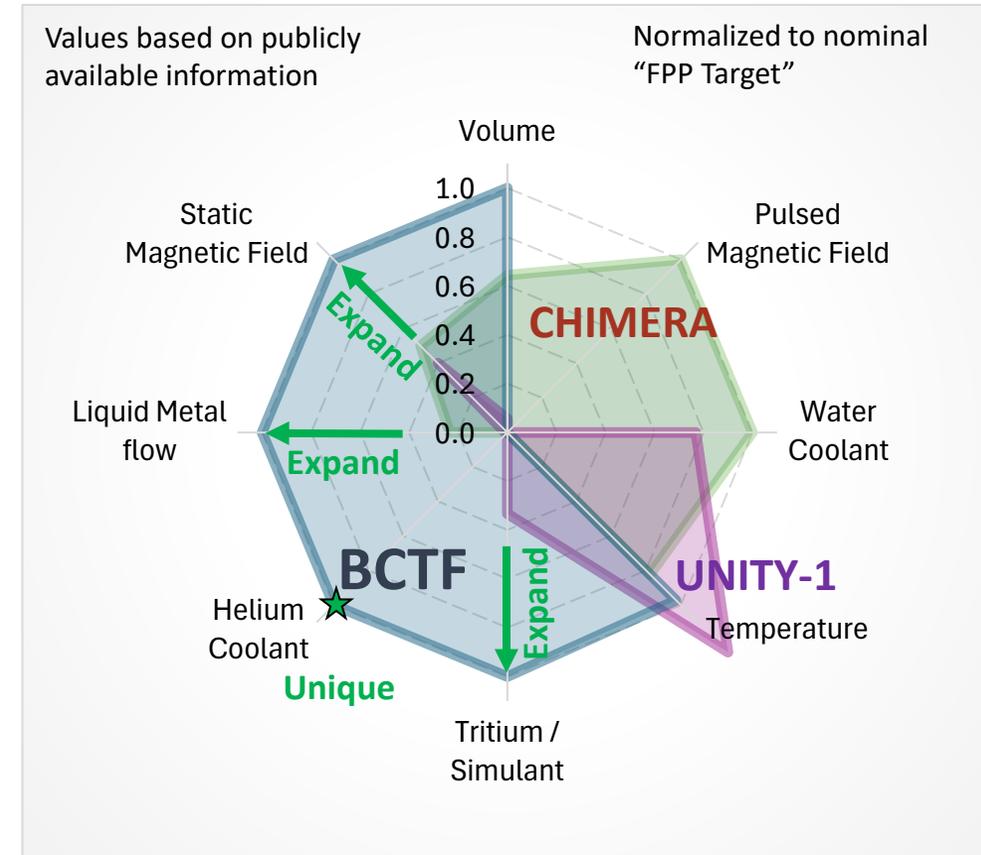


Blanket Component Test Facility (BCTF)

Gap: Uncertainty in blanket component performance and low technical maturity of blanket technology

Focus areas

- **Engineering:** Establish requirements for blanket components including flow loops, prototypic heat flux, coolant flow, and magnetic fields, & validate models
- **In situ testing:** Non-nuclear, iterative testing and risk reduction before system level integration with proven thermal management, mechanical performance, confirmed tritium extraction rates, & permeation limits
- **Non-nuclear/nuclear alternatives:** Options with and without neutron bombardment and significant tritium inventory have merit, including development of maintenance schemes and power extraction



CHIMERA: Barrett et al., Fusion Science & Technology 79 (2023) 1039-1050
 UNITY-1: https://kyotofusioneering.com/kfwp/wp-content/uploads/2024/06/KF_whitepaper.pdf

Integrated Blanket and Fuel Cycle Test Facility



Fuel Cycle and Tritium Processing

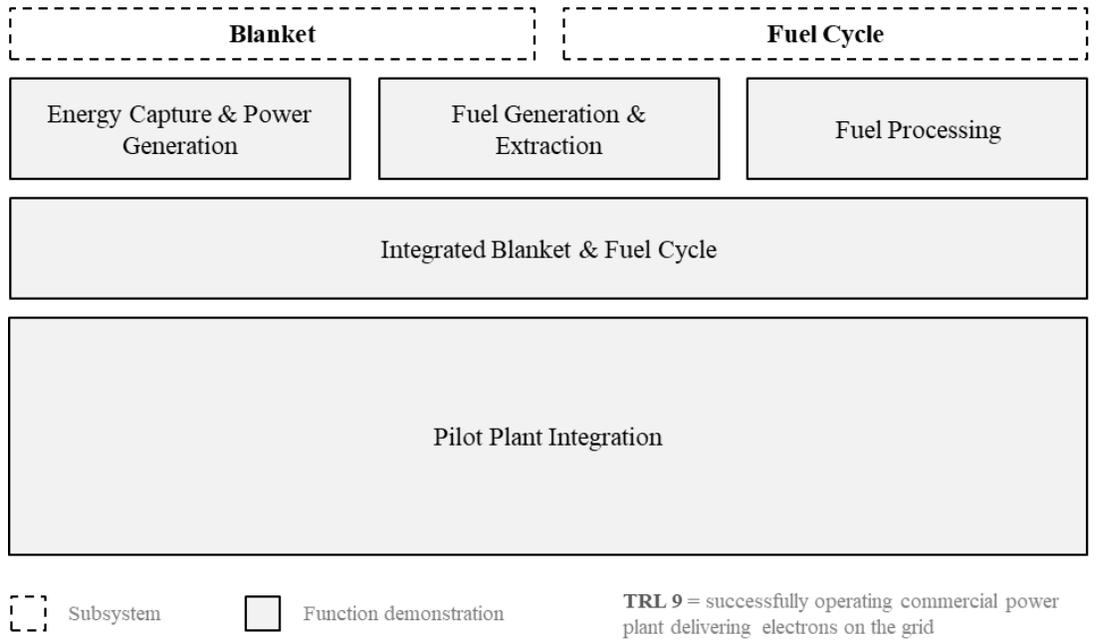


Blanket Science & Technology

Gap: Integrated tests of both fusion blanket and fuel cycle technologies with neutron and tritium at scale

Focus areas

- **Fuel Cycle:** tritium production, processing, and closed-loop handling at relevant throughput
- **Blanket:** Testing of materials and components under fusion-relevant neutron irradiation
- **Neutronics:** Benchmark cross-sections, T breeding ratios, and shielding performance using VNS
- **Maturation:** Continuous operations supports maturation of blanket and fuel-cycle technologies



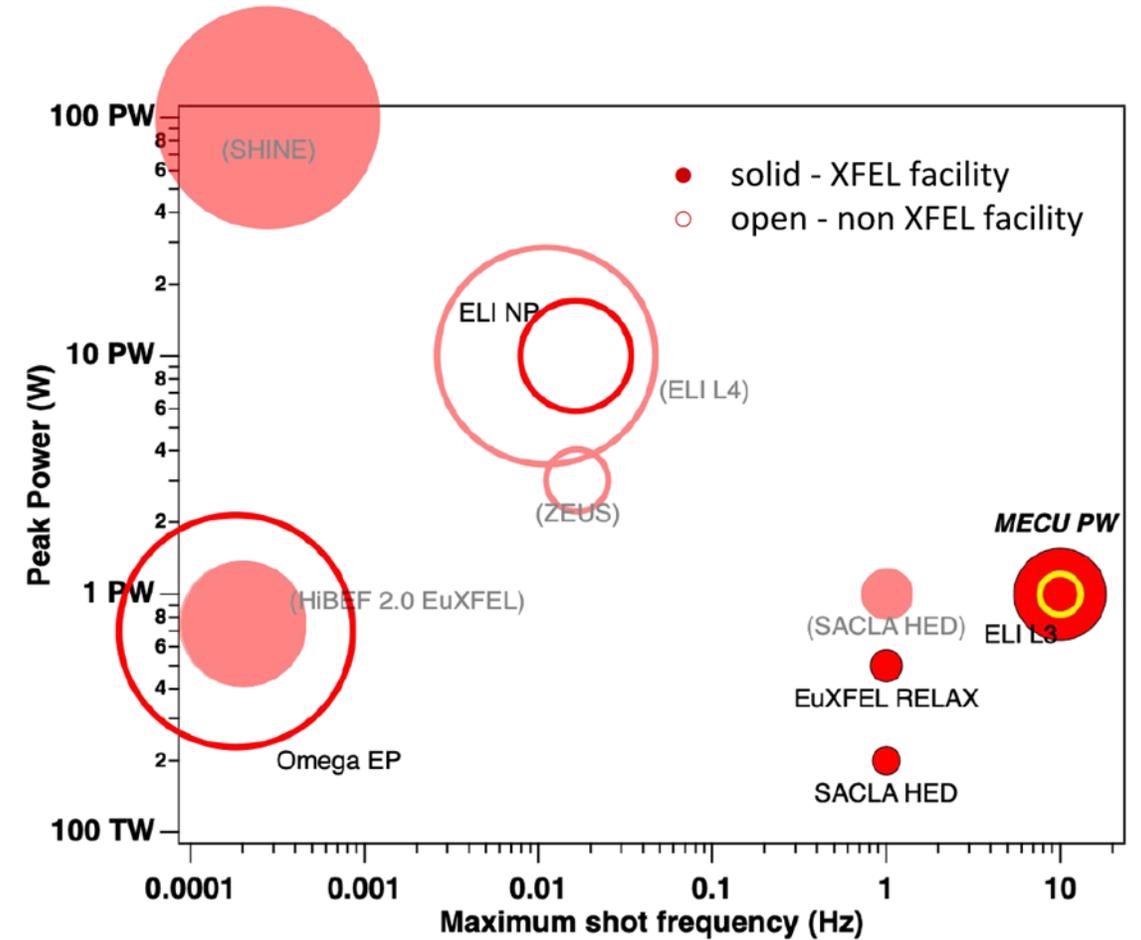
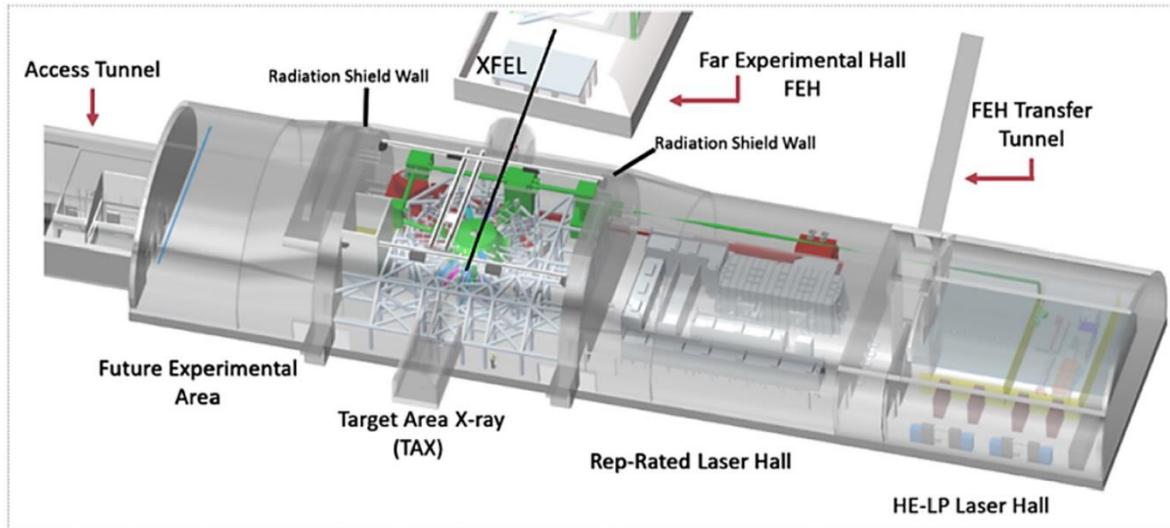
- TRL5**
Subsystem validation in relevant environment
- TRL6**
System prototype in relevant environment
- TRL7**
System prototype in operational environment
- TRL8**
Actual system completed and qualified

TRL 9 = successfully operating commercial power plant delivering electrons on the grid

Schematic of TRL advancement from IB-FCTF

Matter in Extreme Conditions Petawatt Upgrade (MEC-U)

- MEC at the Linac Coherent Light Source (LCLS) combines a high-power optical laser with a hard X-ray beamline to study the transient behavior of matter in extreme conditions.
- MEC-U synergies vary across IFE, astrophysics, materials, & security





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Fusion Science & Technology Roadmap

**Thank
you for your
Attention!**



BUILD

INNOVATE

GROW