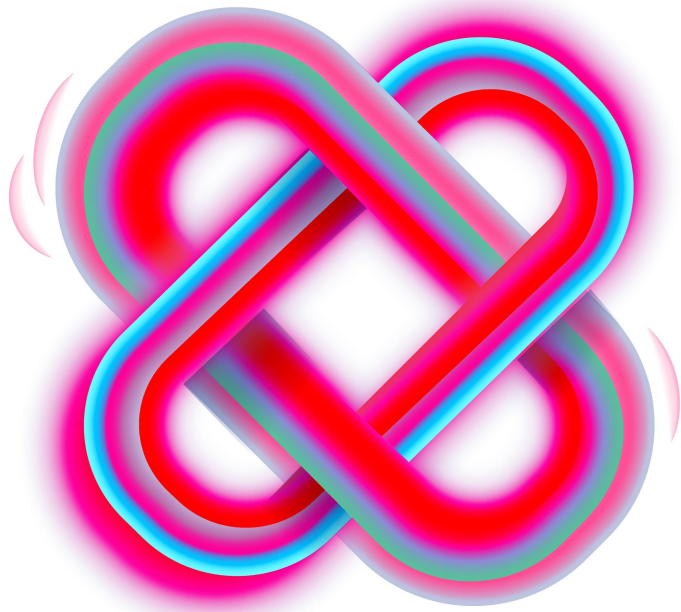




Powering the Future Fusion & Plasmas

A long-range plan to deliver
fusion energy and to advance
plasma science

A report of the DOE Fusion Energy Sciences Advisory Committee

MIPSE Seminar, Feb 9, 2021



Context: First-of-a-kind Planning Process for DOE FES

- Report presents a 10-year strategy for DOE Fusion Energy Sciences
 - ◆ Agency that provides majority of federal support for fusion energy research, but importantly also supports fundamental and applied plasma science research
 - ◆ Research-community-driven planning process for FY22-FY31, considering the entire FES portfolio
- Important reports that provide additional context:
 - ◆ 2018 NASEM Opportunities in Intense Ultrafast Lasers
 - ◆ 2019 NASEM Burning Plasma Research Report
 - ◆ 2020 NASEM Plasma 2020 Decadal Report

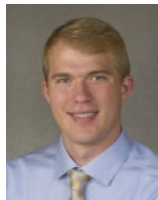


2018 Fusion Energy Sciences Advisory Committee Charge

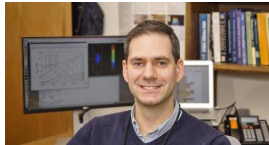
- Charge covers entire DOE Fusion Energy Sciences portfolio: “...**should identify and prioritize the research required to advance both the scientific foundation needed to develop a fusion energy source, as well as the broader FES mission to steward plasma science.**”
- Two part process, community driven phase (APS DPP Community Planning Process) and FESAC-led phase
- “Optimized FES program over the next ten years” (FY22-FY31). Consider three budget scenarios: **constant level of effort**, **modest growth** (2% above inflation), and **unconstrained** but prioritized
- “...assume that the US Contributions to ITER project will continue throughout this entire period”: focus on the non-ITER-project portion of the budget.



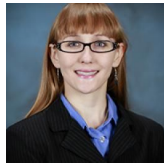
Successful Phase 1, thanks to CPP leadership and the community



Scott Baalrud



Nathan Ferraro



Lauren Garrison



Nathan Howard



Carolyn Kuranz



John Sarff



Wayne Solomon



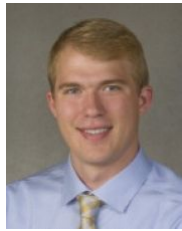
Earl Scime

- APS DPP Community Planning Process (CPP): Year-long community-led process. Whitepapers, webinars, town halls and 5 major workshops; Open process, with community review/vetting of draft report
- Process not only enumerated the many scientific and technical opportunities, but did the hard work of establishing guidance for prioritization of these activities
- Consensus CPP report expresses community's excitement to move forward urgently to develop fusion power and advance plasma science and is the scientific and technical basis for the FESAC report

Thank you!



FESAC Long Range Planning Subcommittee



Scott Baalrud



Riccardo Betti



Troy Carter



Tyler Ellis



John Foster



Cameron Geddes



Arianna Gleason



Chris Holland



Paul Humrickhouse



Chuck Kessel



Ane Lasa



Tammy Ma



Rajesh Maingi



David Schaffner



Oliver Schmitz



Uri Shumlak



Lance Snead



Wayne Solomon



Erik Trask



Francois Waelbroeck



Anne White

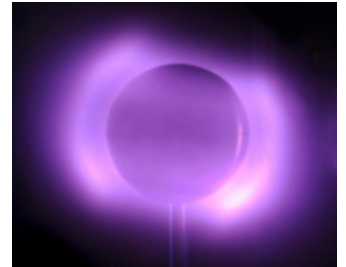


Don Rej (ex officio)



Thank you!

- To Laurie Moret, for her guidance throughout the two-year process
- To Sam Barish, for his advice and assistance as FES liaison
- To Sandbox Studio (Michael Branigan & Ana Kova) for illustration and graphic design and to Jim Dawson & Martha Hanna for editing.





Subcommittee Process

- Subcommittee work began February 2020, ramped up with delivery of the “Phase 1” Community Planning Process report in March
- Entire process conducted virtually (many subcommittee members have never met before in person). Uncountable number hours spent on Zoom (countable number on MS Teams)
- Many guest speakers: from other federal agencies, on related reports, on public–private partnership models
- Community engagement through focus groups, virtual workshop
- Scenarios developed using extensive budget analysis: utilizing data from FES, range of inputs on facilities costs including costing experts with extensive DOE project experience (**Jeff Hoy, Carl Strawbridge**)
- Worked by consensus process to produce the final report



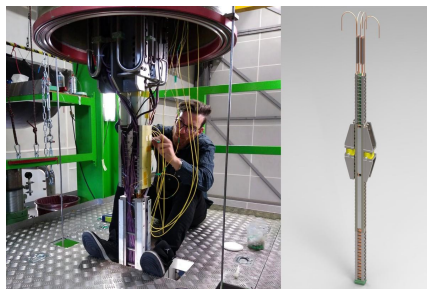
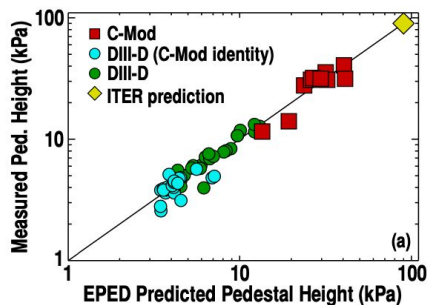
Report Status

- Draft report released publicly December 4, 2020
- Report approved by unanimous vote during FESAC meeting December 7-10, 2020
 - ◆ That approval required changes to draft to improve, clarify report
- FESAC changes have been implemented
- Report has had professional editing and copy editing
- **Final report has been transmitted to DOE SC Leadership**
- Public release should be very soon...
- Report will be posted at <http://usfusionandplasmas.org>



Executive summary: Now is the time for fusion & plasmas

- **Now is the time** to move aggressively toward the development of fusion energy. Scientific and technological innovations enable a unique US vision for economically attractive fusion energy, with the goal of a fusion pilot plant by the 2040s. Growth of a fusion energy industry is important for this vision and that industry is already seeded.



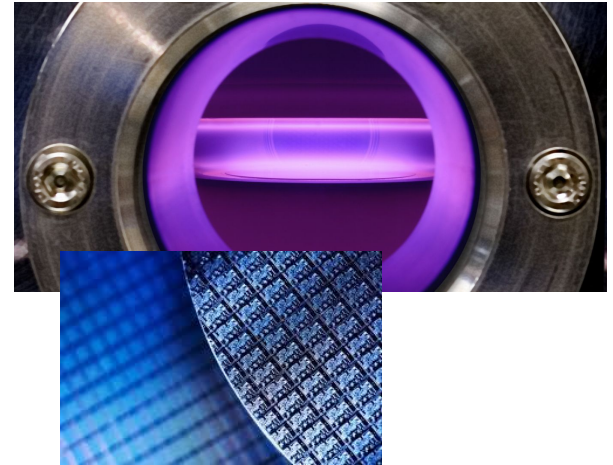
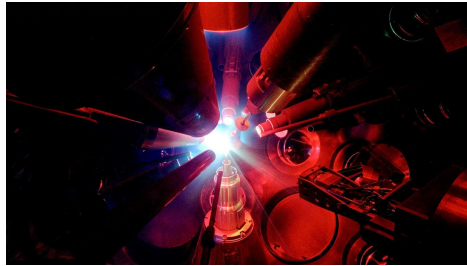
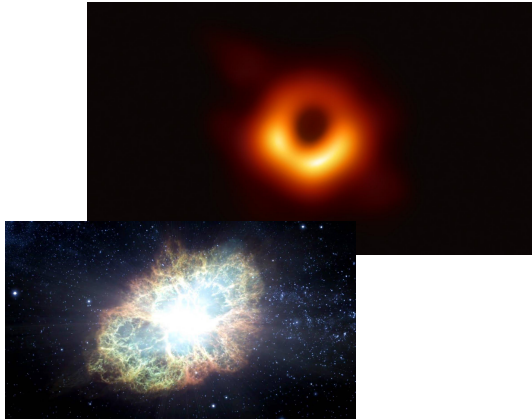
Membership





Executive summary: Now is the time for fusion & plasmas

- **Plasmas transform society.** Far-reaching impact spans: advances key to enabling fusion energy; deeper understanding of our universe; creating exotic states of matter with the most intense lasers in the world; transformative applications that impact our everyday lives and have the potential to enable a more sustainable society





Executive summary: Now is the time for fusion & plasmas

- **Now is the time** to move aggressively toward the development of fusion energy. Scientific and technological innovations enable a unique US vision for economically attractive fusion energy, with the goal of a fusion pilot plant by the 2040s. Growth of a fusion energy industry is important for this vision and that industry is already seeded.
- **Plasmas transform society.** Far-reaching impact spans: advances key to enabling fusion energy; deeper understanding of our universe; creating exotic states of matter with the most intense lasers in the world; transformative applications that impact our everyday lives and have the potential to enable a more sustainable society
- **Fusion and plasmas are inextricably linked,** have strong connections and important shared history



Executive summary: Partnerships and Leadership

- **Partnerships accelerate progress.** International partnership, especially ITER, is critical. Public–private partnerships have the potential to reduce time to commercially viable fusion and support the growth of a fusion energy industry. Interagency partnerships can maximize progress in research and development.
- **Fusion and plasma research in the US are world-leading; continued scientific leadership requires nurturing and agility.** US is poised to create world-leading fusion industry, should be supported. Leadership in key areas is threatened by the absence of investment in major new facilities to address critical R&D needs.



Executive summary: First time process

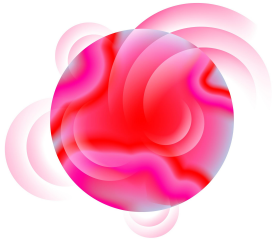
- **For the first time, scientists have created a long-range plan to accelerate the development of fusion energy AND advance plasma science.** The community-driven CPP process is the foundation of this long-range planning process. Not only identified important new opportunities, but developed guidance for prioritization through a consensus process. The resulting CPP report forms the basis for this strategy.

THANK YOU!

New directions for the FES program



The **Fusion Science and Technology (FST)** area should focus on establishing the scientific and technical basis for a fusion pilot plant by the 2040s



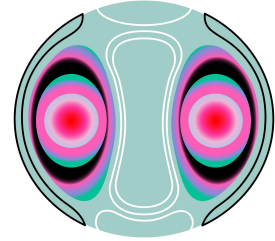
The **Plasma Science and Technology (PST)** area should focus on new opportunities to advance fundamental understanding, and in turn translate these advances into technologies that benefit society

→ These new directions are embodied in six technology and science drivers



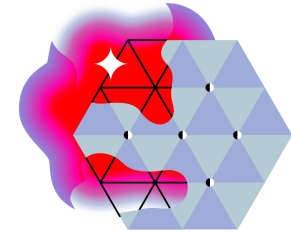
Sustain a burning plasma

Build the science and technology required to confine and sustain a burning plasma



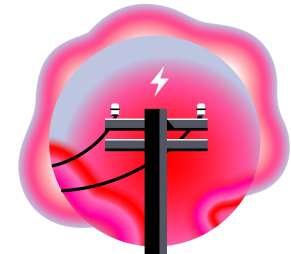
Engineer for extreme conditions

Develop the materials required to withstand the extreme environment of a fusion reactor



Harness fusion power

Engineer the technologies required to breed fusion fuel and to generate electricity in a fusion pilot plant

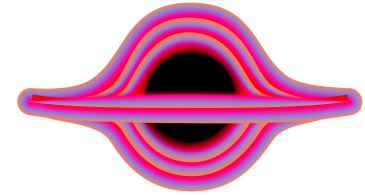




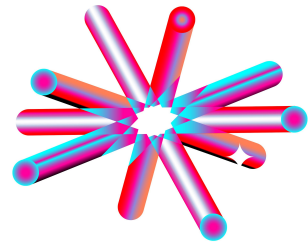
Technology and Science Drivers: PST



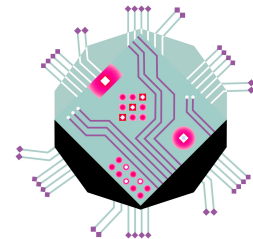
Understand the plasma universe Plasmas permeate the universe and are the heart of the most energetic events we observe



Strengthen the foundations Explore and discover new regimes and exotic states of matter, enabled by new experimental capabilities



Create transformative technologies
Unlock the potential of plasmas to transform society





Overarching Recommendations

- ➔ **Resources for ongoing design and construction of major new experimental facilities should be established in the DOE Fusion Energy Sciences budget**
- ➔ **Opportunities should be provided for developing new experimental capabilities at a range of scales, as appropriate to address the goals of this strategic plan**
- ➔ **Maturation of pre-conceptual designs, scope, and costing for proposed new experimental facilities should be part of regular program activities**
- ➔ **This long-range planning process, including a strong community-led component, should be repeated no later than every five years in order to update the strategic plan**



Overarching Recommendations, cont'd

- **Expand existing and establish new public–private partnership (PPP) programs to leverage capabilities, reduce cost, and accelerate the commercialization of fusion power and plasma technologies** *Appendix B provides further discussion on PPP*
- **Explore and implement mechanisms for formal coordination between funding agencies that support fusion and plasma science research**
- **DOE and FES should develop and implement plans to increase diversity, equity and inclusion in our community. This should be done in consultation with DEI experts and in collaboration with other institutions; involving study of workplace climate, policies, and practices, via assessment metrics and standard practices.**
- **Restore DOE's ability to execute discipline-specific workforce development programs that can help recruit diverse new talent to FES-supported fields of research** *Appendix C provides further discussion on DEI and Workforce*



FST Recommendations



- **Initiate a design effort that engages all stakeholders to establish the technical basis for closing critical gaps for a fusion pilot plant, utilizing and strengthening the US's world-leading theory and computation capabilities and engineering design tools.**
- **Rapidly expand the R&D effort in fusion materials and technology**
- **Immediately establish the mission need for a **Fusion Prototypic Neutron Source (FPNS)** facility to support development of new materials suitable for use in the fusion nuclear environment and pursue design and construction as soon as possible**
- **Develop the scientific infrastructure necessary for the study of plasma-materials interactions needed to develop plasma facing components for an FPP by completing the **Materials Plasma Exposure eXperiment (MPEX)** and additional high-heat flux testing facilities**
- **Significantly expand blanket and tritium R&D programs**



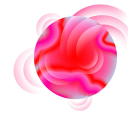
FST Recommendations, cont'd



- Utilize research operations on **DIII-D** and **NSTX-U**, and collaborate with other world-leading facilities, to ensure timely closure of FPP design gaps.
- 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
- Immediately establish the mission need for an **EXCITE** facility (EXhaust and Confinement Integration Tokamak Experiment) to close the integrated tokamak exhaust and performance gap and pursue design and construction as soon as possible
- Strengthen the innovative and transformative research that offers promising opportunities for fusion energy commercialization: stellarators, liquid metal plasma facing components, inertial fusion energy and alternate concepts



PST Recommendations



- **Steady support for fundamental plasma science is needed to enable a stream of innovative ideas and talent; laying the scientific foundation upon which the next generation of plasma-based technologies can be built**
- **Complete the design and construction of **MEC-Upgrade** (Matter in Extreme Conditions Upgrade)**
- **Establish a plasma-based technology research program focused on translating fundamental scientific findings into societally beneficial applications**
- **Coordinate a High Intensity Laser Research Initiative in collaboration with relevant DOE offices and other federal agencies**
- **Pursue the development of a multi-petawatt laser facility and a high-repetition-rate high-intensity laser facility in the US, in partnership with other federal agencies where possible.**



PST & Cross Cutting Recommendations

- **Support networks to coordinate research and broaden access to state-of-the-art facilities, diagnostics, and computational tools**
- **Strengthen support of laboratory-based research relevant to astrophysical and space plasmas through increased programmatic and facility funding as well as expansion of partnership opportunities**

Cross cutting:

- **Ensure robust support for foundational research activities that underpin all aspects of plasma and fusion science and technology**
- **Support research that supplies the fundamental data required to advance fusion energy and plasma science and engineering**



Budget exercises: Scenarios

- Plans have been developed for the three budget scenarios as described in the charge
 - ◆ constant level of effort [published OMB inflators]
 - ◆ modest growth [2% above published OMB inflators]
 - ◆ unconstrained (but prioritized)
- Scenarios help convey information about prioritization, but there are no additional recommendations made that stand outside of these specific budget exercises
- Following the charge, the scenarios are considered starting from the FY19 budget, specifically focusing on the non-ITER construction project portion, which does not include significant resources dedicated to design and construction of facilities
- For this reason, in the two constrained scenarios, **any recommended new construction is funded by redirecting resources from current facility operations and research programs. This redirection is confined within each of the two thematic areas (FST and PST).**
- We assume that all costs for programs and facilities are born entirely by FES. All activities, especially major facilities, should seek partnership, but we do not take credit for this in assembling the scenarios, making these conservative projections.



Consequences of Constrained Scenarios

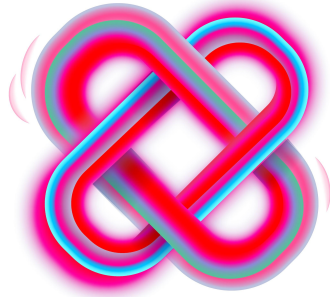
- While the constrained scenarios require difficult choices, they are constructed to represent a balanced program with prioritization and emphasis on critical elements that advance the fusion energy mission and sustain scientific impact and technological progress
- Nonetheless, **the constrained scenarios do not provide sufficient resources to confidently prepare for an FPP by the 2040s**
- **In order to fund new projects, resources must be redirected from existing facilities operation and research programs.** In FST, reduction in tokamak operations and research is needed to redirect funds toward needed new facilities and increased focus on FM&T
- **Large projects in the plasma science and technology area are unfunded in these scenarios, including MEC-U,** which is already at CD-0 and heading toward CD-1 this FY
 - ◆ Construction of major facilities can not be supported by redirecting small resources currently in PST program
- This has consequences as it **will cost the US its position as a global leader in fusion energy and plasma science**, and compromise future developments with important

Significant return on increased investment

- **Constant level of effort:** redirection can occur and important scientific and technical progress will continue, **but major lost opportunities, significant risk to FPP goal and US leadership position**
- **Significant return on the investment for the increment from the constant to the modest growth scenario.** However, risks and missed opportunities remain, including threat to the goal of an FPP by 2040s.
- **Unconstrained scenario:** the complete strategy can be implemented. **Additional investment beyond the modest growth scenario will have substantial return.** Important scientific advances would be enabled and progress toward realizing practical fusion energy would be accelerated.
 - ◆ With staging, program pivoting, and utilization of partnerships, we believe these additional activities can be accomplished in a timely manner and under realizable budgets



Thank you!



<http://usfusionandplasmas.org>

