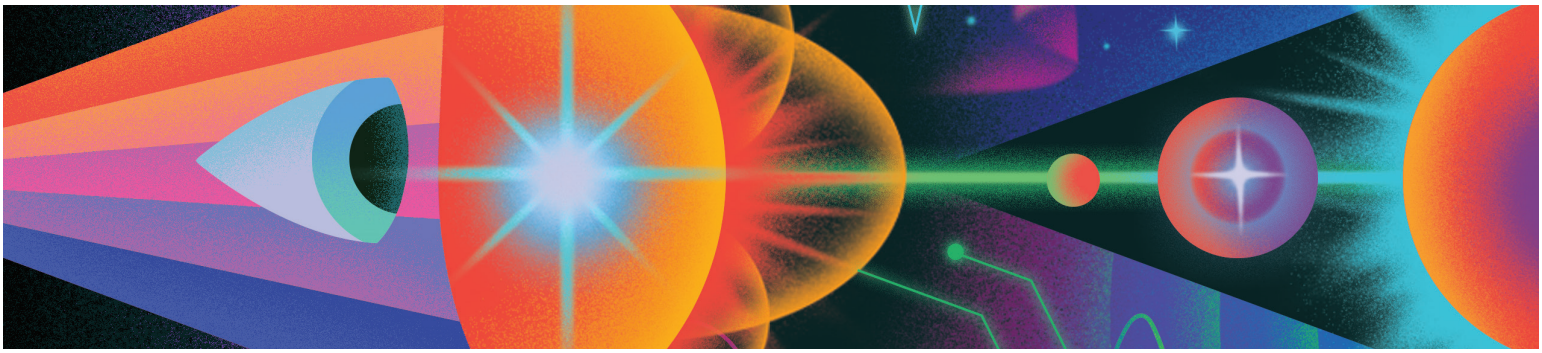
Measurement Innovation for U.S. Leadership



Meeting The Moment

Fusion energy and the broader landscape of plasma-based technologies are entering a decisive decade. Scientific progress has brought the United States to the threshold of sustained burning plasmas and high-gain inertial fusion, while global competition accelerates not only in fusion energy, but also in plasma-enabled applications. Achieving a Fusion Pilot Plant (FPP) in the U.S. in the 2030s to 2040s now depends on the ability to measure, understand, control, and optimize plasmas, materials, and fuel-cycle systems under extreme conditions. These same capabilities underpin a broader plasma-technology ecosystem critical to U.S. economic leadership.

Diagnostics will be critical to determining whether the U.S. can sustain a burning plasma, engineer for extreme environments, and translate plasma science into deployable systems. The speed of progress across fusion and plasma tech now hinges on our ability to innovate. DOE's new *Build–Innovate–Grow* strategy reinforces this imperative by calling for enabling technologies, advanced tools, and a world-leading workforce to secure U.S. competitiveness in the global landscape for fusion and plasma technologies.

A National Vision

Diagnostics are key to converting plasma science into commercial fusion power. Measurement innovation will introduce new techniques and diagnostic architectures capable of operating in the high-radiation, high-heat, and limited access environments of next-generation fusion systems.

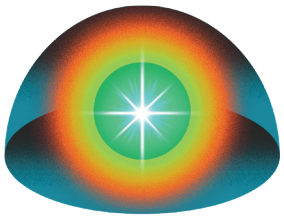
These capabilities enable:

- Monitoring of non-thermal populations
- In situ calibration systems
- Real-time and high-repetition-rate autonomous plasma control
- Radiation-hard sensing for harsh FPP conditions
- ML- and AI-enhanced data interpretation and integrated data analysis
- Digital twins that unite simulation and experiment
- Autonomous monitoring of materials and the fuel-cycle essential for plant safety

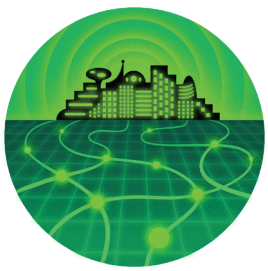
Together, they form the scientific foundation required to deploy a U.S. FPP and strengthen domestic industry.

Strategic Drivers for Measurement Innovation for a Fusion Pilot Plant

Sustain a Burning Plamsa



Engineering for Extreme Conditions



Harness Fusion Energy

Priority Research Opportunities

A Basic Research Needs Workshop on Measurement Innovation sponsored by the U.S. Department of Energy's Office of Science and Fusion Energy Science (FES) was held to collect information on opportunities for advances in diagnostics. The workshop brought together national experts from academia, national laboratories, and industry to identify the critical diagnostics and measurement technologies needed to advance U.S. leadership in fusion energy and plasma technologies.

The findings of this workshop provide a roadmap for DOE and Congress to align R&D priorities with the technologies and talent needed to make a fusion pilot plant a reality within the next decade. The workshop focused on identifying the Priority Research Opportunities (PROs) to meet this challenge across seven major research areas:

- Low Temperature Plasma
- High Energy Density Plasma
- Plasma Material Interaction
- Magnetic Confinement Fusion — Burning Plasma
- Inertial Confinement Fusion — Burning Plasmas
- Magnetic Fusion Energy — Fusion Pilot Plant
- Inertial Fusion Energy — Fusion Pilot Plant

Measurement innovations have led and will continue to lead to scientific and engineering breakthroughs in plasma science and technology activities supported by the DOE's FES, especially fusion energy sciences.

Findings

Accelerate innovation: The pace of progress for measurement innovations for the FES community, especially for the realization of nuclear fusion energy, could be accelerated by the use of validation and verification (V&V) of design modeling codes, artificial intelligence and machine learning (AI/ML), and the use of digital twins.

Establish a national network: Measurement innovation offers a critical cross-thread in the FES community and could be better supported by a program modeled after LaserNetUS. Such a community could be called CalibrationNetUS.

Form national teams: National teams should be formed to transform ideas for measurement innovations into working diagnostics in an efficient and economical way.

Standardize calibrations: A more systematic approach to diagnostic calibrations would significantly benefit measurement innovations.

Transfer knowledge to the private sector: Transferring diagnostics and operational expertise from the public sector to private facilities offers synergistic benefits to the fusion energy science community.

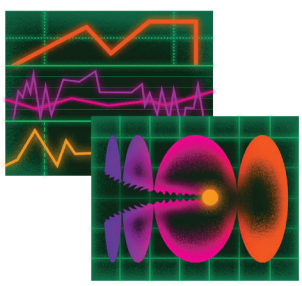
Invest in a workforce pipeline: The measurement innovations needed for fusion pilot plants require a momentous workforce development.

Plan now for remote operations: Measurement innovations needed for remote operation and maintenance of FPPs should be the topic of future workshops.

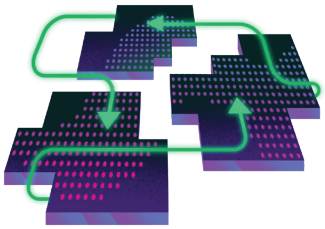
Crosscutting Opportunities

These areas offer natural platforms for national teams, multi-lab coordination, and public-private partnerships Four crosscutting themes will anchor national investment:

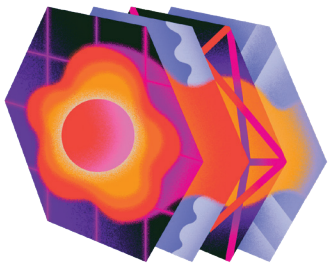
Radiation-hard diagnostic development



FPP infrastructure for controls and sensing



AI/ML and real-time data architectures



Tritium, PMI, and heat-load measurement systems