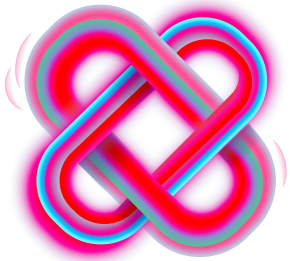
FESAC Decadal Plan Subcommittee Mid-process Update to FESAC



Presented by:
Prof. Carlos Paz-Soldan and Dr. Tammy Ma
On behalf of the FESAC Decadal Plan Subcommittee

FESAC Virtual Meeting 9/30/24

Presentation Outline

- Reminder of our Subcommittee and our Charge
- Process, Timeline, and Community Input
- Framework Provided by the FESAC Long-Range Plan
- Discussion of FM&T Directions and Opportunities
- Considerations of Workforce Continuity
- Public-Private Partnerships
- Q&A and FESAC Discussion

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Charge (slide 1/2)

Department of Energy
Office of Science
Washington, DC 20585

Office of the Director

Professor Anne White
Associate Provost and Associate Vice President for Research Administration
School of Engineering Distinguished Professor of Engineering
Department of Nuclear Science and Engineering
Massachusetts Institute of Technology
77 Massachusetts Avenue, 24-107
Cambridge, Massachusetts 02139

Dear Professor White:

The 2020 report of the Fusion Energy Sciences Advisory Committee (FESAC) Long-Range Plan (LRP) "Powering the Future: Fusion & Plasmas" states in its Executive Summary that "*Now is the time to move aggressively toward the deployment of fusion energy which could substantially power modern society while mitigating climate change.*" In addition, the same report states, "*Fulfilling the [fusion] energy mission demands a shift in the balance of research toward FM&T (Fusion Materials and Technology), which connects the three science drivers: Sustain a Burning Plasma, Engineer for Extreme Conditions, and Harness Fusion Energy.*" Furthermore, a key recommendation in the 2021 Consensus Study Report of the National Academies of Sciences, Engineering, and Medicine (NASEM) "Bringing Fusion to the U.S. Grid" was that "*For the United States to be a leader in fusion and to make an impact on the transition to a low-carbon emission electrical system by 2050, the Department of Energy and the private sector should produce net electricity in a fusion pilot plant in the United States in the 2035-2040 timeframe.*" The recommendations in these reports, which reflected the tremendous progress in fusion science and technology over the last decades as well as the rapid growth and significant investments of the private sector in fusion, contributed to the Administration's recognition of the potential of fusion energy to advance the goal to get to net-zero emissions by 2050.

In March 2022, the White House Office of Science and Technology Policy and the Department of Energy co-hosted a summit on *Developing a Bold Decadal Vision for Commercial Fusion Energy*, which called for accelerating the viability of commercial fusion energy in partnership with the private sector. As a first major step in achieving the Bold Decadal Vision (BDV), the Fusion Energy Sciences (FES) program issued a Funding Opportunity Announcement (FOA), "Milestone-Based Fusion Development Program", to accelerate the development of a fusion pilot plant (FPP) by working with private industry. This initiative is also consistent with the Energy Act of 2020, which expanded the scientific mission of FES with supporting "*the development of a competitive fusion power industry in the U.S.*"

The private sector responded enthusiastically to this FOA, and in May 2023, FES announced $46 million in awards to eight fusion startup companies. The Office of Fusion Energy Sciences (FES) budget request for fiscal year (FY) 2024 includes additional support for the BDV, specifically enhanced support for the Milestone Program, the establishment of fusion research and development (R&D) centers to resolve critical science and technology gaps, and support for future facilities studies including a fusion prototypic neutron source.

The BDV builds upon the FESAC LRP and the NASEM report and accelerates the timeline to an FPP. The FESAC LRP and the American Physical Society/Division of Plasma Physics (APS/DPP) Community Planning Process provided important community input on prioritization among various FES program elements. Given recent developments, it is necessary to re-assess the alignment of the FES program with the FESAC LRP and the expanded mission of the FES program in addressing the BDV in a decadal timeframe. Namely, what new opportunities exist for accelerating fusion energy development and what are some unique synergistic opportunities with discovery plasma science and technology.

Charge (slide 1/2)

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Charge (slide 2/2)

We are therefore asking FESAC to form a subcommittee to re-assess the program elements and their alignment with the FESAC LRP science drivers and the BDV, within the four major categories of the FES budget structure: Burning Plasma Science: Foundations (which includes Advanced Tokamak, Spherical Tokamak, Theory & Simulation, Public-Private Partnerships, and Inertial Fusion Energy); Burning Plasma Science: Long Pulse (which includes the FES international collaborations under Long Pulse: Tokamak, international collaborations and domestic efforts under Long Pulse: Stellarators, and Materials & Fusion Nuclear Science); Burning Plasma Science: High Power (which includes ITER Research); and Discovery Plasma Science (which includes General Plasma Science, High-Energy Density Laboratory Plasmas, and Measurement Innovation). The subcommittee should represent diversity in experiences and perspectives, especially as relates to the private sector engagement requirements to achieve the goals of the BDV.

The following program elements will not be part of the requested assessment: United States (U.S) Contributions to ITER project, Artificial Intelligence/Machine Learning, Material Plasma Exposure eXperiment project, Matter in Extreme Conditions – Upgrade project, Quantum Information Science, Advanced Microelectronics, Advanced Manufacturing, Reaching a New Energy Science Workforce, Funding for Accelerated Inclusive Research, Accelerate Innovations in Emerging Technologies (Accelerate), Established Program to Stimulate Competitive Research, General Plant Projects/General Purpose Equipment/Infrastructure, and Other Research.

For each program element in each category, identify opportunities or current plans to contribute to the FESAC LRP FM&T and fusion plasma science gaps establishing the basis of an FPP in the context of the BDV, taking into consideration the diversity in FPP concepts represented in the Milestone Program awardees. In particular, identify a scope that will address near-term scientific and technological gaps impacting the design and construction of an FPP on the pathway to commercialization within the timeframe of the BDV. For the scope within a program element that is not identified as critical to support the LRP Science Drivers or the BDV, identify specific elements that can be deferred with minimal or modest impact on the FES Program to enable redirection in support of the LRP FM&T gaps and the BDV. Identify the program elements that need to be increased to meet the goals of the LRP FM&T gaps establishing the basis of an FPP in the context of the BDV and those that can be decreased. In addition, the subcommittee should identify the role of the public sector and the FES user facilities (National Spherical Torus Experiment - Upgrade and Doublet III) in addressing the FM&T gaps and advancing commercial fusion applications going forward. Throughout the process, please take the full FESAC LRP into account and consider sustainable support for foundational research as synergies between discovery plasma science and fusion energy development (e.g., spin-off plasma technology applications from fusion) are valued.

In your deliberations, you should consider the impact of your recommendations on workforce continuity, diversity of the workforce, and continuing U.S. leadership in fusion and plasma science. Your assessment should be informed by the APS/DPP Community Planning Process report, FESAC LRP, NASEM report, objectives of the Administration's BDV, and recent workshop reports and community reports. We would appreciate receiving a final written report from FESAC by Fall 2024.

Please contact Dr. Jean Paul Allain, Associate Director for Fusion Energy Sciences, if there is anything we can do to help you in this process.

I appreciate FESAC's willingness to undertake this important activity.

Sincerely,

Asmeret Asefaw Berhe
Director, Office of Science

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Asmeret Asefaw Berhe
Director, Office of Science

FESAC DP Subcommittee members


Troy Carter
(UCLA), Chair


Tammy Ma
(LLNL), Vice-Chair


Arianna Gleason
(SLAC)


Brenda Garcia-Diaz
(SRNL)

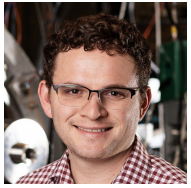

Brian Grierson
(GA)


Carmen Menoni
(CSU)


Chris Holland
(UCSD)


Cristina Rea
(MIT)


Davide Curreli
(U. Illinois)


Derek Sutherland
(Zap Energy)


Elizabeth Paul
(Columbia)


Katharina Stapelmann
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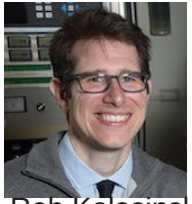
Rob Kolasinski
(SNL)

Ex-officio:


Anne White
(MIT)


Brian Wirth
(UTK)


Carlos Paz-Soldan
(Columbia)


Sam Barish
(DOE Liaison)

FESAC DP Subcommittee members - with new leadership!

Carlos Paz-Soldan (Columbia), Chair

Tammy Ma (LLNL), Vice-Chair

Arianna Gleason (SLAC)

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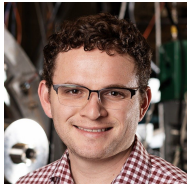

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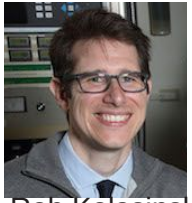

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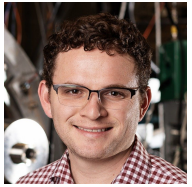
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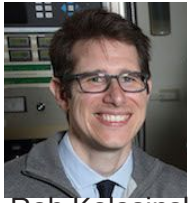
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Ex-officio:


Anne White (MIT)


Brian Wirth (UTK)


Sam Barish (DOE Liaison)

Magnetic Fusion Energy (MFE) Expertise


Carlos Paz-Soldan (Columbia), Chair


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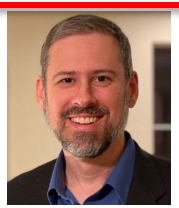
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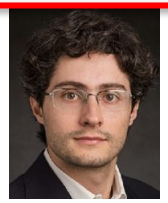
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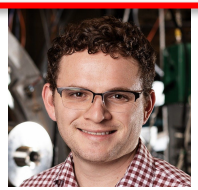
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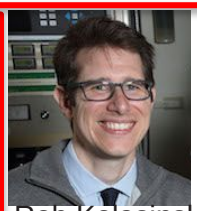
Rob Kolasinski (SNL)

Ex-officio:


Anne White (MIT)


Brian Wirth (UTK)


Sam Barish (DOE Liaison)

Inertial Fusion Energy (IFE) Expertise


Carlos Paz-Soldan (Columbia), Chair


Tammy Ma (LLNL), Vice-Chair


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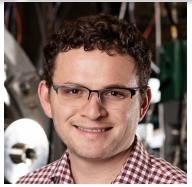
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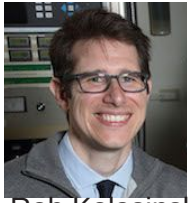
Rob Kolasinski (SNL)

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Basic Plasma Science (GPS + HED) Expertise

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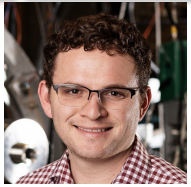

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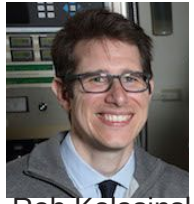

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Fusion Materials & Technology (FM&T) Expertise


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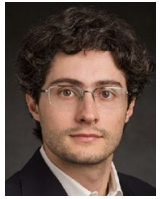
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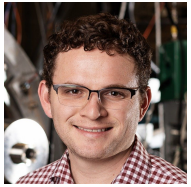
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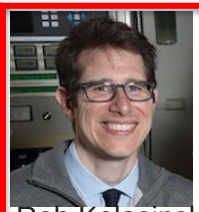
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Fusion Industry Members


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Arianna Gleason (SLAC)


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Chris Holland (UCSD)


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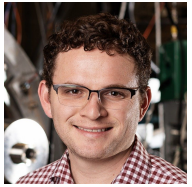
Davide Curreli (U. Illinois)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Rob Kolasinski (SNL)

Ex-officio:


Anne White (MIT)


Brian Wirth (UTK)


Sam Barish (DOE Liaison)

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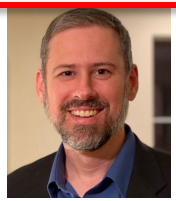
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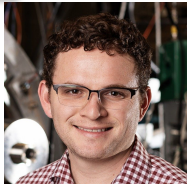
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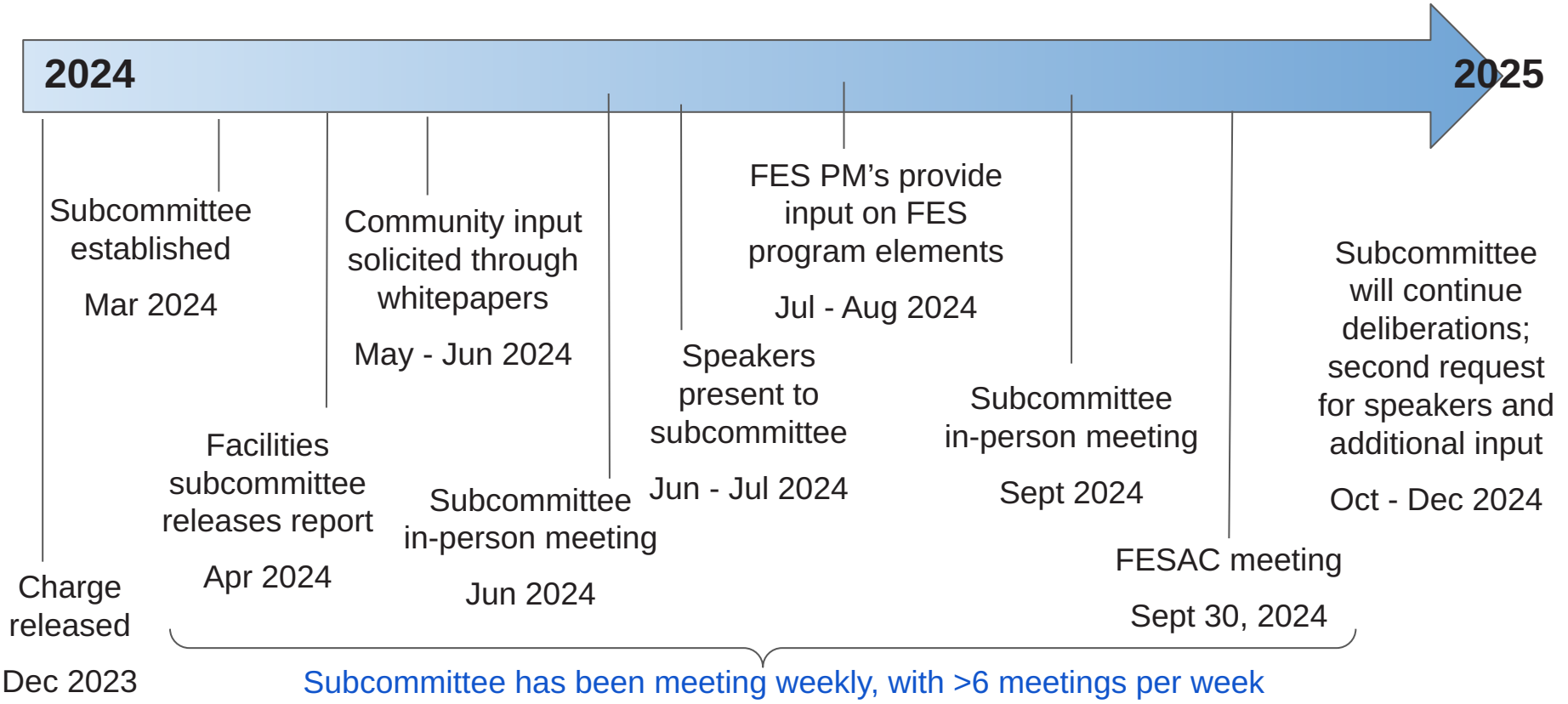
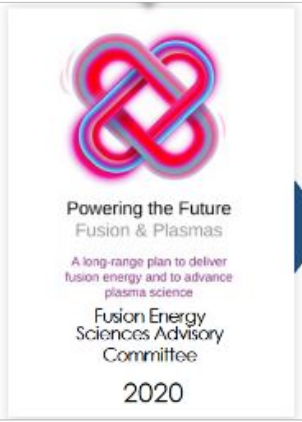
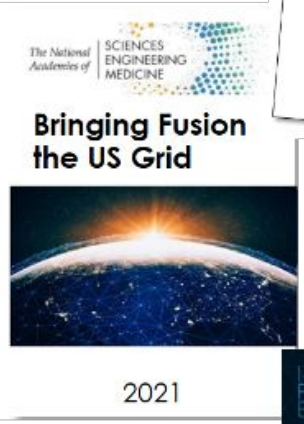
Timeline

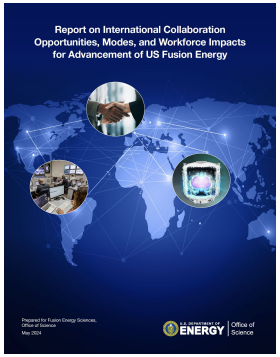

2024
2025
Charge released
Dec 2023
Subcommittee established
Mar 2024
Facilities subcommittee releases report
Apr 2024
Community input solicited through whitepapers
May - Jun 2024
Subcommittee in-person meeting
Jun 2024
Speakers present to subcommittee
Jun - Jul 2024
FES PM's provide input on FES program elements
Jul - Aug 2024
Subcommittee in-person meeting
Sept 2024
FESAC meeting
Sept 30, 2024
Subcommittee will continue deliberations; second request for speakers and additional input
Oct - Dec 2024
Subcommittee has been meeting weekly, with >6 meetings per week

Our work is informed by community reports





2024 FESAC Facilities Report



We are building off the CPP and LRP process that resulted in community-led, consensus report

CPP:
year-long community-led process. Whitepapers, webinars, town halls and 5 major workshops (including final plenary in Houston 2020); Open process, with community review/vetting of draft reports

LRP:

- response to charge "…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."
- "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

New input was requested on a subset of our charge

Since the FESAC LRP and NASEM reports were completed, there has been a significant change in the fusion energy landscape; in particular private investment in fusion has more than tripled to over $6B. We view this part of the charge as an **opportunity to provide input to DOE on the role of the public program** in this context and on **possible new public-private partnership mechanisms**. We also recognize the chance to call out **new synergies and opportunities for interactions** between fusion science and technology R&D and broader plasma science and technology R&D.

To that end, we requested two kinds of input:

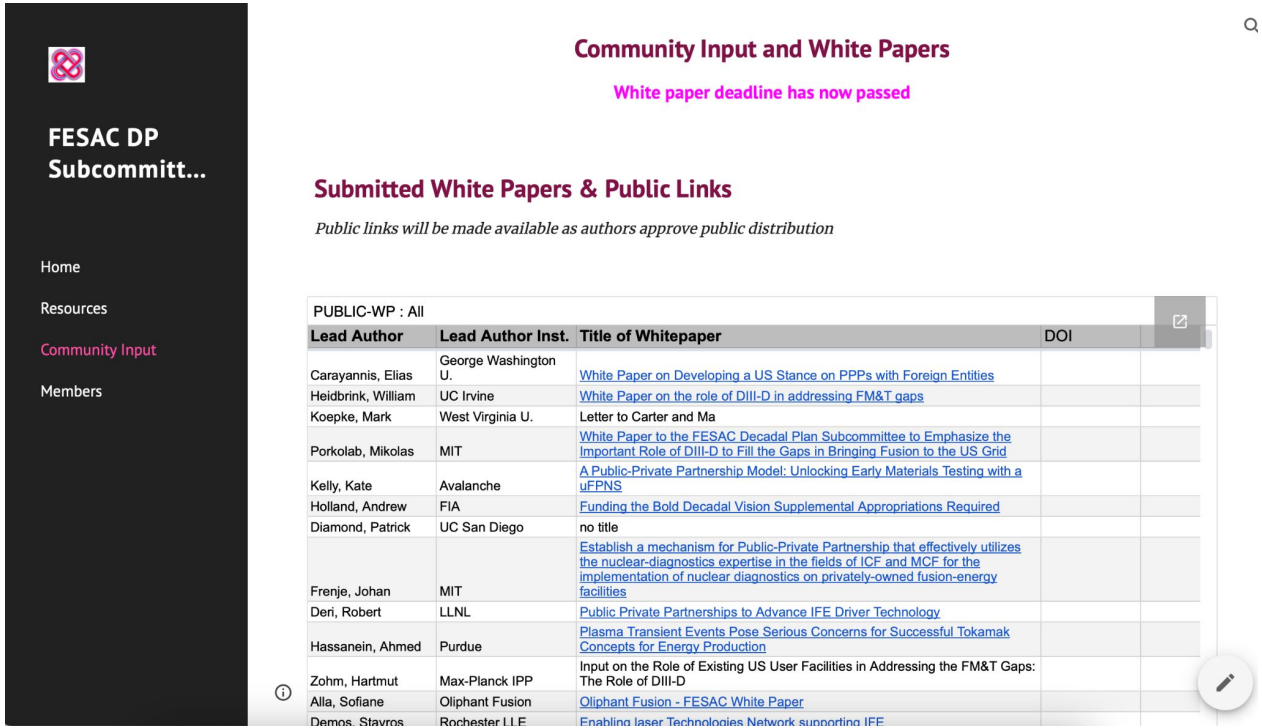
(1) We are planning to bring guests to talk with the subcommittee on relevant topics (e.g. PPP activities in other sectors). We welcome suggestions for speakers/guests using this form.

(2) Concise (< 5 pages) white papers addressing this piece of the charge are welcome, including **proposals for new PPP mechanisms, proposals for approaches for better coupling between the private and public efforts, and opportunities for synergies with fundamental and applied plasma science.**

Community Input can be found at FESAC DP Website

https://sites.google.com/view/fesacdpsubcommittee/home

76 white papers were received - thank you!



Lead Author	Lead Author Inst.	Title of Whitepaper	DOI
Carayannis, Elias	George Washington U.	White Paper on Developing a US Stance on PPPs with Foreign Entities	
Heidbrink, William	UC Irvine	White Paper on the role of DIII-D in addressing FM&T gaps	
Koepke, Mark	West Virginia U.	Letter to Carter and Ma	
Porkolab, Mikolas	MIT	White Paper to the FESAC Decadal Plan Subcommittee to Emphasize the Important Role of DIII-D to Fill the Gaps in Bringing Fusion to the US Grid	
Kelly, Kate	Avalanche	A Public-Private Partnership Model: Unlocking Early Materials Testing with a uFPNS	
Holland, Andrew	FIA	Funding the Bold Decadal Vision Supplemental Appropriations Required	
Diamond, Patrick	UC San Diego	no title	
Frenje, Johan	MIT	Establish a mechanism for Public-Private Partnership that effectively utilizes the nuclear-diagnostics expertise in the fields of ICF and MCF for the implementation of nuclear diagnostics on privately-owned fusion-energy facilities	
Deri, Robert	LLNL	Public Private Partnerships to Advance IFE Driver Technology	
Hassanein, Ahmed	Purdue	Plasma Transient Events Pose Serious Concerns for Successful Tokamak Concepts for Energy Production	
Zohm, Hartmut	Max-Planck IPP	Input on the Role of Existing US User Facilities in Addressing the FM&T Gaps: The Role of DIII-D	
Alla, Sofiane	Oliphant Fusion	Oliphant Fusion - FESAC White Paper	
Demos, Stavros	Rochester LLE	Enabling laser Technologies Network supporting IFE	

All white papers received are listed

If author permission was received, WPs are publicly linked

Plenary speakers to date

Dr. Scott Hsu
DOE Fusion Coordinator
March 28, 2024

Mr. Andrew Holland
CEO, Fusion Industry Associates
June 20, 2024

Dr. David Pace
Deputy Director, DIII-D, GA
June 25, 2024

Dr. Stan Kaye
Director of Research, NSTX-U, PPPL
July 11, 2024

Prof. Saskia Mordijck
President, UFA
College of William & Mary
July 11, 2024

Requested each speaker to address:
how the **FES user facilities can advance commercial fusion applications**

not focusing on technical/scientific elements - rather we would like to hear about **engagements model with industry**: successes, challenges, and invite any recommendations for consideration by our sub-committee

Additionally:
role of universities in the FES program

current FES program elements and their effectiveness in workforce continuity and diversity of the workforce

Also subgroup speakers: Li isotope separation (Brian Egle, ORNL & Jessee Smith, SRNL), Blanket + tritium (Paul Humrickhouse, ORNL & Tommy Fuerst, INRL), Fuel cycle (George Larsen, SRNL)

We expect to request additional input from more speakers

We are answering the following charge questions for each program element

Theory and Simulation (incl. SciDAC)
PPPs (INFUSE, Milestone, Private Facility Res.)
Measurement Innovation / Diagnostics
Discovery Plasma (GPS + HED)
Inertial Fusion Energy
Stellarator (small scale & international)
International ST + AT
Small-scale & Enabling Tech
FM&T Engineer (PFC/PMI + Structural Materials)
FM&T Harness (Blankets & Fuel Cycle, RAMI)
FM&T Sustain (Enabling Technology)
FES User Facilities - NSTX-U
FES User Facilities - DIII-D

1. How does the program element align the with FESAC LRP technology and science drivers?
2. How does the program element align with the FESAC LRP recommendations?
3. How does the program element contribute to establishing the basis for an FPP in the context of the NASEM Report/BDV?
4. What is the current impact of the program element on workforce, workforce diversity, and continuing U.S. leadership in fusion and plasma science?
5. What program elements can be deferred/decreased to make room for other needed investments?
6. What elements are missing or need additional investment to align with LRP/BDV?

Process and Conflict-of-Interest Posture

- Our subcommittee chosen to be broadly representative of the entire FES program
  - Members have received funding from specific lines … fully expected for experts
  - … but are not guaranteed funding → based on the strength of a given proposal
- Open discussion is encouraged, nobody “leaves the room”
  - We identify if we personally receive funding from a given program
- All members asked to take a **broad view of what’s best for overall program**
- We seek to work toward consensus
- Data collected through: community whitepapers, other reports, presentations, invited speakers, FES program manager input, discussions with Dr. JP Allain, draft text and comments (seen by full subcommittee), polling, discussion

Comment on the role of this “interim update”

Goal:

- Update FESAC members on our progress, process, and broad directions
- Solicit input from FESAC on targeted questions

Out of bounds:

- We will NOT be sharing any draft / candidate recommendations
- Please don’t ask us what we are “leaning towards” - it’s premature
- Our next presentation to FESAC will contain our subcommittee report and recommendations

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Overarching comment on needed resources

- Our community has incredible ambition and capability to deliver on the Bold Decadal Vision
  - With resources, coordination, and partnerships, we know we can go faster!

- But: we need to be **realistic** on the level of effort required to close the significant remaining science & technology gaps

- <u>Finding:</u>

  Bold budgets are needed to meet the **bold <u>decadal</u> vision**

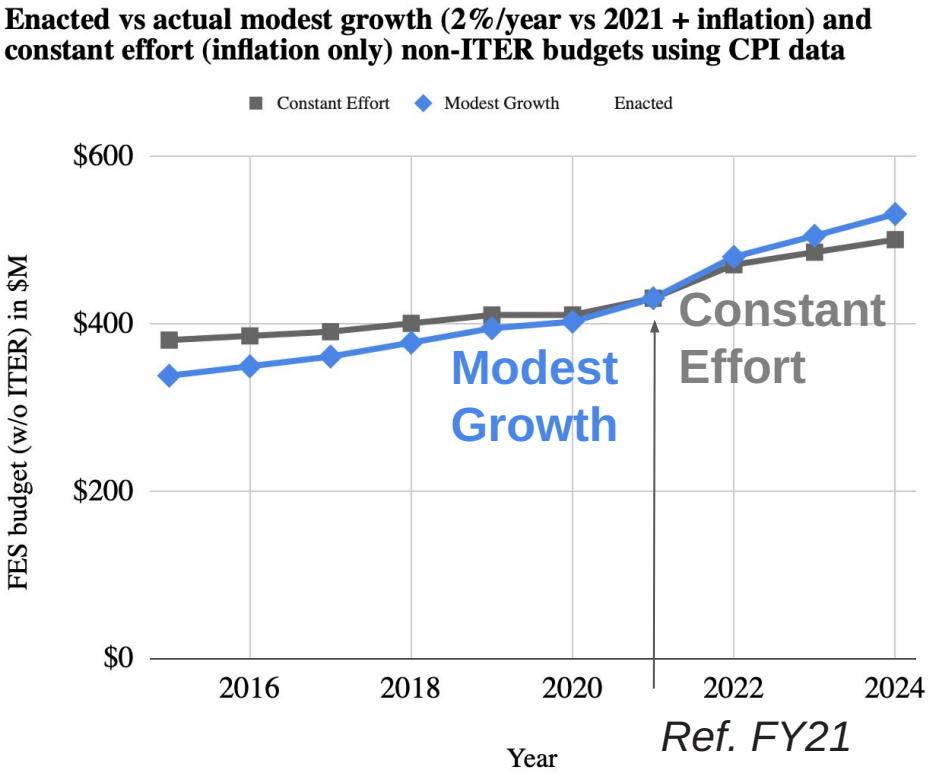
  ! Other fields and other countries have bold budgets !

The LRP considered several budget scenarios

- Constant Level of Effort → defined as matching inflation
- Modest Growth → defined as 2% + inflation
- Unconstrained → defined as “blue sky”

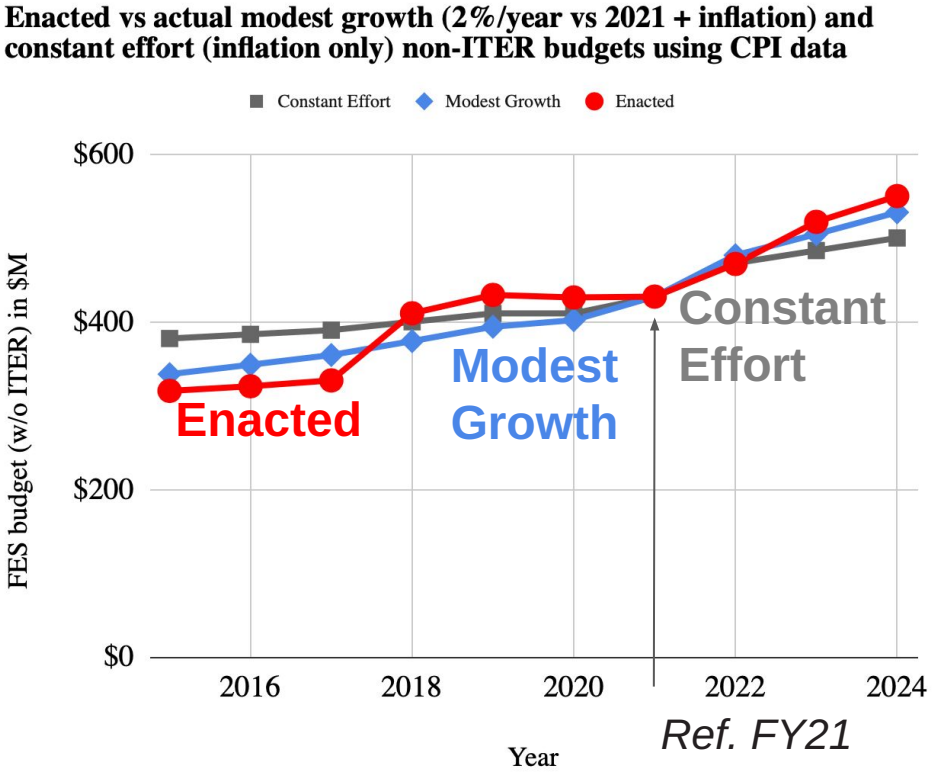
Which budget framework scenario of the LRP is most appropriate? (most realistic)?

Inflation has significantly modified budget landscape



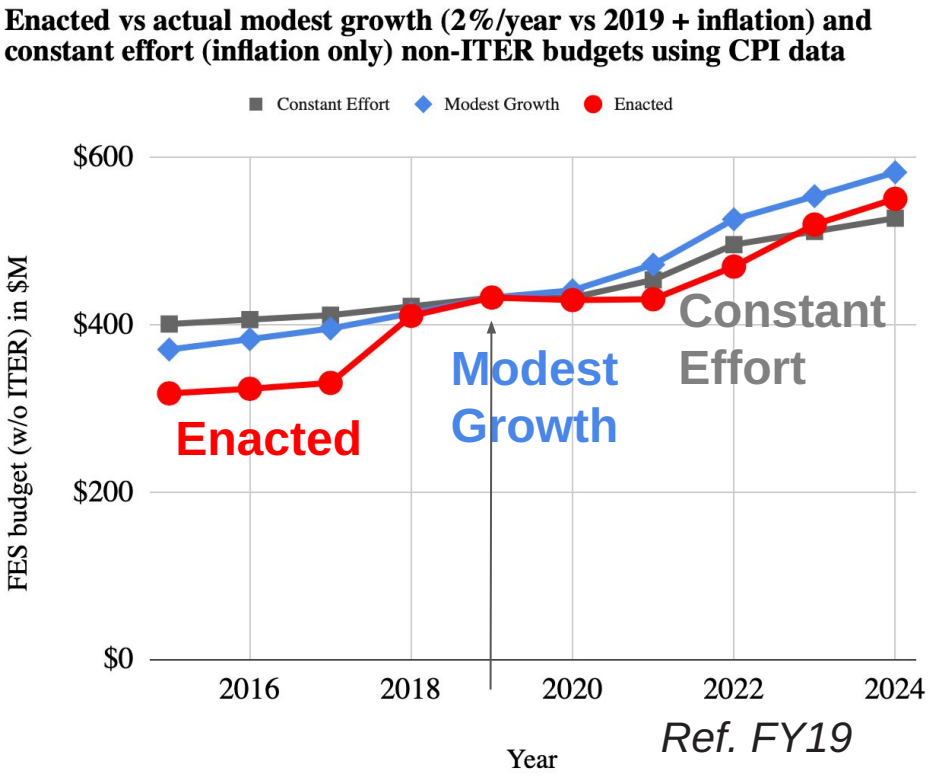
- Use LRP publication (FY21) as ref. point, non-ITER only
- Just to keep up with inflation, “constant effort” required sizable budget increases

Inflation has significantly modified budget landscape



- Use LRP publication (FY21) as ref. point, non-ITER only
- Just to keep up with inflation, "constant effort" required sizable budget increases
- Growth in budget is **closest to modest growth**
- We have not felt the increase:
  - Milestone, IFE hub, FIRE just starting
  - We have already felt inflation

Inflation has significantly modified budget landscape



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  - Milestone, IFE hub, FIRE just starting
  - We have already felt inflation
- Ref. FY19 (LRP ref. point), *not even modest*

The LRP clearly stated “modest growth” implications

“The return on the investment of the relatively small increment from the constant level of effort to the modest growth scenario is substantial. It accelerates the fusion energy mission and gives excellent science per incremental dollar by continuing to support the high-impact work being done across the program.”

LRP Page 46

The LRP clearly stated “modest growth” implications

“The return on the investment of the relatively small increment from the constant level of effort to the modest growth scenario is substantial. It accelerates the fusion energy mission and gives excellent science per incremental dollar by continuing to support the high-impact work being done across the program.”

“However, there are still significant costs incurred and opportunities missed in this scenario. Most notably, meeting the goal of FPP readiness by the 2040s remains highly unlikely, significant reductions to the US tokamak program are still required, and some important time-sensitive opportunities for US leadership such as construction of MEC-Upgrade cannot be acted upon.”

LRP Page 46

APS-DPP Community Plan: Transition Highlighted

"The community recognizes that designing and constructing major new facilities may not be possible without progressively redirecting resources from existing facilities. Given the possibility of constrained budgets, there is significant support among the community to pivot resources from existing facilities to fund new programs and facilities, if necessary, so that new facilities can be operational within ten years or less. The resources and research programs of existing facilities should immediately evolve to reflect the priorities of this plan. Any such transition must be mindful of the workforce needs and impacts associated with diverting operations budgets to construction."

CPP Page 46
LRP Page 41

We plan to stay consistent with LRP

- LRP represents incredible effort and strong community consensus
- Difficult discussions and decisions were taken, we won't re-litigate
- Any deviations will be explained, in light of recent developments:
  - Significant growth of the fusion private sector (>$7B in recent years)
  - Ignition @ NIF and advances in the IFE physics basis
  - FESAC Facilities Construction Projects Report
  - Bold Decadal Vision
  - Delays at ITER

LRP provides a framework for our deliberations

Portfolio Elements	Scenarios: Constant Level of Effort — Significant loss of US leadership & significant missed opportunities	Scenarios: Modest Growth — Loss of US leadership & missed opportunities
Research, Operations, and Small Scale Construction		
FM&T Programs	Yes, enhance	Yes, enhance
US Tokamak Operations and Research	Yes, but reduce	Yes, but reduce
Stellarator and Alternates Operations and Research	Yes, but flat	Yes
IFE program	Yes, but limited	Yes, but limited
FPP Design Effort	Yes, but limited	Yes
GPS Program	Yes, but reduce modestly	Yes
HEDP Program	Yes, but reduce modestly	Yes
Plasma-Based Technology Program	Yes, but limited	Yes
Theory and Computation	Yes	Yes

Our deliberations thus far are preliminary, but consistent with LRP framework

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← Now emphasized in the DOE Milestone Program

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← Other areas are not dramatically adjusted

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← Missed opportunities and lost leadership

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← FES user facility research & operations impacted

← Now emphasized in the DOE Milestone Program

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The science of “Sustain a Burning Plasma” remains essential

- Before we elaborate on FM&T, we re-affirm that the science of burning plasmas remain an essential part of our program

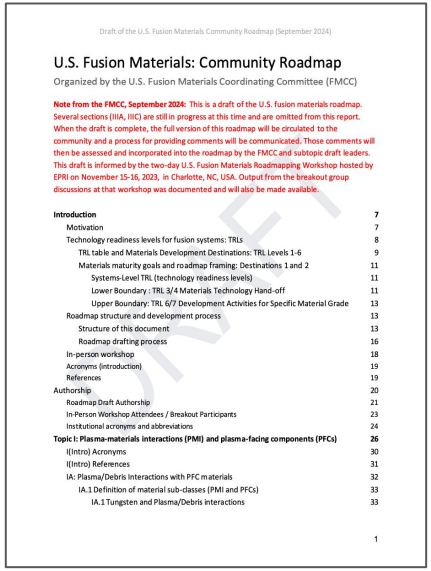
The plasma physics is not “done”

- Investments in FM&T are essential to sustain a burning plasma, and FM&T weaves throughout the LRP science drivers

- Our charge is focused on FM&T, so we will focus on it here

Fusion Materials & Technology: The Next Frontier

- Broad recognition among the community that significant low TRL mission critical elements remain in this category
- Several community efforts actively defining programmatic scope


Draft of the U.S. Fusion Materials Community Roadmap (September 2024)

U.S. Fusion Materials: Community Roadmap

Organized by the U.S. Fusion Materials Coordinating Committee (FMCC)

Note from the FMCC, September 2024: This is a draft of the U.S. fusion materials roadmap. Several sections (IIIA, IIIC) are still in progress at this time and are omitted from this report. When the draft is complete, the full version of this roadmap will be circulated to the community and a process for providing comments will be communicated. Those comments will then be assessed and incorporated into the roadmap by the FMCC and subtopic draft leaders. This draft is informed by the two-day U.S. Fusion Materials Roadmapping Workshop hosted by EPRI on November 15-16, 2023, in Charlotte, NC, USA. Output from the breakout group discussions at that workshop was documented and will also be made available.

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Motivation 7
Technology readiness levels for fusion systems: TRLs 8
TRL table and Materials Development Destinations: TRL Levels 1-6 9
Materials maturity goals and roadmap framing: Destinations 1 and 2 11
Systems-Level TRL (technology readiness levels) 11
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I(Intro) Acronyms 30
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IA: Plasma/Debris Interactions with PFC materials 32
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IA.1 Tungsten and Plasma/Debris interactions 33

1


EPRI

2024 TECHNICAL UPDATE

Fusion Blankets Research Objectives

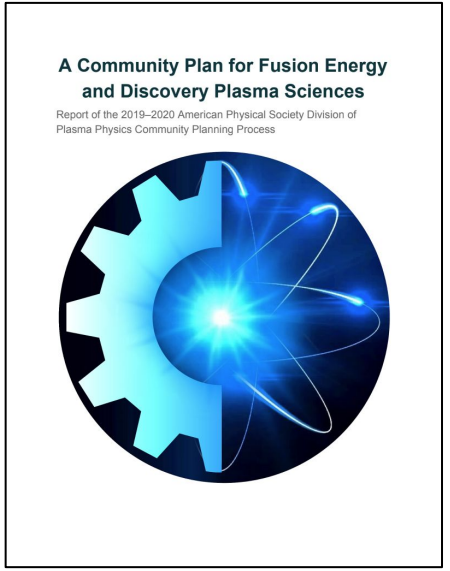
Results from the 2023 Fusion Blankets Workshop


EPRI

2024 TECHNICAL UPDATE

Fusion Fuel Cycles Research Objectives

Results from the 2023 Fusion Fuel Cycles Workshop


A Community Plan for Fusion Energy and Discovery Plasma Sciences

Report of the 2019–2020 American Physical Society Division of Plasma Physics Community Planning Process

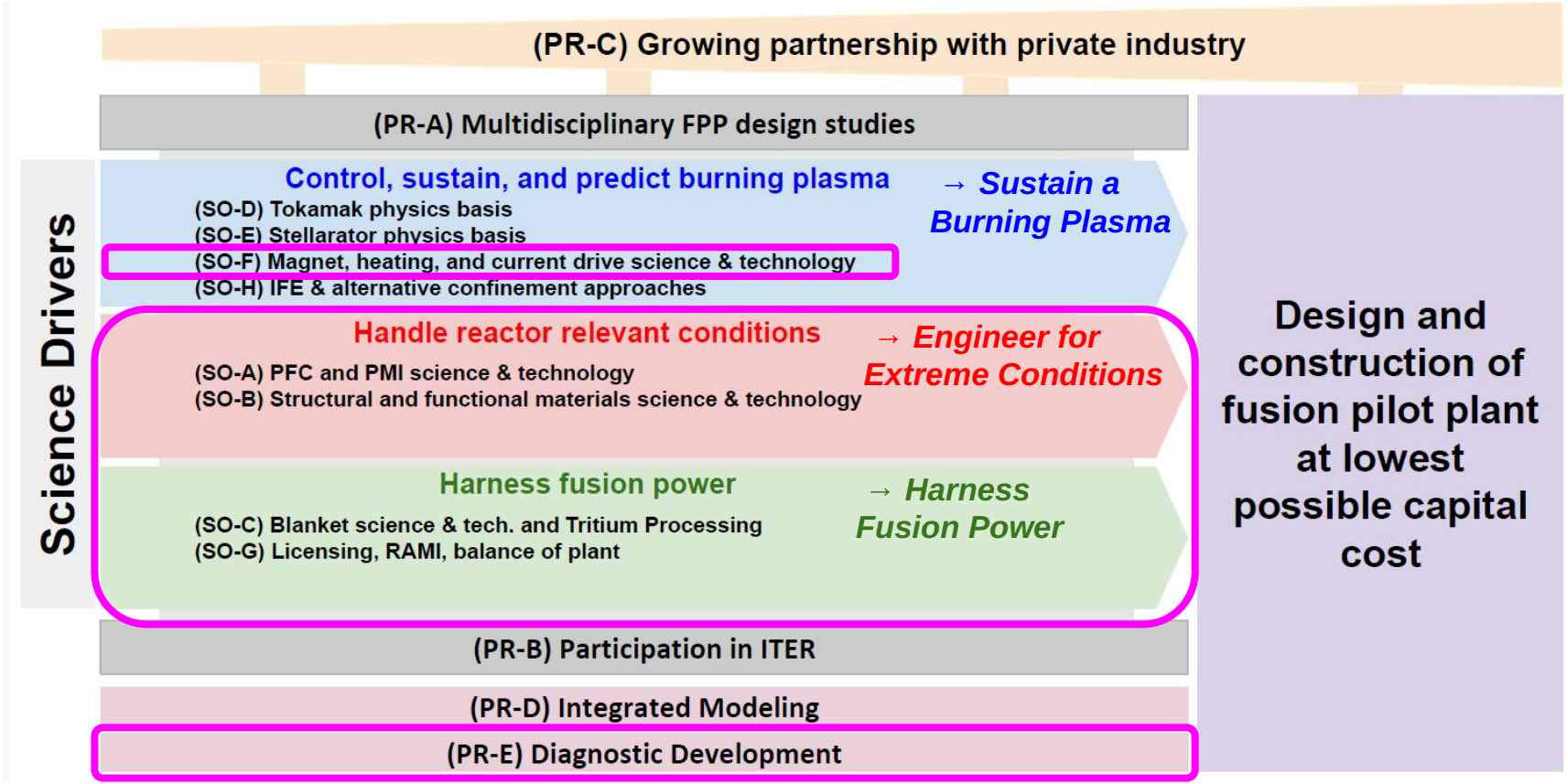
Example: TRL for Plasma/Debris Interaction PMI/PFC

- Similar tables can be created for other areas of FM&T research
- The goal of these slides is to communicate how we are considering FM&T

PMI/PFC operational challenge (solids)	W W composites	SiC SiC/SiC CMCs	UHTCs	CFCs
Erosion • Surface chemistry effects like wall conditioning • Importance of charge exchange neutrals	1	1	2	3
H/D/T retention • Bulk/operating temperature • Co-deposition	1	2	2	3
Heat flux management • Steady-state vs. transient • Thermal mechanical response • Cracking	1	2	2	3
Oxidation behavior	2	2	3	3
Combined loading conditions (inclusive of neutron effects)	3	3	3	3
Impact on design of He pumping strategy • cryo-pumping • pumping solutions for fusion ash	3	3	3	3
Lifetime assessment	3	2	3	3
Impurity/material movement (slag, dust) formation and impact on fusion performance, safety	1	1	3	3

Source: US Fusion Materials Community Roadmap, page 32

We're structuring FM&T gaps by CPP Strategic Objectives (SOs)



Source: CPP Presentation to FESAC, Mar 2020

Summary of FM&T Directions in the CPP Report

- SO-F: Magnets, Heating and Current Drive, Material Injection
- SO-A: PFC and PMI science & technology
  - Solid PFC development, liquid PFC development, materials cross-cuts
- SO-B: Structural and functional materials science & technology
  - Neutron effects on materials, next-generation materials, design criteria database
- SO-C: Blankets science & tech, Fuel Cycle
  - Blanket material fundamentals & nuclear science: solid and liquid breeders
  - Tritium science and technology: fundamentals and devices
- SO-G: Licensing, RAMI, Balance of Plant
- PR-E: Diagnostic Development

IFE Basic Research Needs incorporated into FM&T

- SO-F: Magnets, Heating and Current Drive, Material Injection
  - **Driver development:**
    - Advancing diode efficiency, reliability, and mean-time-to-failure; broad bandwidth
    - Increase the damage threshold of optics and crystals
    - Solid-state technology for high-power switching and capacitor energy storage
  - **Target development:**
    - Mass production techniques, accurate target engagement: injector and tracking
    - Cryogenic targets at reactor-relevant rep-rates & under harsh conditions
- SO-A + B: PFC / PMI & Structural Materials:
  - Dynamic effects of pulsed irradiation/damage, high cyclic loading
  - Pulsed X-ray and high energy ion effects on surface ablation
- SO-C: Blankets science & tech, Fuel Cycle
  - Different impurity profile in an IFE system (i.e., potential capsule debris)
- PR-E: Diagnostic Development
  - High rep-rate pulsed measurement systems & radiation/electromagnetic-hardened

Source: 2023 IFE BRN

Where do our Existing User Facilities Advance FM&T?

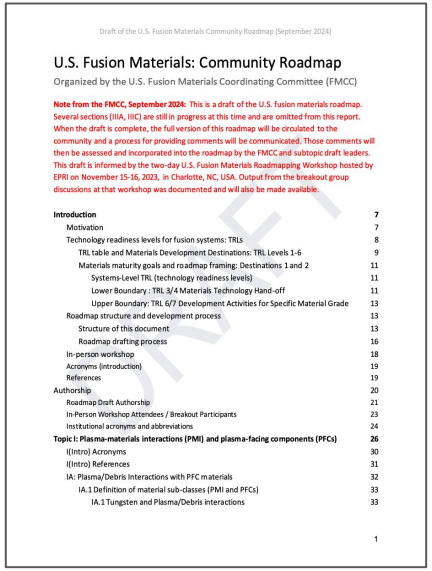
- SO-F: Magnets, Heating and Current Drive, Material Injection
  - Interface with high-temperature plasma provides increased TRL maturation
  - Unexpected plasma phenomena may arise that impacts technical readiness level
- SO-A: PFC and PMI science & technology
  - Several low-TRL elements directly related to plasma (PMI) behaviour at high fluxes
- SO-B: Structural and functional materials science & technology
- SO-C: Blankets science & tech, Fuel Cycle
- SO-G: Licensing, RAMI, Balance of Plant
- PR-E: Diagnostic Development
  - High-temperature plasma provides fields and emissions representative of an FPP

Where do our Existing User Facilities NOT Advance FM&T?

- SO-F: Magnets, Heating and Current Drive, Material Injection
  - Magnet technology of our FES user facilities is not extrapolable
  - Test stands are appropriate for several facets of enabling technology
- SO-A: PFC and PMI science & technology
  - Our facilities do not assess long-term material degradation or neutron damage
  - Test stands are appropriate for several facets of PMI/PFC development
- SO-B: Structural and functional materials science & technology
  - Due to insufficient neutron generation, our FES facilities cannot test these materials
- SO-C: Blankets science & tech, Fuel Cycle
  - Our FES user facilities were never intended to do this work
- SO-G: Licensing, RAMI, Balance of Plant
  - Our FES user facilities were never intended to do this work
- PR-E: Diagnostic Development
  - Harsh environment of an FPP not accurately reproduced

What are the major opportunities in FM&T?

- We are relying on the community reports to define the important objectives
- FIRE Collaboratives, other solicitations have recently appeared



Draft of the U.S. Fusion Materials Community Roadmap (September 2024)

U.S. Fusion Materials: Community Roadmap

Organized by the U.S. Fusion Materials Coordinating Committee (FMCC)

Note from the FMCC, September 2024: This is a draft of the U.S. fusion materials roadmap. Several sections (IIIA, IIIC) are still in progress at this time and are omitted from this report. When the draft is complete, the full version of this roadmap will be circulated to the community and a process for providing comments will be communicated. Those comments will then be assessed and incorporated into the roadmap by the FMCC and subtopic draft leaders. This draft is informed by the two-day U.S. Fusion Materials Roadmapping Workshop hosted by EPRI on November 15-16, 2023, in Charlotte, NC, USA. Output from the breakout group discussions at that workshop was documented and will also be made available.

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EPRI

2024 TECHNICAL UPDATE

Fusion Blankets Research Objectives

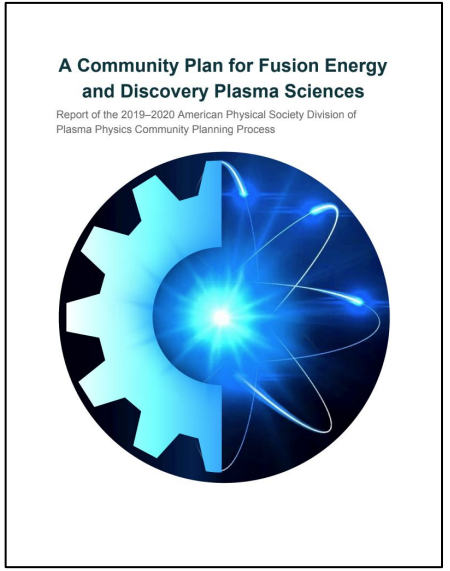
Results from the 2023 Fusion Blankets Workshop

EPRI

2024 TECHNICAL UPDATE

Fusion Fuel Cycles Research Objectives

Results from the 2023 Fusion Fuel Cycles Workshop



A Community Plan for Fusion Energy and Discovery Plasma Sciences

Report of the 2019–2020 American Physical Society Division of Plasma Physics Community Planning Process

Building bridges to close FM&T gaps

“The least developed domain in the mission portfolio is in FM&T. Fulfilling the energy mission demands a shift in balance of research toward FM&T.” - LRP p. 6

Questions to FESAC:

Are the FM&T opportunities well-captured in the community and FESAC facilities reports?

Other opportunities in FM&T: New Facilities

- FESAC Facilities Construction Projects Subcommittee labored throughout the spring and came to a strong consensus on:

- Three facilities beyond ITER that "Best Serve Fusion"
  - Blanket Component Test Facility (BCTF)
  - Fuel Cycle Test Facility (FCTF)
  - Fusion Prototypic Neutron Source (FPNS)

- These facilities will not be realized without significantly increasing emphasis and budget for FM&T programs
  - Concept maturation and cost estimation required to assess readiness

Presentation Outline

- Reminder of our Subcommittee and our Charge
- Process, Timeline, and Community Input
- Framework Provided by the FESAC Long-Range Plan
- Discussion of FM&T Directions and Opportunities
- Considerations of Workforce Continuity
- Public-Private Partnerships
- Q&A and FESAC Discussion

Workforce continuity is being taken seriously

- Our charge clearly indicates emphasis on workforce continuity:

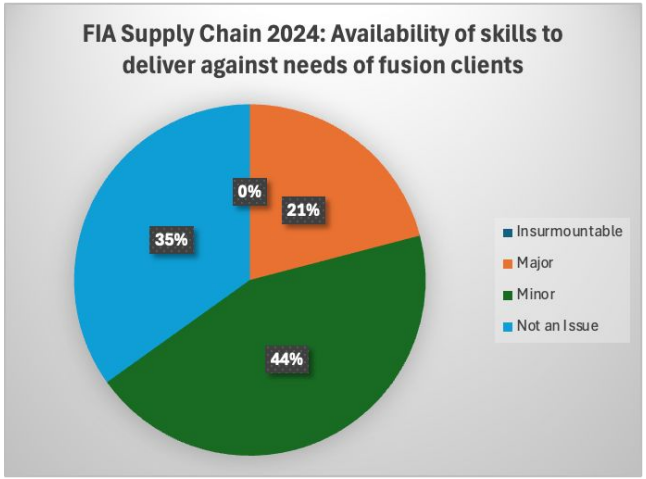
> ***In your deliberations, you should consider the impact of your recommendations on workforce continuity, diversity of the workforce, and continuing U.S. leadership in fusion and plasma science***

- A growing fusion program should offer opportunities for performers
- We're considering these areas as workforce continuity vehicles
  - Public-Private Partnerships & Private Facility Research
  - International Collaborations
  - Transitioning into FM&T programs

We invite feedback from FESAC on this important question

Continuity of workforce with Public-Private Partnerships

- Bulk of U.S. fusion knowledge lies in the public programs
  - Programs that prioritize open science are mostly likely to attract public sector participation
- INFUSE and Milestone recipients benefit from senior public sector SMEs to advance commercial interests
  - These programs do not incentivize early career workforce development but may provide opportunities for workforce continuity
- Private facilities research** (PFR) prioritizes open science benefiting public program
  - PFR could incentivize workforce development initiatives and workforce continuity



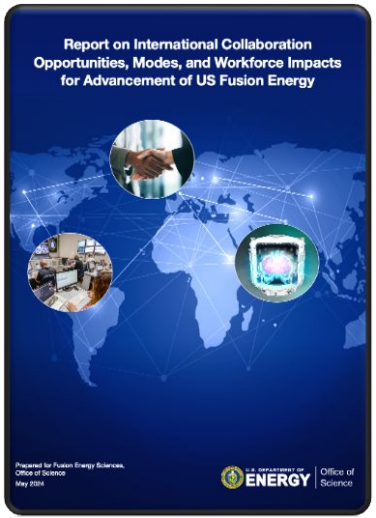
Workforce development will be crucial to large scale fusion energy production. Governments, universities, and companies need to invest in strategic workforce development initiatives to support this growing demand. - FIA 2024

**PFR: FES-funded research exploiting unique capabilities of private-sector facilities

Continuity of workforce with international opportunities

- International programs are leaping ahead with new, unique facilities[1] and capabilities
  - U.S. participation in int'l programs provides return on experience currently unavailable in U.S.
- International opportunities span the FST science drivers
  - Community reports[2] emphasize establishing international agreements, close coordination, efficiency
- International collaborations can provide near-term opportunities for workforce continuity and evolution
  - U.S. bilateral agreements could expand to include technology programs
  - A *temporary* solution, not a replacement for a vibrant domestic program

International Partnerships in a New Era of Fusion Energy Development



Int'l Benchmark recommendations R5-5→R5-7 suggest private sector engagement, technical and engineering topic focus, and long-term visas are opportunities

[1] FESAC FCP report
[2] EPRI Fuel Cycle and Blanket Research Objectives

Continuity of workforce with upskilling for FM&T

- Increased interdisciplinary workforce beyond typical plasma/fusion curriculum is needed to recover lost art in areas of past U.S. leadership** to address FM&T gaps
  - Includes range of training (technician to PhD)
  - Includes re/up-skilling
  - RENEW and FAIR are welcome initiatives to diversify the workforce
- "Traditional" plasma/fusion scientists are willing and able to contribute and achieve leadership in enabling fusion technologies
  - Additional test stands would be needed to develop/upskill the workforce and increases diversity of expertise
  - Includes SBIR/STTR

A low level of sustained investment… has resulted in knowledge gaps arising from lack of familiarity with early R&D work in the field; a concerted knowledge retention and transfer effort is needed to address this

** Engineering designs, manufacturing, fusion safety

Building bridges to ensure workforce continuity

“The success of this strategic plan requires innovation, creativity, and a multidisciplinary and diverse workforce.” - LRP p. 62

Question to FESAC:

What are additional considerations for framing how to think about workforce continuity?

Presentation Outline

- Reminder of our Subcommittee and our Charge
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- Considerations of Workforce Continuity
- Public-Private Partnerships
- Q&A and FESAC Discussion

Additional charge element: PPP Modalities

- Our charge includes an opportunity to advise DOE-FES on the ongoing efforts towards advancing public-private partnerships:

> ***"In addition, the subcommittee should identify the role of the public sector … in … advancing commercial fusion applications going forward"***

- Since the FESAC LRP and NASEM reports, significant increase in private investment to over $7B, mostly to US companies

- We plan a dedicated effort to provide timely input on this topic

We also thank the community for their white paper input

Spectrum of PPPs activities being considered

- **Private Facility Research**: DOE funding of performers to exploit unique capabilities available at private sector facilities
- **Public-Private Consortium Framework**: New initiative in development with recent a Request for Information call
- **INFUSE**: Voucher program supporting access to key performers at national labs and universities by the private sector
- **Milestone Program:** Direct DOE funding to companies upon completion of key milestones, allowing cost-recovery

Our broad goals in the PPP Modalities section:

- Provide additional input on programs that are not yet fully formed
- Provide input on how to prioritize scarce DOE resources among these different programs
- Provide comments on the role of our FES user facilities for PPP
- Provide comments on the use of private facilities for FM&T gap closure, workforce development

Building bridges toward FPPs through PPPs

“Strategic PPPs can be effective in resolving common technical problems that face fusion and plasma science, in creating a competitive energy source in the US market, and in developing technologies that use plasma processes.” - LRP p. 55

Question to FESAC:

Are we missing any topics for our consideration of PPP modalities?

Summary and Conclusions

- Our process and deliberations are now well underway
  - *We **greatly value** all the community input received thus far*

We've highlighted a few questions for discussion during this meeting:

- Are the FM&T opportunities well-captured in the community and FESAC facilities panel reports?
- What are additional considerations for framing how to think about workforce continuity?
- Are we missing any topics for our consideration of PPP modalities?

We look forward to providing FESAC with our consensus recommendations at the conclusion of our process

Bonus Slides

Community Input available at the FESAC DP Website

https://sites.google.com/view/fesacdpsubcommittee/home

Bonus: What is the Bold Decadal Vision to us ?

- Per the FES strategy 2024 document, guided by the 2021 National Academies report Bringing Fusion to the U.S. Grid and informed by the 2020 DOE Fusion Energy Sciences Advisory Committee (FESAC) Long-Range Plan (LRP), the Bold Decadal Vision aims to **leverage public-private partnerships (PPPs) to**:
  1. Accelerate fusion energy R&D to enable commercially relevant fusion pilot plants (FPP).
  2. Demonstrate an operating fusion pilot plant, led by the private sector, in the 2030s.
  3. Prepare the path to enable aggressive commercial fusion deployment scale-up.
  4. Ensure that fusion energy is developed and deployed equitably, stimulating economic development across diverse communities.
- DOE defines a fusion pilot plant (FPP) as producing greater than 50 MW of net electricity for at least 3 continuous hours with a timely path to 1 full-power year, at a capital cost that will attract private investors and commercialization partners (adapted from the National Academies report Bringing Fusion to the U.S. Grid)