FESAC
Facilities Construction Projects
Report to FESAC

Apr 30, 2024

Presented by:
Prof. Brian Wirth (chair), Prof. Carlos Paz-Soldan (vice-chair)

Outline of Presentation

Process used by the Subcommittee to respond to Dr. Berhe’s charge

Cross-Cuts

Description of ‘Best Serves Fusion’ Facilities

Individual Facility Reports

Dr. Berhe's Charge

Department of Energy
Office of Science
Washington, DC 20585

Office of the Director

December 1, 2023

To: CHAIRS OF THE OFFICE OF SCIENCE FEDERAL ADVISORY COMMITTEES:
Advanced Scientific Computing Advisory Committee
Basic Energy Sciences Advisory Committee
Biological and Environmental Research Advisory Committee
Fusion Energy Sciences Advisory Committee
High Energy Physics Advisory Panel
Nuclear Science Advisory Committee

The Department of Energy's Office of Science (SC) has envisioned, designed, constructed, and operated many of the premiere scientific research facilities in the world. More than 38,000 researchers from universities, other government agencies, and private industry use SC User Facilities each year—and this number continues to grow.

Stewarding these facilities for the benefit of science is at the core of our mission and is part of our unique contribution to our Nation's scientific strength. It is important that we continue to do what we do best: build facilities that create institutional capacity for strengthening multidisciplinary science, provide world class research tools that attract the best minds, create new capabilities for exploring the frontiers of the natural and physical sciences, and stimulate scientific discovery through computer simulation of complex systems.

To this end, I am asking the SC advisory committees to look toward the scientific horizon and identify what new or upgraded facilities will best serve our needs in the next ten years (2024-2034). More specifically, I am charging each advisory committee to establish a subcommittee to:

1. Consider what new or upgraded facilities in your disciplines will be necessary to position the Office of Science at the forefront of scientific discovery. The Office of Science Associate Directors have prepared a list of proposed projects that could contribute to world leading science in their respective programs in the next ten years. The Designated Federal Officer (DFO) will transmit this material to their respective advisory committee chairs. The subcommittee may revise the list in consultation with their DFO and Committee Chair. If you wish to add projects, please consider only those that require a minimum investment of $100 million. In its deliberations, the subcommittee should reference relevant strategic planning documents and decadal studies.

2. Deliver a short letter report that discusses each of these facilities in terms of the two criteria below and provide a short justification for the categorization, but do not rank order them:

   a. **The potential to contribute to world-leading science in the next decade.** For each proposed facility/upgrade consider, for example, the extent to which it would answer the most important scientific questions; whether there are other ways or other facilities that would be able to answer these questions; whether the facility would contribute to many or few areas of research and especially whether the facility will address needs of the broad community of users including those whose research is supported by other Federal agencies; whether construction of the facility will create new synergies within a field or among fields of research; and what level of demand exists within the (sometimes many) scientific communities that use the facility. **Please place each facility or upgrade in one of four categories: (a) absolutely central; (b) important; (c) lower priority; or (d) don't know enough yet.**

   b. **The readiness for construction.** For proposed facilities and major upgrades, please consider, for example, whether the concept of the facility has been formally studied; the level of confidence that the technical challenges involved in building the facility can be met; the sufficiency of R&D performed to date to assure technical feasibility of the facility; the extent to which the cost to build and operate the facility is understood; and site infrastructure readiness. **Please place each facility in one of three categories: (a) ready to initiate construction; (b) significant scientific/engineering challenges to resolve before initiating construction; or (c) mission and technical requirements not yet fully defined.**

Many additional criteria, such as expected funding levels, are important when considering a possible portfolio of future facilities, however, for this assessment I ask that you focus your report on the two criteria discussed above.

I look forward to hearing your findings and thank you for your help with this important task. I appreciate receiving your final report by May 2024.

Sincerely,

Asmeret Asefaw Berhe

Asmeret Asefaw Berhe
Director, Office of Science

Sub-Committee Members - Big Thank You!

Prof. Brian Wirth, U. of Tennessee - Knoxville (Chair)

Prof. Carlos Paz-Soldan, Columbia University (Vice-Chair)

Dr. Felicie Albert, Lawrence Livermore National Laboratory

Mr. David Babineau, Savannah River National Laboratory

Dr. Kate Bell, Sandia National Laboratories

Dr. Cami Collins, Oak Ridge National Laboratory

Prof. Evdokiya Kostadinova, Auburn University

Dr. Rajesh Maingi, Princeton Plasma Physics Laboratory

Prof. Jaime Marian, U. of California - Los Angeles

Dr. Thomas Sunn Pedersen, Type One Energy

Dr. Erica Salazar, Commonwealth Fusion Systems

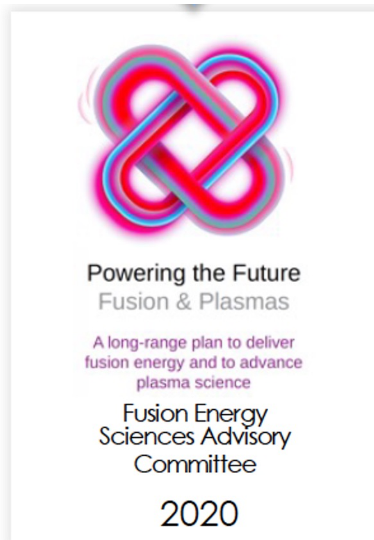
Dr. Chase Taylor, Idaho National Laboratory

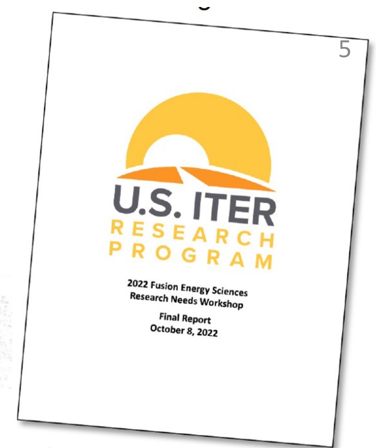
Dr. Kathreen Thome, General Atomics

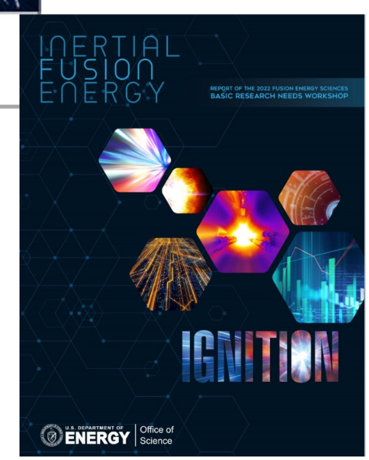
Prof. Troy Carter, U. of California - Los Angeles (ex-officio)

Prof. Anne White, Massachusetts Institute of Technology (ex-officio)

Prior reports & recent events informed our discussions







2022 Whitehouse event to launch 'Bold Decadal Vision' and milestone-based public-private partnerships

2022 & 2023 demonstrations of fusion scientific gain from IFE in the US & 69 MJ fusion heating over 6 seconds in the UK

Process - Call for White Papers

The Subcommittee chairs issued a call for white papers on January 16, 2024 that requested submissions by 12 February 2024. The full Subcommittee announced a plan to hold community webinars to gather information about the facilities

We received **40** whitepapers spanning the range of the facilities provided in FES list, and many that proposed new facilities

- *We thank the community for their comprehensive & input, prepared in a short timescale!*

Based on the white paper input:

- Several facilities < $100M proposed, but our charge indicated: "*please consider only those [facilities] that require a minimum investment of $100M*"
- We acknowledge receipt of those facilities, many of which are well aligned with the LRP and can positively impact fusion energy and fundamental fusion plasma science

We were provided the "FES List" of 10 Facilities:

The "FES List" is Public
- *available on FESAC's website*

BCTF (Blanket Component Test Facility)
DIII-D (eXcite) Upgrade
FCTF (Fuel Cycle Test Facility)
FIRST (Fusion Integration Research and Science Test Facility)
FPNS (Fusion Prototypic Neutron Source)
HHF (High Heat Flux Facility)
ITER
MEC-U (Matter in Extreme Conditions Petawatt Laser Upgrade)
NSTX-U LMCE (NSTX-U Liquid Metal Core Edge Facility)
Midscale Stellarator

Two facilities were added by the committee:
EXCITE Options
New Inertial Fusion Energy (IFE) Concepts and Upgrades

Charge to subcommittee specified to (only) evaluate upgrades to existing facilities

Process - Webinars

One webinar per facility was held and advertised to the community
One or two per week from Mid-February to early April.

Speakers selected based on white paper submissions

Included a "community overview" with consensus elements whenever feasible

Q&A done in the open, community Q&A also included

Essential element of our process as a sub-committee

WE THANK THE ORAU/ORISE TEAM for the technical support of these webinars !

WE THANK THE COMMUNITY FOR THEIR INPUT !

Process - Conflict of Interest (COI) & Consensus

In consultation with FES Designated Federal Official (DFO), the Subcommittee Chair and Vice-Chair defined a process to address COI.

- Members self-identified COI based on affiliation and/or research and service activities with an existing or proposed facility.
- Subcommittee Chair and Vice-Chair assigned Primary and Secondary reviewers for each facility, ensuring COI/pCOI was avoided.
- Primary/Secondary reviewers led discussion in Subcommittee meetings to identify additional questions remaining after webinar, and to draft the additional facility writeup and 'strawman' answer to charge Questions 2a & 2b.

- All members of the Subcommittee participated in all facility discussions and contributed to the development of consensus assessment and report!
- Important that 'every voice is heard' and that no Subcommittee members felt regret that they did not have a chance to voice their opinion(s) – this led us to consensus

Decision to broaden the definition of charge question 2a & categorize facilities that 'Best Serve Fusion'

• Based on the FESAC LRP recommendation to '*move aggressively toward the deployment of fusion energy*', along with the BDV and the rapid growth of a strong private fusion sector, the Subcommittee chose to broaden the definition of Question 2a.

• Thus, in our evaluation and short letter report, we have added 'and/or close fusion technology gaps' to Question 2a. Our evaluation of this question is thus, "***Potential to contribute to world-leading science and/or close fusion technology gaps***".

- This was discussed and approved by Dr. Jean-Paul Allain, the Subcommittee DFO and FES Associate Director

• Further, the subcommittee felt that our report would be more useful to DOE and the fusion community if we categorized which facilities "Best serve fusion energy/fusion science and the BDV"

Criteria to Identify Facilities that:
'Best Serve Fusion and the Bold Decadal Vision'

- Urgency of timeline with decadal impact on fusion industry/science;
- Alignment with FESAC LRP and BDV;
- Response to Charge Questions 2a/2b;
- Opportunities for partnerships that could accelerate timeline and/or reduce costs;
- Technology gaps that would be closed by a facility and/or contribution to world-leading fusion science

These criteria were applied holistically to our evaluation and also incorporated a preference for facilities that supported multiple fusion power plant concepts

No predetermined number of facilities in this category

Report Cross-Cuts

Facilities that Best Serve Fusion

A strong consensus was developed in the Subcommittee that four facilities 'Best Serve Fusion' (in alphabetical order): BCTF, FCTF, FPNS, and ITER.

- Each of these facilities support multiple pathways to fusion energy, including ITER which has/will provide knowledge transfer about fusion technology & engineering experience at reactor scale, including system integration, precision engineering and quality control

The other eight facilities were all deemed 'important' (in response to Q2a). Many of these facilities were associated with single-concept fusion confinement approaches

These facilities are highly important and well-deserving of FES support

The readiness for construction varied significantly between all facilities

Leveraging of Partnerships for Facilities

Comment: FES alone cannot afford the full range of important facilities

The committee identified several modalities to leverage partnerships to accelerate readiness for construction and share costs

Leveraging <u>other agencies</u> (NNSA, BES, NSF) for mission-adjacent work

Leveraging <u>Public-Private Partnerships</u> for concept-specific facilities

Leveraging <u>International Partnerships</u> where strategically relevant

Closing the ITEP-equivalent gap

Several facilities seek to close facets of the "ITEP-equivalent" gap

ITEP = Integrated <<Tokamak>> Exhaust and Performance

As stated in LRP: *"Closing the [ITEP-equivalent] gap is necessary to ensure FPP readiness"*

An ITEP-equivalent gap must be closed for any MFE concept

Each of the proposed single plasma core concept confinement facilities closing ITEP-equivalent gaps are very (b) important and well-deserve FES support

‘Best-Served’ Facility Reports

presented alphabetically

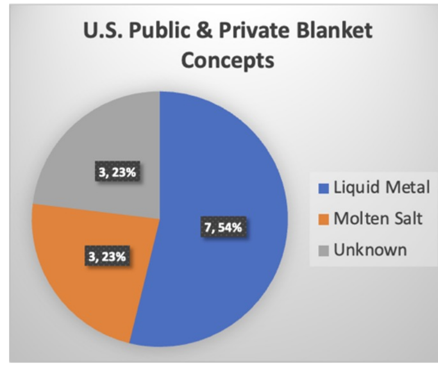
Dr. Berhe’s charge stated:

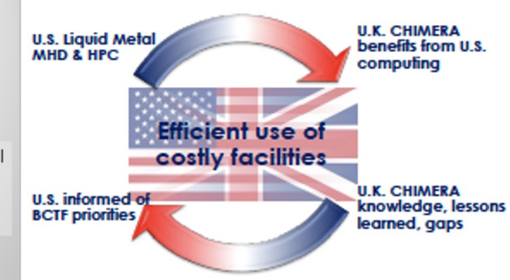
“I am asking the SC advisory committees to look toward the scientific horizon and identify what new or upgraded facilities will ***best serve*** our needs in the next ten years”

Blanket Component Test Facility (BCTF)

BCTF(s) will test blankets and associated systems for FPP designs

- Blanket functions: thermal management, tritium breeding, and shielding
- Multiple options proposed: flexible BCTF vs. single-purpose; nuclear vs. non-nuclear capable.





Potential to contribute to world-leading science &/or close fusion technology gaps

(a) absolutely central

- BCTF(s) is well-aligned with the recommendations and plans laid out in the CPP, the FESAC LRP, the NASEM report, and BDV.
- Several BCTF designs make strong contribution to close various technology gaps, depending on details of the design
    - The US is not participating in the ITER TBM program, underscoring the need for a dedicated BCTF(s).
    - A flexible, public BCTF and one or more private targeted BCTFs may be needed for timely progress. A public, flexible BCTF would support many users in engineering science. A targeted BCTF would serve to focus effort on R&D questions for specific designs of mutual interest to the public and private sectors.
    - There is a good opportunity for US leadership in a nuclear-capable BCTF, and through collaboration with the UK CHIMERA facility.

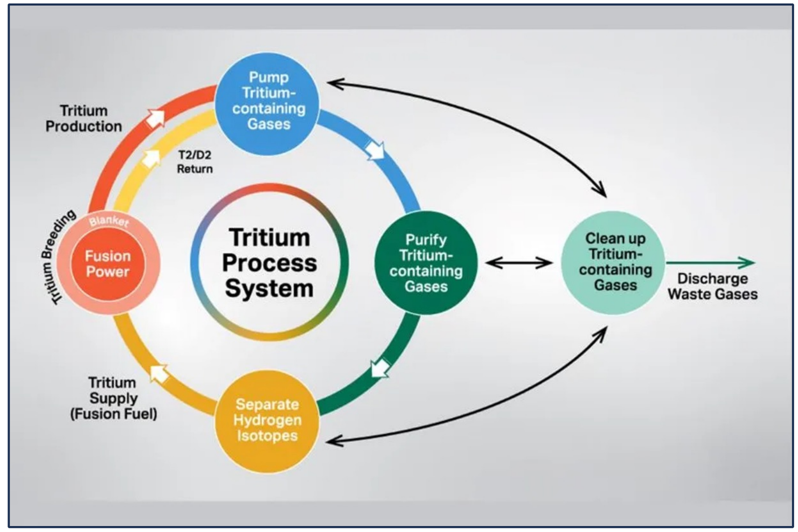
Readiness for construction

(b) significant scientific/engineering challenges to resolve before initiating construction (for non-nuclear BCTF option with trace tritium)**,**
(c) mission and technical requirements not yet fully defined (for nuclear BCTF options)

- Single-purpose, non-nuclear BCTF designs favored by private companies may be more advanced, but are not yet ready for construction via a PPP. However the urgency to advance TRLs underscores the value of a PPP here.
- A design for a multi-purpose, nuclear-capable BCTF has not been initiated, so the engineering questions are not fully identified. One strength in a multi-purpose BCTF is to develop/deploy common elements for various designs.

Fuel Cycle Test Facility (FCTF)

- Facility focused on developing fuel cycle technologies and advancing them to a sufficient TRL level needed for a fusion pilot plant (FPP)
- FCTF will ultimately need to be able to handle sufficient amounts of tritium and allow for full scale processing rates that are orders of magnitude higher than state of the art.
- Provide flexibility to allow testing of multiple technologies and subsystems and support a broad range of fusion concepts
- Facility can utilize non-radiological (with deuterium and protium) and radiological (with tritium handling) capabilities, ideally co-located and operated by the same teams.



Connection to LRP & BDV, and ability to support/leverage private sector & partnerships

- Aligned w/ LRP which emphasizes need for more Tritium research.
- Supports BDV because private sector will use FCTF to develop FPPs and facility will develop workforce to support industry
- Aligned with NASEM report fusion on the grid

Potential to contribute to world-leading science &/or close fusion technology gaps

(a) absolutely central

- A FCTF is critical for the DT fuel cycle. All 8 awardees of DOE milestone program have DT fuel cycle.
- Opportune time and need to make progress on fuel cycle, moving beyond ITER to modernize and scale technology for private sector.

Readiness for construction

(b) significant scientific/engineering challenges to resolve before initiating construction;

- Elements needed for the FCTF are well known by the tritium science and fuel cycle community, ready to be designed, but several technological challenges remain
- Proposed facility location at National Laboratory. Leveraging experience building and operating facilities used for tritium production.
- Non rad facility can de-risk technologies rapidly at lower cost prior to deployment of radiological facility
- Opportunities to collaborate internationally & accelerate technology

Fusion Prototypic Neutron Source (FPNS)

FPNS will address the fundamental question of whether materials retain adequate properties and integrity for damage levels greater than 20–50 displacements per atom (dpa) in a fusion neutron environment

- Explore lifetime limits from an engineering science perspective at higher levels of irradiation
- Essential for development of new materials to support cost effective and safe commercialization
- Multiple proposed Concepts in response to 2023 FES RFI – Pre CD-0, along with several white papers

Consensus Performance Specification from the 2022 EPRI community workshop *

Parameter	Capability by CD0 + 5 yrs	Capability by CD0 + 10 yrs
Damage rate	5-10 dpa/yr (Fe eq.) →	15 dpa/yr (Fe eq.)
Sample volume	≥50 cm^3 →	≥300 cm^3
Spectrum	Gaseous & solid trans. consistent with 14 MeV fusion n spectrum	
Temperature range	~300 to 1200 °C	
Temperature control	3 ind. controlled regions	
Flux gradient	≤20%/cm in plane of sample	

* - Modified original table to change capability dates from fixed dates to CD0 + X yrs

Connection to LRP & BDV, and ability to support/leverage private sector & partnerships

- Highest priority technology facility in the Long Range Plan
- Current DOE Funded Activity to evaluate technical readiness of proposed options including international partnerships

Potential to contribute to world-leading science &/or close fusion technology gaps

(a) absolutely central

- Supports both Science and Engineering needs for most fusion energy concepts:
  - Fundamental Science/Challenges in Radiation Effects (combined effects)
  - Development of an Engineering Design and Licensing Database

Readiness for construction

(b) significant scientific/engineering challenges to resolve before initiating construction

- All proposed concepts require risk reduction and development before being deployed
- Note that significant effort has been put into proposed concept studies to date.
- There are multiple DOE and non-DOE sites that fit within site selection criteria for housing such a device.
- Billion-dollar class facility

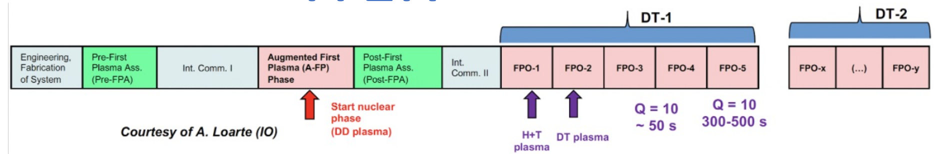
ITER

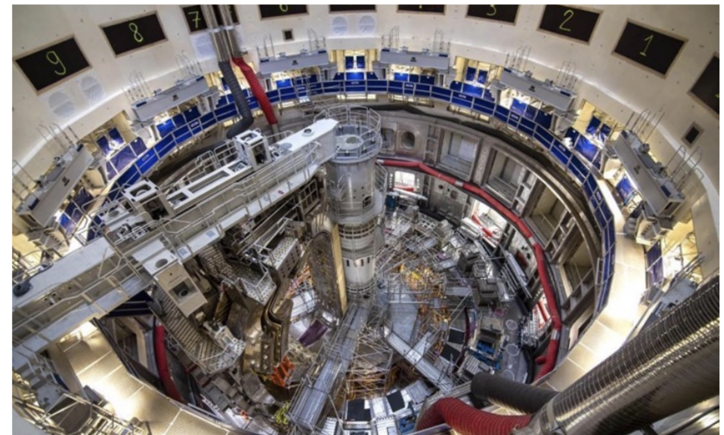
ITER mission is to provide long-pulse (400 to 3000 second), 500 MW burning plasma with fusion gain (Q ~ 10)

- US responsible for 9% of construction & 13% of operation costs.
- ITER is a collaboration among several international partners.

Our review only covers the decadal timeline of completing construction.

- Facility allows significant gap closure: Heat and particle exhaust, disruption mitigation, energetic particles, and core-edge integrated operating scenarios





ITER tokamak pit (October 2022). Credit: ITER Organization

Connection to LRP & BDV, and ability to support/leverage private sector & partnerships

- Well connected to LRP and NASEM reports
- Provides licensing experience with safety features of fusion plant & development of workforce/supply chain
- Industrial-scale fusion systems integration, demonstration of precision engineering including importance of quality control in assembly

Potential to contribute to world-leading science &/or close fusion technology gaps

(a) absolutely central

- Integrated engineering experience, supply chain and workforce development; D-T fuel cycle handling & continuous plasma fueling;
- Provide well-diagnosed burning plasma scenarios
- Key gap: US not partner in ITER test blanket module program

Readiness for construction

(a) ready to initiate construction

- 60% of US contributions delivered ($6.5B US project cost)
- Remaining deliveries: Central solenoid modules (FY25), Disruption mitigation (FY26), Tokamak cooling system, Vacuum auxiliary system, ECH transmission lines & roughing pumps (FY29), tokamak exhaust processing (FY30), Pellet injection (FY32), ICH transmission lines (FY33), Diagnostics (FY31 & TBD)

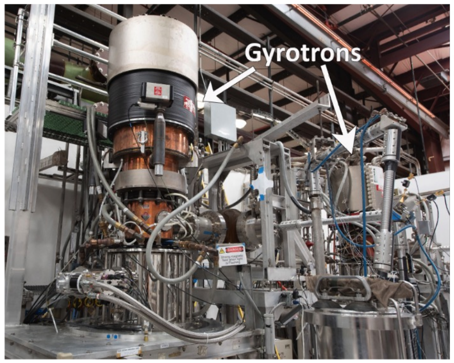
Individual Facility Reports

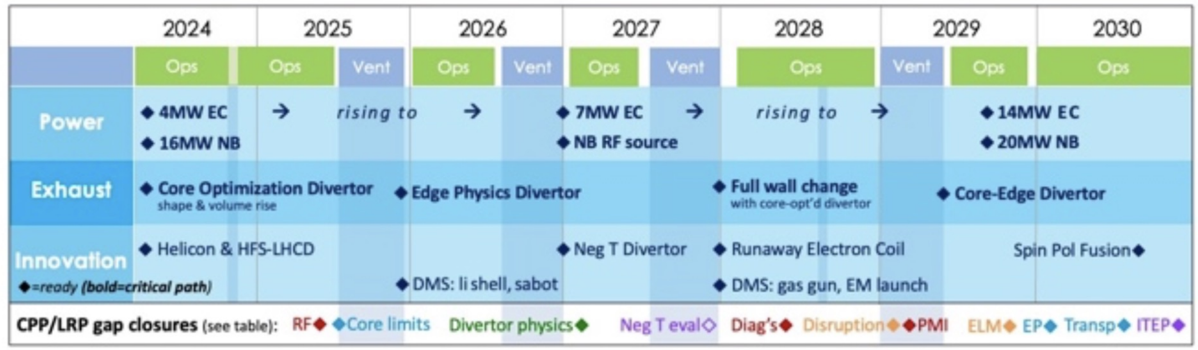
presented alphabetically

These facilities are all important and well-deserving of FES support

DIII-D Upgrade

- Pulsed tokamak
- Operational facility (since 1986)
- Funding request exclusively for ECH power upgrade





Connection to LRP & BDV, and ability to support/leverage private sector & partnerships

- Addresses many elements of the core-edge integration gap with the caveat that not all parameters can be met simultaneously. Additional gap elements may be closed by other DIII-D upgrade elements not considered within this facility upgrade proposal
- Have existing process for engagement with private companies, already engaged with more 15

Potential to contribute to world-leading science &/or close fusion technology gaps

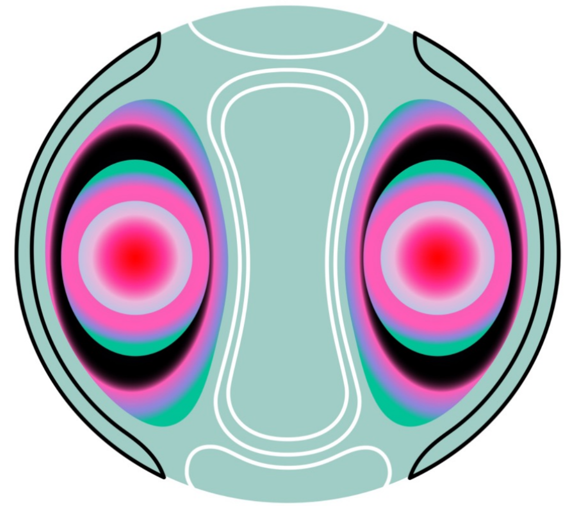
(b) important; DIII-D has a very strong team and a very well diagnosed and well-heated machine, but several facilities worldwide compete in this space (or will soon), and several (will) have higher hardware capabilities (steady-state and/or higher field)

Readiness for construction

(a) ready to initiate construction; it appears that the upgrades to the ECH heating systems and associated infrastructure are ready to start.

EXCITE Options – Exhaust and Confinement Integration Tokamak Experiment

- EXCITE options have a mission to resolve the integrated tokamak exhaust and performance (ITEP) gap, de-risking the tokamak-based FPP plasma core
- EXCITE options target demonstrating integrated strategies for handling exhaust heat fluxes well beyond what is possible in existing devices, while simultaneously supporting sustained high core plasma performance
- Approaches considered were pulsed and advanced tokamaks, negative triangularity, and enhancement of private devices under construction.
- Note the ITEP gap manifests differently for each tokamak approach (ie, pulsed, steady-state, spherical torus, negative triangularity)



Connection to LRP & BDV, and ability to support/leverage private sector & partnerships

- LRP: Closing ITEP gap necessary to ensure tokamak FPP readiness
- BDV: Private sector leads FPP construction, thus each plasma core concept has its own ITEP-equivalent gap and EXCITE-class facility

Potential to contribute to world-leading science &/or close fusion technology gaps:

(b) important; Closing the ITEP gap is central to the extrapolation of the tokamak concept to the FPP. EXCITE facility options provide highest fidelity platform to close ITEP gap.
EXCITE Options narrowly serve just one core-confinement concept

Readiness for construction:

(b) significant scientific/engineering challenges to resolve before initiating construction;
No major technological show-stoppers – TRL is high
Public approaches: Design points consistent with engineering pre-conceptual design were not presented. Mapping of pre-conceptual design to a facility cost or construction timeline was not provided.
Private-led EXCITE options already under construction (post CD-3), opportunities exist to leverage resources and accelerate progress via public-private partnerships

Fusion Integration Research and Science Test Facility (FIRST)

-Experimental facility, which integrates the combined effects of neutron damage from 14.1 MeV neutrons, fully operational blankets and their associated subsystems, and an at-scale fuel cycle.
-Elucidate behavior and issues that may not appear in single-effects test stands.
-Includes key capabilities of many single purpose facilities, and evaluated as an alternative to building those separate facilities.
-Flexibility to explore multiple components and technology choices.

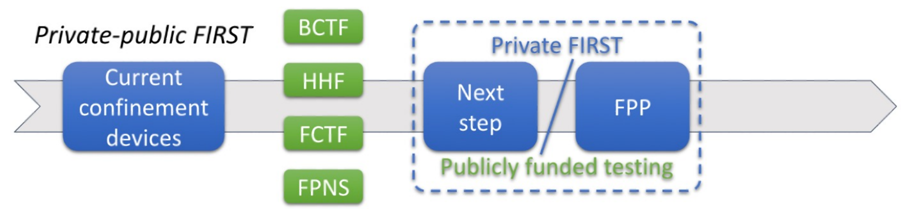
Connection to LRP & BDV, and ability to support/leverage private sector & partnerships

- Not called out directly, but would address numerous strategic objectives.
- Not consistent with a decadal time frame as a public facility.

Potential to contribute to world-leading science &/or close fusion technology gaps

(b) important

-Integrated testing in a nuclear fusion pilot plant is critically important to resolve science and technology gaps prior to a commercial fusion industry.
-To rapidly accelerate towards a FPP, the single purpose facilities were deemed achievable on a more rapid time scale, although leaving a risk associated with integration.
-An integrated facility requires a down selection of a fusion core and potentially the fusion technologies utilized



Readiness for construction

(c) mission and technical requirements not yet fully defined.

-A FIRST that bypasses single-test facilities puts excessive risk on facility readiness for construction.

-Privately funded, publicly supported FIRST-type facilities could provide integrated testing across multiple fusion concepts. That has the potential to accelerate readiness for construction and decrease public cost.

High Heat Flux Test Facility (HHF)

Multiple possible options for HHF including:
-Non-nuclear laser driven coupon testing facility proposed with later option to upgrade into nuclear facility with ease depending on initial siting.
-Non-nuclear electron beam driven component testing facility proposed with helium cooling and options for varied cooling loops.
-CHIMERA UK-AEA facility under construction for multi-effects component testing, including thermal radiation HHF testing with applied magnetic fields and water cooling. Upgrade plans include addition of HHF laser source and PbLi loops.

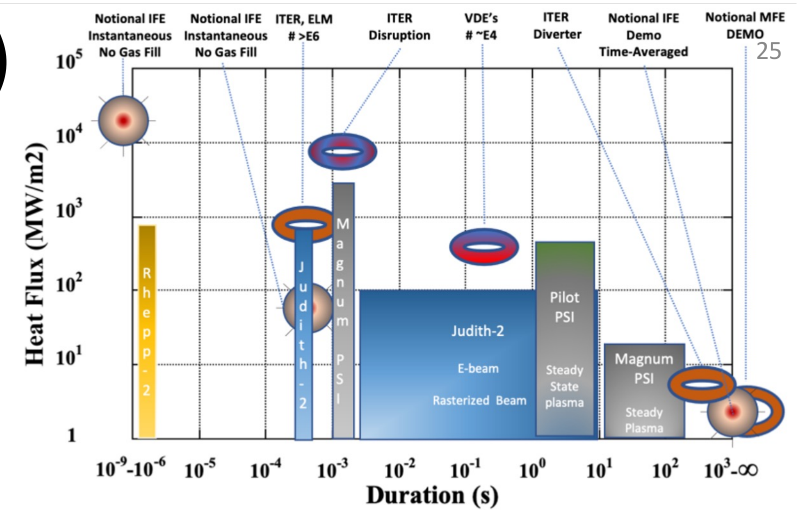
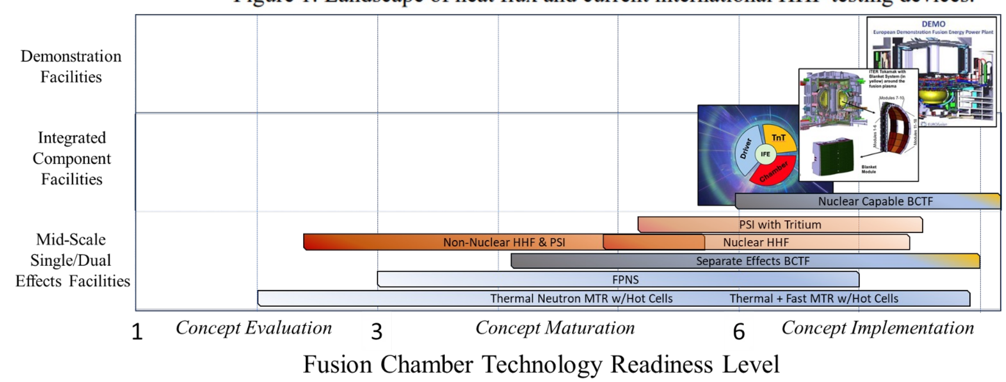


Figure 1: Landscape of heat flux and current international HHF testing devices.

Connection to LRP & BDV, and ability to support/leverage private sector & partnerships
Compact fusion devices drive high heat flux in PFC – need to find innovative solutions and be able to test them. Steady state and transient heat flux testing features required at coupon level and component level, and later nuclear component level.
Opportunity to leverage UKAEA's CHIMERA facility.

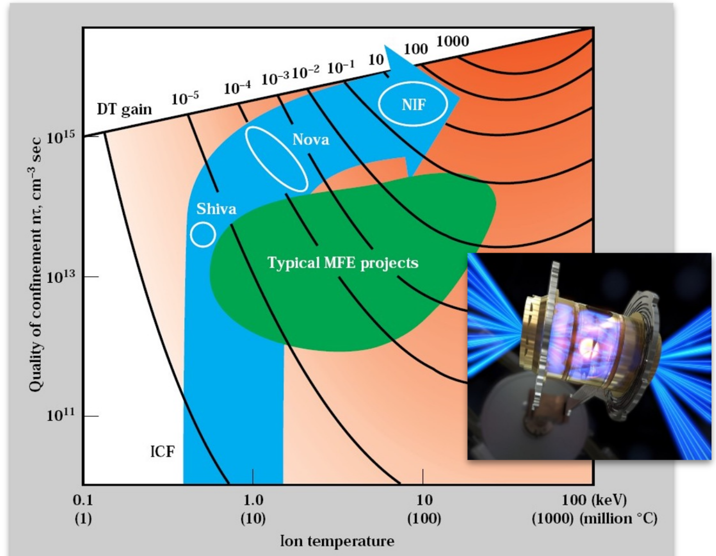


Potential to contribute to world-leading science &/or close fusion technology gaps *(b) important*
Domestic HHF capabilities represent an important need for both solid & liquid PFC development needs for public/private fusion energy development. Urgency for HHF testing due to timeline need to develop & validate materials prior to system level reactor testing.

Readiness for construction *(a) ready to initiate construction;* HHF technology at a high TRL. Relatively low cost non-nuclear, coupon-level HHF concepts exist allowing for agile timelines and build.

New Inertial Fusion Energy (IFE) Concepts and Upgrades

- Demonstration of ignition at NIF has enabled a path for laser-based fusion energy and an IFE-FPP. Upgrades to existing ultrahigh power lasers and construction of a modular, integrated IFE demonstration facility are essential to achieve FPP status.
- Upgrades to existing high-power laser facilities would enable breakthrough science to improve target design, materials, and workforce training for IFE.
- Construction of a new modular IFE facility would provide a platform to study target injection devices, systems integration and engineering, and operational aspects of an IFE-FPP.



Connection to LRP & BDV, and ability to support/leverage private sector & partnerships

- LRP calls for an IFE program to maintain US leadership and to pursue the development of a multi-petawatt laser facility. However, ignition at NIF and emergence of robust private sector have changed the context under which LRP was drafted.
- IFE is part of BDV, BRN priorities, Milestone plan, and 2023 NASEM HEDP report.

Potential to contribute to world-leading science &/or close fusion technology gaps

(b) important: Building a modular, integrated IFE facility is important to close the scientific and technological gaps needed to develop an IFE-FPP (cont'd →)

→ However, the IFE field and the funding landscape are evolving too rapidly and no mature concepts exist at the moment. Defining the engineering basis for such a facility is the next necessary step.

Readiness for construction

Construction of modular, integrated, IFE testing/ engineering systems facility: (c) Technical basis not yet defined. Potential for leveraging the private (multiple IFE companies) and public (several Offices) sectors could provide an accelerated transition to (b).

Matter in Extreme Conditions-Upgrade (MEC-U)

Unique combination of hard X-rays from LCLS, rep-rated high intensity petawatt laser, & high-energy shock-compression laser.

- Long-pulse laser – order-of-magnitude higher energy than at any US or international X-ray light source
- Short-pulse laser – highest power laser at any X-ray light source

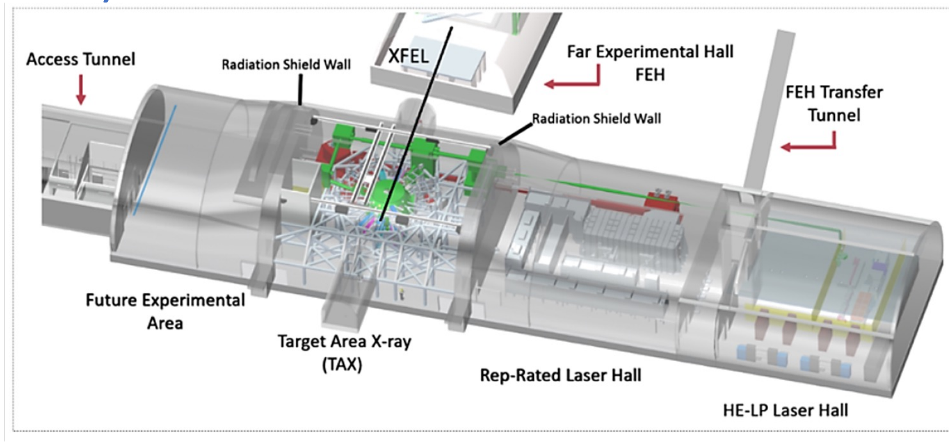
Connection to LRP & BDV, and ability to support/leverage private sector & partnerships

- LRP drivers: plasma universe, foundational physics, & transformative technologies
- IFE: understanding of HED plasma, design/test of new IFE target materials, IFE-relevant rep-rate

Potential to contribute to world-leading science &/or close fusion technology gaps:

(b) important

- Strong potential to contribute to world-leading fundamental science; Relatively limited scope for closing fusion technology gaps



Readiness for construction:

(a) ready to initiate construction

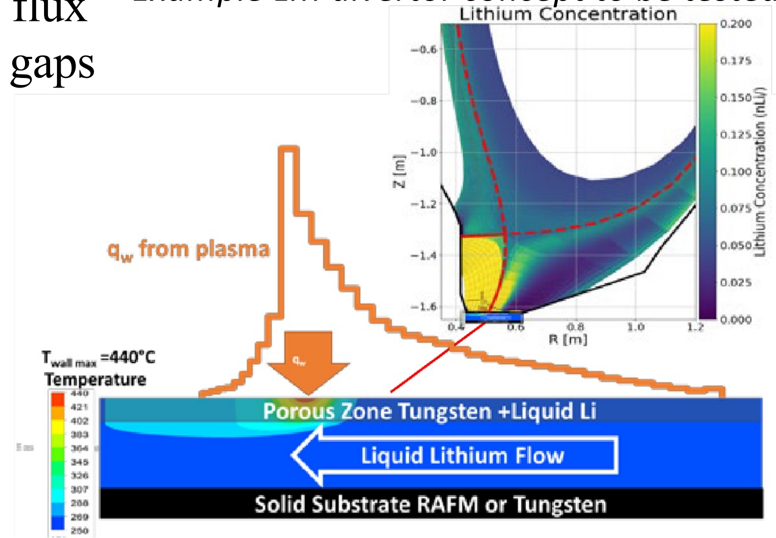
- Conceptual design (CD-1) approved in Oct 2021; $264–461M cost range; baseline (CD-2) planned for FY26; Early completion of CD-4 possible in FY2029.
- Opportunity to address major capability gaps in the technical missions across BES, NNSA, NSF, and NASA

NSTX-U Liquid Metal Core Edge (LMCE)

NSTX-U Liquid Metal Core Edge (LMCE)

- Aims to evaluate viability of lithium for managing high heat flux + improving plasma performance, partially addressing ITEP gaps
- Test multiple LM divertor concepts, extensive diagnostics
- Actively controlled wall temp, replace C wall w/ high Z
- Includes LM test stands for risk reduction prior to tokamak

Example LM divertor concept to be tested



Connection to LRP & BDV, and ability to support/leverage private sector & partnerships

- Unique on the world stage, consistent with LRP + NASEM
- Potential innovation for future energy commercialization
- Multiple private company interest in collaboration

Potential to contribute to world-leading science &/or close fusion technology gaps: *(b) Important*

- Potential to extend PFC lifetime, avoid solid 'slag'
- Well-suited for long-term public program, applicable to multiple concepts
- Some common LM tech challenges can be addressed in non-confinement facilities (HHF, BCTF, FCTF)

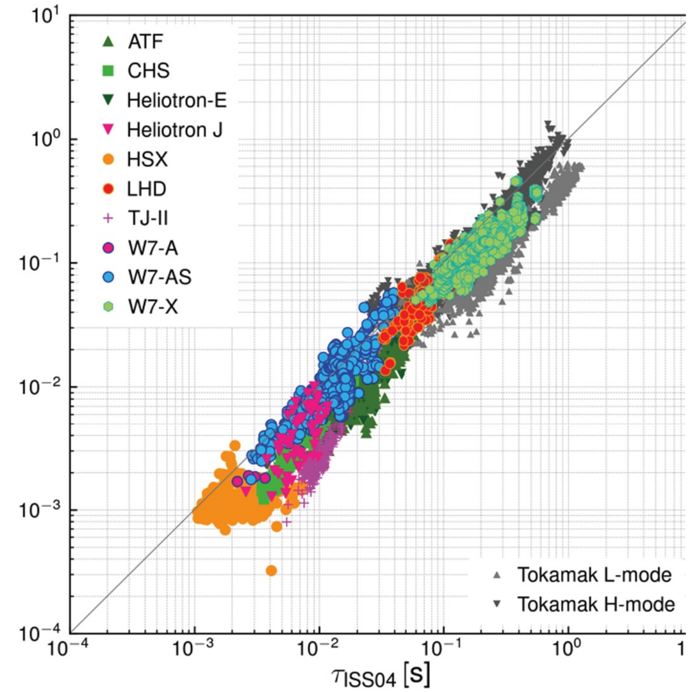
Readiness for construction

(b) significant scientific/engineering challenges to resolve before initiating construction;

- Re-design leverages Recovery analysis, has ID'd preliminary scope, schedule, cost, and risk (~2029 for LM divertor)
- NSTX-U Recovery, timeline, and operation is a technical risk

Midscale Stellarator

-Experimental demonstration of innovative recent theoretical, modeling, manufacturing advances and novel concepts to address transport and divertor challenges
-Alternative to tokamak: steady-state, disruption free, low recirculating power, largely dictated by external control
-Test new optimized stellarator configuration(s)
-Two options include a public or PPP DOE user facility



Dr. Golo Fuchert, IPP, Germany – similar figures appear in the peer-reviewed literature

Connection to LRP & BDV, and ability to support/leverage private sector & partnerships

- Key facility alternative to tokamak
- Consistent with LRP
- 3 U.S. private companies, multiple int'l partners

Potential to contribute to world-leading science &/or close fusion technology gaps *(b) important*

Would test optimized stellarator configurations and provide general MFE scientific and tech knowledge

Readiness for construction

(b) significant scientific/engineering challenges to resolve before initiating construction;

Community consensus on some but not all aspects, especially size/cost. TRL depends on magnet tech. Private sector proceeding towards construction; a PPP could be a good option to leverage.

Summary

- New fusion facilities addressing critical technology and science gaps are urgently needed to meet the timelines of the BDV and private industry to provide economically-attractive fusion energy to the U.S. grid, especially related to the growing excitement about fusion (IFE Q>1 and UK-AEA demonstration of 69 MJ fusion power)
- We thank the community for the rapid input and participation in our community webinars as part of the evaluation of 12 facilities/facility upgrades for fusion
- Our Subcommittee developed a strong consensus that four facilities 'Best Serve Fusion' - BCTF, FCTF, FPNS and ITER. *Each of these facilities support multiple pathways to fusion energy, including ITER which has/will provide knowledge transfer about fusion technology*
- Our Subcommittee developed consensus evaluation that the remaining eight facilities were deemed important. Each of the facilities were evaluated to be at varying levels of readiness for construction. No further attempt to prioritize or rank these facilities was performed, consistent with the charge from Dr. Berhe