2024

U.S. DEPARTMENT OF ENERGY | Office of Science

BUILDING BRIDGES

A VISION FOR THE OFFICE OF FUSION ENERGY SCIENCES

The mission of the Fusion Energy Sciences (FES) program is expanding the fundamental understanding of matter at very high temperatures and densities, building the scientific foundations needed to develop a fusion energy source, and supporting the development of a competitive fusion power industry in the U.S.

The mission is accomplished by studying the plasma state and its interactions with its surroundings. Section 2008 of the Energy Act of 2020 amended the Department of Energy Research and Innovation Act (42 U.S.C. § 18645) to expand the scientific mission of FES by adding the goal of "supporting the development of a competitive fusion power industry in the U.S."

In 2020, alongside this expansion, the Fusion Energy Sciences Advisory Committee (FESAC) released its report that included developing a Long-Range Plan (LRP)[1] for FES.

The FESAC LRP articulated that achieving a thriving and sustainable fusion energy industry of the future requires addressing key scientific and technology gaps with a diverse set of tools and strategic approaches. The FESAC LRP is the blueprint from which a new Office of Science (SC) FES program is being designed, complemented by the Bold Decadal Vision to help guide programmatic priorities and timelines ultimately converging the interests of the public and private sectors in the U.S. to establish a robust fusion energy industry.

The three major elements of the Building Bridges vision:

Workforce Development and Sustainment: Ensuring we establish sustainable and resilient pathways for diverse and exceptional talent.

Bridging Gaps: Creating innovation engines with national laboratories, universities, and industry to support science excellence and technology readiness for fusion energy.

Transformational Science: Nurturing plasma science and technology discovery translating to innovation impact.

Both the mission and vision help define the strategy and goals for the program as it begins to help bridge the interests of a growing private fusion energy sector and public programs supported by SC FES. To achieve this vision there are three major strategic actions: 1) building a U.S. Fusion Science & Technology (FS&T) Roadmap, 2) establishing Fusion Innovation Research Engine Ecosystems, and 3) helping develop a public-private consortium framework supporting fusion energy development. These strategic actions will be supported by a coalition of public-private and international partnerships that align resources and expertise to address critical S&T gaps towards fusion energy.

Strategy Action #1: U.S. Fusion Science & Technology Roadmap

The SC FES will build a United States FS&T Roadmap that enables prioritization and the development of scenarios in a decision tree that will guide the United States towards charting and accelerating the path towards commercialization of fusion energy. The FESAC LRP was the "what" and the "why" of fusion energy and plasma science in the SC FES program. The U.S. FS&T Roadmap will provide the "how" and the "when". The FS&T Roadmap will be defined by metrics with input from the fusion community and will include fulfilling the fusion energy mission focused on the FESAC LRP FS&T drivers:

Sustain a Burning Plasma: Building the science and technology required to confine and sustain a burning plasma.

Engineer for Extreme Conditions: Developing the materials required to withstand the extreme environment of a fusion energy system.

Harness Fusion Power: Engineering the technologies required to breed fusion fuel and generate electricity in a fusion pilot plant by the 2040s.

Complementing the FESAC LRP as input to the U.S. FS&T Roadmap are multiple workshop reports (e.g., Inertial Fusion Energy Basic Research Needs Workshop, Fusion Prototypic Neutron Source Performance Requirements Workshop, Fusion Fuel Cycles and Blankets Workshop, U.S. Fusion Materials Road Mapping Workshop, DOE Workshop on Fusion Energy Development via Public-Private Partnerships), and additional reports e.g., DOE Workshop on Fusion Energy Development via Public-Private Partnerships (PPPs), FESAC International Benchmarking, the Bold Decadal Vision as underpinned by the National Academics Science Engineering Medicine (NASEM) 2021 report "Bringing Fusion to the U.S. Grid", and the FESAC Decadal Plan and Facilities Construction Projects charges in 2024.

This information will be distilled and, through strategic retreat sessions within SC FES, a U.S. FS&T Roadmap will be constructed for release in early 2025. To help support the first strategic action, a re-organization of the SC FES Program and re-structure of the SC FES budget will be completed. The new FES organization structure consists of a new division named Enabling Sciences and Partnerships that will include programs such as Fusion Nuclear Science, Fusion Materials, Plasma Technology, Enabling Fusion Technologies, and a new program, Fusion Workforce Pathways. This division will also oversee all public-private partnership programs including a novel program where private sector facilities will host public-based science research.

The new reorganization in will support a new budget structure that provides the framework to align the SC FES to the FESAC LRP and build the bridges needed with the private sector to help accelerate development of fusion technologies to realize fusion energy. The FES budget restructure is the first step towards enabling a re-alignment of the FES program to better reflect the recommendations outlined in the FESAC LRP. Since the budget restructuring process is very complex and lengthy, FY 2025 is the earliest opportunity to begin this process. Three overall goals are envisioned in this budget re-structure: 1) flexibility, 2) balance, and 3) strategy. The new budget re-structure is shown in Fig. 1.

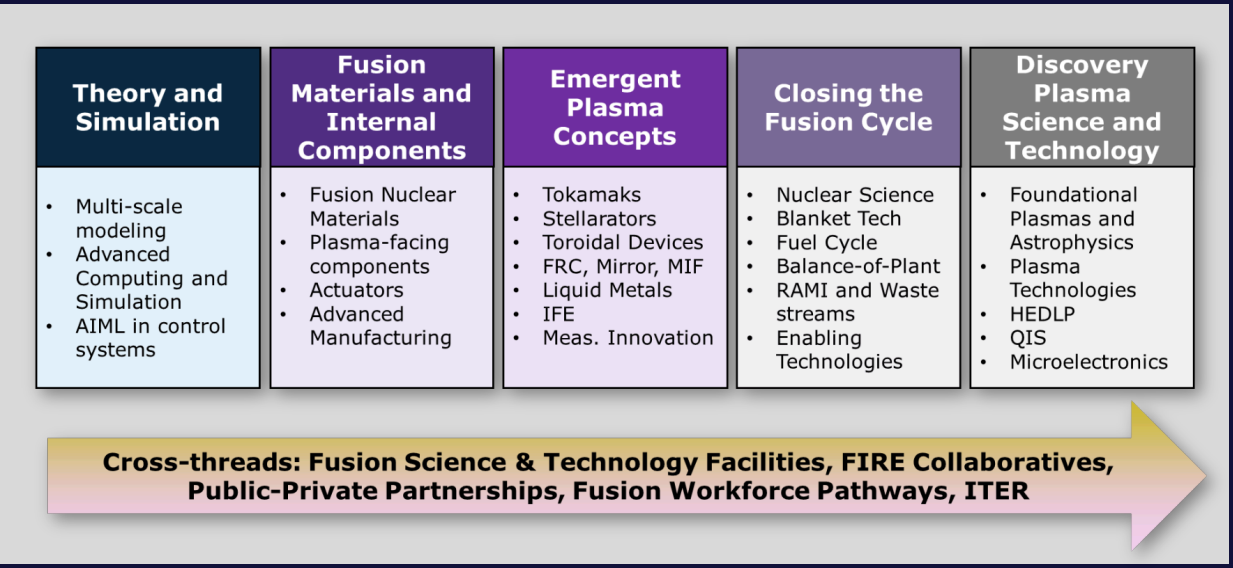

Fig. 1. New DOE SC FES budget structure consisting of five major budget elements that reflect the alignment of SC FES with the FESAC Long Range Plan.

The budget re-structure provides flexibility, allowing the fusion and plasma science and technology communities budget elements that map to the FESAC LRP three science drivers: Sustain a burning plasma, Engineer for extreme conditions, and Harness fusion power. The new budget re-structure also provides balance in the overall program by highlighting primary areas that include Theory and Simulation, Fusion Materials and Internal Components, Emerging Plasma Concepts, Closing the Fusion Fuel Cycle, and Discovery Plasma Science and Technology. Finally, the new FES budget re-structure is strategic. The re-structure has several strategic cross-threads including Fusion Science & Technology Facilities, FIRE Collaborative, Public-Private Partnerships, Fusion Workforce Pathways, and activities in ITER.

Strategy Action #2: Establish FIRE Collaborative Ecosystems

The second strategic action is to establish innovation research engine ecosystems that enable the bridge between foundational science activities (e.g. Technical Readiness Level [TRL]˜ 1-2) to more mature development (TRL ˜ 3-4) and enabling a bridge between science and early-stage technology development defined and inspired by the growing fusion industry (e.g., the technology roadmaps of the Milestone Program awardees). Fig. 2 illustrates how the FIRE Collaborative activities fit within the SC FES program. The "Engine" ecosystem bridges incubation activities within the base program in SC FES and acceleration of fusion technologies supporting translation to industry. The latter is supported by public-private partnerships complemented by additional public-private partnership elements such as a fusion energy consortium (see Strategy #3) that helps accelerate fusion energy by de-risking Fusion Materials & Technology (FM&T) gaps.

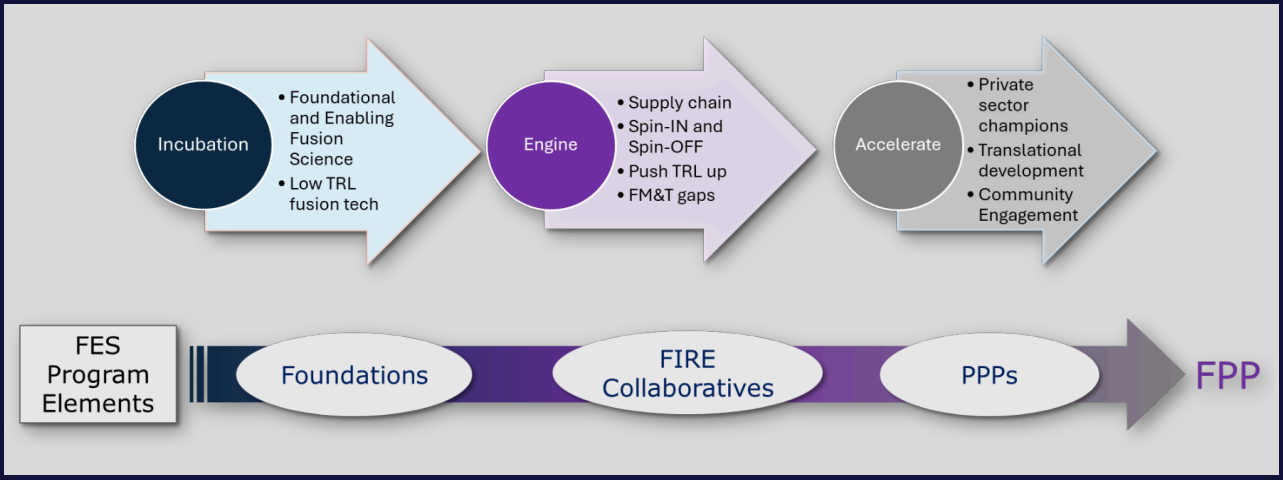

Fig. 2. Interconnection of three major elements within the re-aligned and re-structured SC FES program. The FIRE Collaborative acts as a bridge between incubation of ideas in foundational fusion science and public-private partnership activities that help link to user-defined FM&T gaps.

A significant distinction between FIRE Collaboratives and existing foundational science programs lies in their approach to research. While foundational science programs typically follow a basic research model, experimental or theoretical work is undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts. FES expects the FIRE Collaboratives to function as accelerated, results-driven research projects utilizing real-time results to inform research direction, allowing for agile adjustments, and potentially discontinuing projects if deemed necessary based on outcomes or a pivot in priorities. This dynamic approach ensures that FIRE Collaboratives remain focused on achieving tangible advancements in de-risking FS&T within specified timelines and metrics.

Strategy Action #3: Develop a Public-Private Consortium Framework

To support development of a competitive fusion power industry in the United States. (consistent with the expanded Fusion Energy Sciences mission under the Energy Act of 2020), the FES program is exploring the near-term feasibility of a fusion energy public-private consortium framework (PPCF). This PPCF, inspired by the successful 1980s PPP between the Department of Defense and Sematech and other unique PPP models (e.g., research parks in Asia, NY Creates, etc…), would support the U.S. Bold Decadal Vision (BDV).[2,3,4]

The proposed PPCF would aim to accelerate fusion energy research, development, demonstration, and deployment (RDD&D) and amplify federal funding by bringing together state/local government, private, and philanthropic funding, with an initial focus on delivering and operating small-to-medium scale fusion technology facilities and conducting R&D with these tools to help resolve significant, remaining S&T gaps (aligned with FPP technology roadmaps of private-sector fusion developers and critical supply-chain providers).[5] Fig. 3 illustrates the PPCF as a bridge towards fusion pilot plant (FPP) demonstrations.[6] A key rationale for pursuing a PPCF is because the required funding and pace of R&D and project delivery are not readily achievable within the BDV timeframe. The proposed PPCF is envisioned to be executed (e.g., tool delivery and operation, R&D, growing supply chains, and broader engagements/activities to support fusion demonstration and commercialization) by a network of regional ecosystems that will build upon local expertise, stimulate economic development and bolster domestic supply chains anchored in fusion S&T translation and innovation.[7] The creation of the PPCF will be industry-led and will help support the construction of small-to-midscale FM&T de-risk facilities or upgrades of existing assets with a strategic PPP approach.

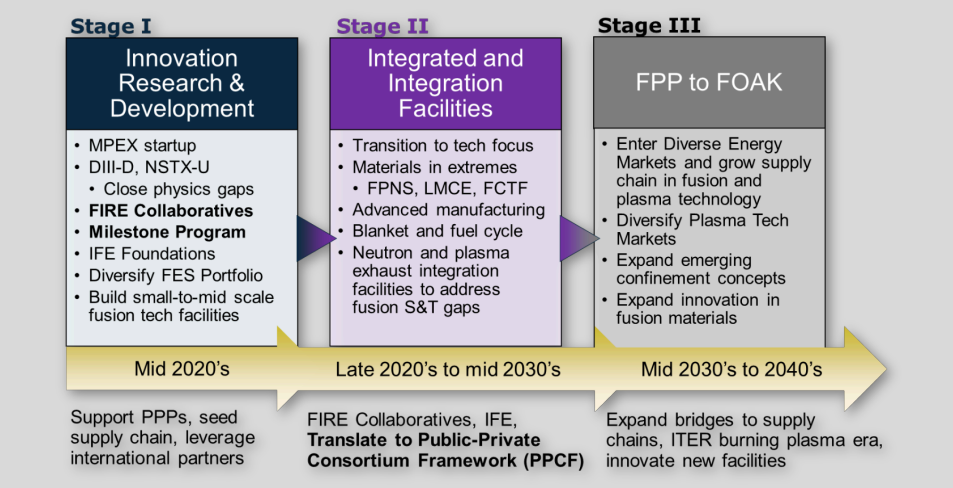

Fig. 3. A staged approach towards de-risking critical Fusion Materials and Technology (FM&T) gaps supporting the development of fusion energy and a viable path towards fusion pilot plants (FPP) and first-of-a-kind (FOAK) fusion energy systems.

[1] Carter, T., Baalrud, S., Betti, R., Ellis, T., Foster, J., Geddes, C., ... & Rej, R. (2020). Powering the future: Fusion & plasmas. US Department of Energy (USDOE), Washington, DC (United States). Office of Science, https://science.osti.gov/-/media/fes/fesac/pdf/2020/202012/FESAC_Report_2020_Powering_the_Future.pdf
[2] https://www.whitehouse.gov/ostp/news-updates/2022/03/15/fact-sheet-developing-a-bold-vision-for-commercial-fusion-energy.
[3] The purpose of Sematech was to (1) conduct research on advanced semiconductor manufacturing techniques and (2) develop techniques to use manufacturing expertise for the manufacture of a variety of semiconductor products; https://www.esd.whs.mil/Portals/54/Documents/FOID/Reading%20Room/Science_and_Technology/10-F-0709_A_Final_Report_to_the_Department_of_Defense_February_21_1987.pdf.
[4] https://www.csis.org/analysis/implementing-chips-act-sematechs-lessons-national-semiconductor-technology-center.
[5] The S&T gaps and critical testing platforms, discussed in multiple recent consensus expert reports and ongoing FESAC charges, will be formally laid out in a national fusion S&T roadmap under development by FES.
[6] Future FPP demonstration projects may be milestone-based and would be administered outside of the Office of Science.
[7] The PPCF is also partially inspired by J. Gruber and S. Johnson, *Jump-starting America: How Breakthrough Science Can Revive Economic Growth and the American Dream* (Public Affairs, New York, 2019).