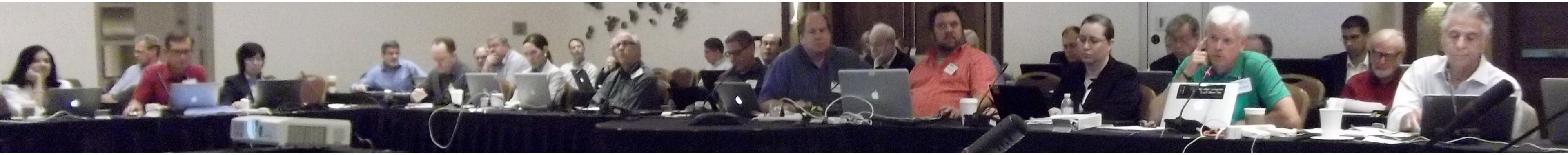
2014 Fusion Energy Sciences Advisory Committee (FESAC) Strategic Planning Panel Report

Mark Koepke, *West Virginia University*

FESAC Chair, Strategic Planning Panel Chair



www.science.energy.gov/fes/fesac
www.burningplasma.org
http://fire.pppl.gov

FPA Annual Meeting
Wednesday 17 December 2014
Hyatt Regency Capitol Hill

FESAC June 2014 – June 2015

Amitava Bhattacharjee, PPPL, Princeton U.
Troy Carter, UCLA
Bruce Cohen, LLNL
Arati Dasgupta, NRL
John Foster, U. Michigan
Chuck Greenfield, General Atomics
Richard Groebner, General Atomics
Valerie Izzo, UCSD
Chris Keane, Washington State U. , **Interim Chair**
Jin-Soo Kim, FAR-TECH, Inc.
Fred Skiff, U. Iowa, *APS-DPP* →
Minami Yoda, Georgia Tech, *ANS-FED* →

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Gert Patello, Pacific Northwest Nat. Lab
Juergen Rapp, ORNL
Chris Hegna, U. Wisconsin
Don Rej, Los Alamos National Lab
Linda Sugiyama, MIT
Steven Zinkle, U. Tennessee, **Vice Chair**
Ellen Zweibel, U. Wisconsin
John Steadman, U. South Alabama, *IEEE*
Riccardo Betti, U. Rochester, *APS-DPP*
Susana Reyes, LLNL, *ANS-FED*

Blue = Vote-eligible FESAC member

Italic = SP Panel member

FESAC Strategic Planning (SP) Panel Member List

Mark Koepke: **Panel Chair**: West Virginia Univ.
Discovery, Partnerships, **APS-DPP Chair**, **FESAC Chair**

Steve Zinkle: **Panel Vice Chair**: Univ. Tennessee
Long Pulse, **FESAC Vice Chair**

Kevin J. Bowers: LANL (guest scientist)
Foundations

Troy Carter: Univ. of California – Los Angeles
Foundations, Discovery

Don Correll: Lawrence Livermore National Lab
Discovery, Partnerships

Arati Dasgupta: Naval Research Laboratory
Discovery, Partnerships

Chris Hegna: University of Wisconsin – Madison
Foundations, Long Pulse

Bill Heidbrink: Univ. California – Irvine
Foundations

Stephen Knowlton: Auburn University (retired)
Foundations, Long Pulse

Douglas Kothe: Oak Ridge National Laboratory
Foundations, Partnerships

Stan Milora: Oak Ridge National Lab (retired)
Long Pulse, Partnerships, High Power

David E. Newman: University of Alaska
Foundations, Discovery

Gert Patello: Pacific Northwest National Lab
Long Pulse, Partnerships

Don Rej: Los Alamos National Laboratory
Long Pulse, Partnerships

Susana Reyes: Lawrence Livermore National Lab
High Power, Long Pulse

John Steadman: University of South Alabama
FESAC ex-officio member representing IEEE
Partnerships

Karl A. Van Bibber: Univ. California – Berkeley
Long Pulse, Partnerships

Alan Wootton: Univ. of Texas-Austin (retired)
Foundations, Discovery, Partnerships

Minami Yoda: Georgia Institute of Technology
FESAC ex-officio member representing ANS-FED
Long Pulse, Partnerships

*Names highlighted in **blue italics** are FESAC members*

Panel unanimously signed the submitted draft report

Mark E. Koepke: Chair
West Virginia University

Steve J. Zinkle: Vice Chair
University of Tennessee – Knoxville

Kevin Bowers
LANL (guest scientist)

Troy Carter
University of California – Los Angeles

Don Correll
Lawrence Livermore National Laboratory

Arati Dasgupta
Naval Research Laboratory

Chris Hegna
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Minami Yoda
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Report: Initiatives and Primary/Supporting Recommendations from Priorities Assessment and Budget Scenario Formulation

Charge issued**: 8 April**; Report deadline: **1 Oct**
www.burningplasma.org/activities/

Strategic planning is the acceptable process for making investment decisions to realize the mission and goals of a program's vision. A good strategy should extend a little bit outside the comfort zone.

True strategy is about placing bets, making hard choices, and maximizing the odds for success, rather than minimizing risk. Good strategic development involves deciding the goals that are worth achieving, what it would take to achieve them, and whether or not they are realistic.

Ranking of strategic priorities comprised the FESAC SP Panel charge. The priority assessment and budget scenarios were to address the next 10 years (2015 through 2024) with a 2025 vision for being ready for 2025-2034.

FESAC Strategic Planning (SP) Panel gathered options for initiatives and recommendations

FESAC was charged to assess the priorities among continuing and potential new scientific, engineering, and technical research program investments within and among each of the three subprograms in FES's newly structured program:

- the science of *prediction and control of burning plasmas* ranging from the strongly-driven state to the self-heated state (**FOUNDATIONS**),
- the science of *fusion plasmas , plasma-material interactions, engineering and materials physics modeling and experimental validation,* and *fusion nuclear science* approaching and beyond ITER-relevant heat fluxes neutron fluences, and pulse lengths [stellarators and long-pulse tokamaks] (**LONG PULSE**), and
- the study of laboratory plasmas and the high-energy-density state relevant to *astrophysical phenomena,* the development of *advanced measurement validation,* and the science of *plasma control important to industrial applications* (**DISCOVERY PLASMA SCIENCE**).
- A 4th subprogram (**HIGH POWER**, separate budget is assumed), establishing the scientific basis for robust control of the self-heated, burning plasma state, uses ITER as the keystone, is not so focused on domestic capabilities, and is not emphasized in this charge.

FESAC Strategic Planning (SP) Panel assessed priorities and prioritized initiatives

So that FES can formulate the FES strategic plan required by the Fiscal Year 2014 Omnibus Appropriations Act by mid-January 2015, the DOE Office of Science (DOE-SC) asked FESAC

- to prioritize between the FES Program's subprogram elements,
- to include views on new facilities, new research initiatives, and facility closures,
- to establish a scientific basis for advancing fusion nuclear science,
- to assess potential for strengthened or new partnerships with other federal agencies and international research programs that foster opportunities otherwise unavailable to FES-supported scientists, and
- to make use of prior studies and reports.

Prioritize among continuing and potential new FES program investments required to ensure that the U.S. is in a position to exert long term leadership roles in the FES program.

This was an extremely important charge in the eyes of the Office of Science and for the fusion community, with high visibility to policymakers and to our own universities and national laboratories.

Built into the process was the commitment to having the panel **gather information openly** and **deliberate in an unencumbered, unbiased, and independent manner** that minimizes conflict of interest issues while providing the best technical advice for the charge.

The initiatives that were ranked came from the research community. To satisfy the budget scenarios, a strategic spectrum of subprogram elements were able to be accelerated ahead of other elements while balancing facility closure with new facility planning and expanded collaborations.

The Panel worked in four subpanels

Burning Plasma Science: Foundations and **Long Pulse**
Discovery Plasma Science
Partnerships with other-federal and international programs.

2007 FESAC Report served as the roadmap.

2009 MFE-ReNeW framed 18 science questions into Thrusts

Community input to the Panel in 2014 through presentations, Question & Answer sessions, and white papers.

Closely related Thrusts that addressed an overarching topic were combined as an Initiative. Prioritization of the Thrusts in terms of metrics that included their importance to Vision 2025 directly led to formulation of primary recommendations and four overarching initiatives. These four highest priority Initiatives are categorized into two tiers.

Report Structure

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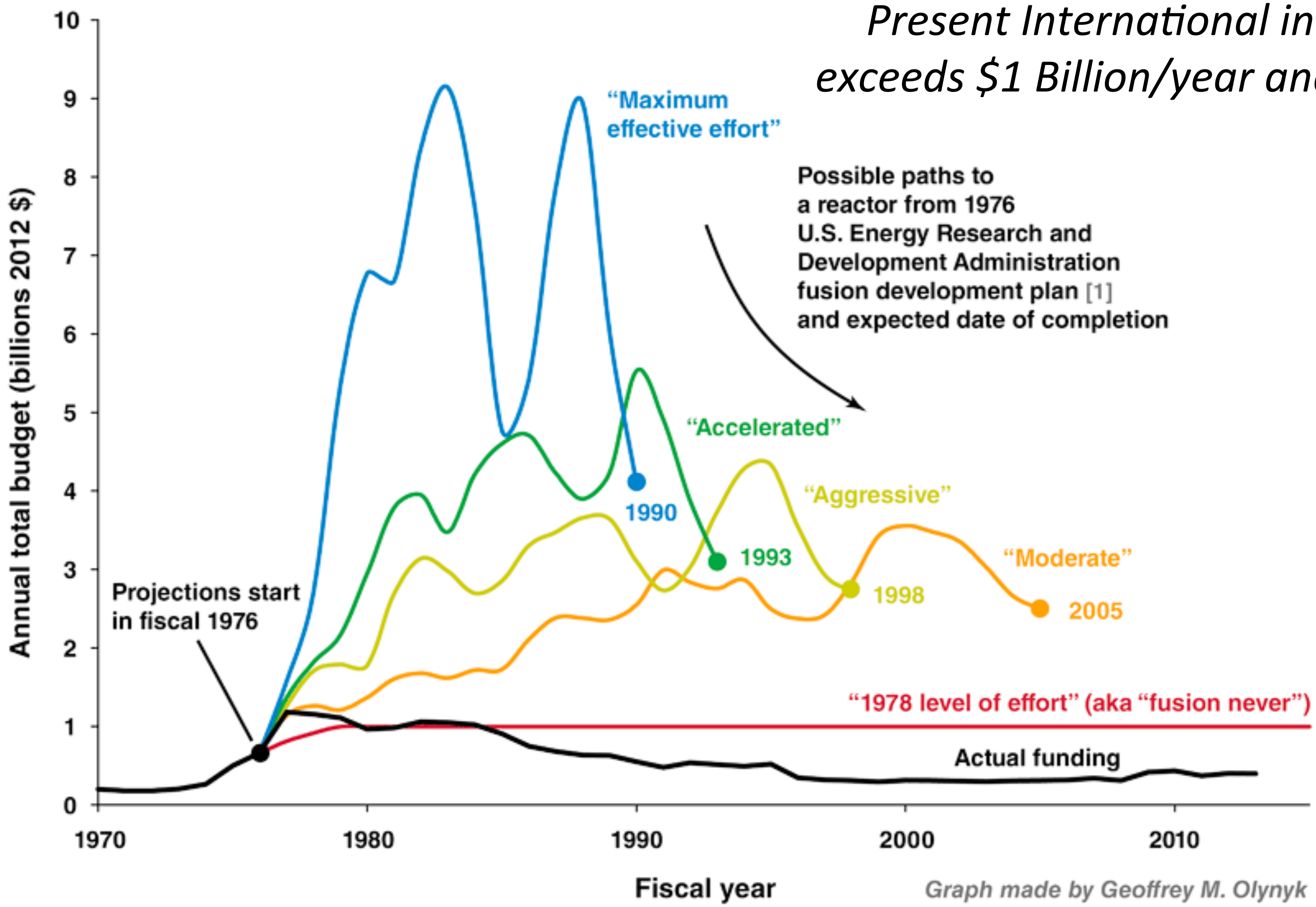
Recent international investments compensate the shortfall of the historical U.S. fusion budget profile toward fusion development

Present International investment exceeds $1 Billion/year and will rise



[1] U.S. Energy Research and Development Administration, 1976. "Fusion power by magnetic confinement: Program plan" ERDA report ERDA-76/110. Also published as S.O. Dean (1998), *J. Fus. Energy* **17**(4), 263–287, doi:10.1023/A:1021815909065

http://commons.wikimedia.org/wiki/File:U.S._historical_fusion_budget_vs._1976_ERDA_plan.png

Vision
Primary recommendations
Initiatives

Vision 2025: Priorities resolve the ranked scientific/technical gaps

Enable U.S. leadership in burning plasma science and fusion power production research, including programs planned for ITER – the world's premier upcoming fusion facility.

Provide the scientific and technological basis for a U.S. Fusion Nuclear Science Facility (FNSF) – a critical next step towards commercial fusion power.

Continue U.S. leadership in discovery plasma science, fusion-related technology, and other areas needed to realize the promise of fusion energy and develop the future fusion workforce.

As scientific opportunities on the path to fusion energy development, including international partnering, are pursued, the U.S. can:

- participate significantly in the successful operation of ITER;
- initiate a broad fusion nuclear science subprogram with the intent to construct, operate, and host researchers at a U.S. Fusion Nuclear Science Facility (FNSF); &
- create a pioneering research atmosphere for a U.S. "Generation ITER-FNSF" workforce that is leading global scientific discoveries and technological innovation.

Vision 2025: Primary Recommendation 1

Control of Burning Plasmas:

The FES experimental subprogram needs an integrated and prioritized approach to achieve significant participation by the U.S. on ITER. Specifically, new proposed solutions will be applied to two long-standing and ubiquitous issues relevant to tokamak-based burning fusion plasma:

- dealing with unwanted transients, and
- dealing with the interaction between the plasma boundary and material walls.

Vision 2025: Primary Recommendation **2**

Fusion Predictive Modeling:

FES theory and simulation subprogram should develop the modeling capability to understand, predict, and control

(a) burning, long-pulse, fusion plasmas and

(b) plasma-facing components.

Such a capability, when combined with experimental operational experience, will optimize ITER operation and maximize ITER-results interpretation for burning, long-pulse, fusion plasmas, and will decide the necessary requirements for future fusion facilities. This endeavor must encompass the regions from plasma core through to the edge and into the surrounding materials, and requires coupling the nonlinear, multi-scale, multi-disciplinary, phenomena, in experimentally validated, theory-based models

Vision 2025: Primary Recommendation **3**

<u>Fusion Nuclear Science</u>:

A fusion nuclear science subprogram should be created to, besides push the fusion nuclear science frontier and exert a long-term leadership role in this area, provide the science and technology understanding for informing decisions on the preferred plasma confinement, materials, and tritium fuel-cycle concepts for a Fusion Nuclear Science Facility (FNSF), a proposed U.S.-based international centerpiece beyond 2025. FNSF's mission is to utilize an experimental plasma platform having a long-duration pulse (up to one million seconds) for fusion plasma science's and fusion nuclear science's complex integration and convergence.

Vision 2025: Primary Recommendation **4**

Discovery Plasma Science:

FES stewardship of basic plasma research should be accomplished through peer-reviewed university, national laboratory, and industry collaborations. In order to achieve the broadest range of plasma science discoveries, the research should be enhanced through federal-agency partnerships that include cost-sharing of intermediate-scale, collaborative facilities with which grand scientific challenges in select physics-discovery frontiers can be resolved.

Vision 2025: Partnering with other-federal and international programs

The experiments available to implement these four primary recommendations are located in the U.S. and at major international sites.

The international experiments provide access both to unique magnetic geometries and to extended operating regimes unavailable in the U.S..

These experiments should provide information required to design FNSF beyond 2025 and, ultimately, a fusion demonstration power plant.

Four Initiatives

Tier 1:

- Control of deleterious transient events (**Transients**)
- Taming the plasma-material interface (**Interface**)

Tier 2:

- Experimentally validated integrated predictive capabilities (**Predictive**)
- A fusion nuclear science subprogram and facility (**FNS**)

Tier 1 Initiatives are higher priority than Tier 2 Initiatives.

Within a tier, the priority is equal.

Control deleterious transient events in burning plasmas: Transients Initiative (Tier 1 Initiative)

This Initiative combines experimental, theoretical, and simulation research to understand highly damaging transients and minimize their occurrence in ITER-scale systems.

Undesirable transients in tokamak plasmas are ubiquitous, but tolerable, occurrences in most present-day experiments, but could prevent regular operation of a burning plasma experiment on the scale of ITER without frequent shutdown for repairs. To reduce the threat of disruptions to tolerable levels in upcoming nuclear experiments, both passive and active control techniques, as well as preemptive plasma shutdown measures, will be employed.

Taming the plasma-material interface: Interface Initiative (Tier 1 Initiative)

This Initiative combines experimental, theoretical, and simulation research to understand and address the plasma-materials interaction challenges associated with long-pulse burning plasma operation.

Understanding the boundary that extends from the high-temperature plasma core to the surrounding material is a priority.

The boundary establishes heat & particle fluxes incident on surfaces, and the response of the surfaces, in turn, influences the boundary.

Understanding, accommodating, and controlling PMI, at high confinement, is prerequisite for ITER success and for designing FNSF.

A self-consistent solution to the PMI challenge requires the construction of a high-power and high-fluence linear divertor simulator.

Experimentally Validated Integrated Predictive Capabilities: Predictive Initiative (Tier 2 Initiative)

This Initiative develops an integrated "whole-device" predictive capability and will rely on data from existing and planned facilities for validation.

The coming decade provides an opportunity to break ground in integrated predictive understanding.

Traditionally, Theory and Simulation model isolated phenomena based on mathematical formulations that have restricted validity regimes. An increasing number of situations are found where the validity regime and the phenomena need to be coupled to account for all relevant phenomena.

Expanded computing capabilities, enhancements in analytic theory, and the use of applied mathematics is required.

Fusion Nuclear Science:
FNS Initiative (Tier 2 Initiative)

This Initiative takes an integrated approach to address key scientific/technological issues for harnessing fusion power.

Selections of the plasma magnetic configuration & operational regimes need to be established based on collaborative long-pulse, high-power research (domestic and international).

A viable approach to a robust plasma-materials interface needs to be identified that provides acceptably high heat flux capability and low net erosion rates without impairing plasma performance or resulting in excessive tritium entrapment.

Materials research needs to expand to comprehend/mitigate neutron-irradiation effects, and fuel-cycle research is needed to identify a feasible tritium generation and power-conversion blanket/first-wall concept. A materials neutron-irradiation facility that leverages an existing megawatt-level neutron spallation source is envisioned as a cost-effective option.

Discovery Plasma Science

In concert with the above Initiatives, DPS will advance the frontiers of plasma knowledge to ensure continued U.S. leadership.

DPS elements can provide transformational new ideas for plasma topics. DPS research seeks to address a wide range of fundamental science, including fusion, as outlined by the NRC Plasma 2010 report.

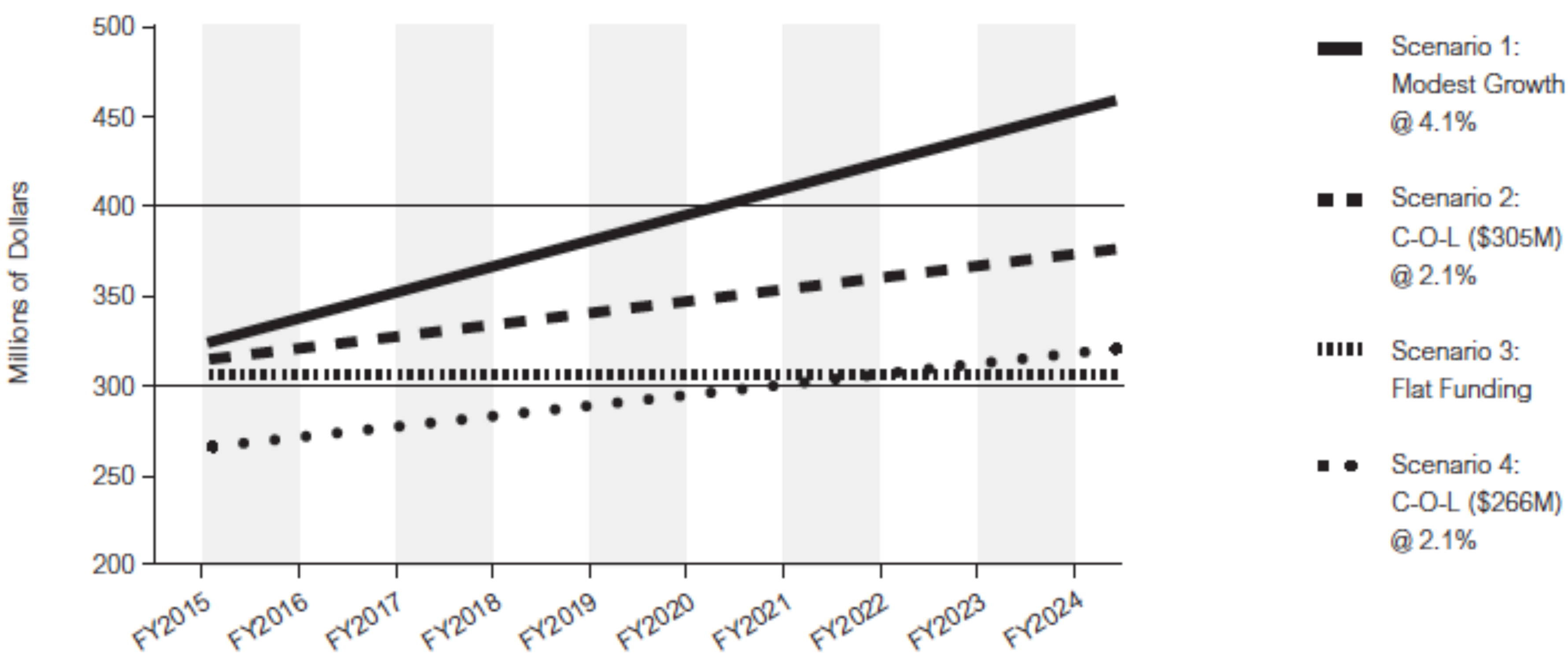
DPS activities are synergistic with the research mission of other federal agencies, and opportunities exist to broaden the impact of DPS through development and expansion of strategic partnerships.

Addressing fundamental science questions at the frontier of plasma science requires a spectrum of lab facilities, from small-scale with a single principal investigator to intermediate-scale highly collaborative.

Interactions between larger facilities at national labs and small and intermediate-scale facilities will play a role in advancing DPS frontiers and in training. Universities train the next generation of fusion researchers and support graduate-student-scale experiments, and thus play a critical role in the DPS subprogram.

Budgetary Considerations for Vision 2025

FES Domestic Program Budgets in As-Spent Dollars



Implementation

0, -$400M, -$780M, -$900M in the integrated funds are the decrements between Scenarios 1, 2, 3, and 4 (previous page).

For all scenarios, it was assumed that the scientific workforce was retained in the event of a facility closure.

For the first ~5 years (~2015 to ~2020), the number of run weeks of the two operating facilities (NSTX-U and DIII-D) should be kept significantly higher than in the recent past. Between ~2020 and ~2025, the number of facilities should be at least one, with the date of any shut down (or cold storage) being dependent on budget beyond the smooth scenario. If two facilities were maintained for 10 years (a possibility, but perhaps in only the highest budget, Budget Scenario 1), the operational availability of one, but not both, could be reduced.

Vision 2025, recommendations, and initiatives will require redirection of resources over the decade

Construction a prototypic **high-power and high-fluence linear divertor simulator** and an **intense, neutron-irradiation facility** leveraging an existing MW-level neutron spallation source, are recommended.

Resources for investments in **plasma technology and materials science**, **fusion nuclear science**, **theory and simulation**; **and DIII-D and/or NSTX-U upgrades** should come from major-facility closure(s) and, in the lower budget scenarios, reduction of run weeks and reconsideration of DPS funding allocations. For all budget scenarios, the Panel recommends:

- increased international collaborations in targeted areas of importance,
- the operation of at least one major domestic plasma machine,
- the simultaneous operation of DIII-D and NSTX-U for of order 5 years, and
- C-Mod operations end.

The five-year operation of NSTX-U enables consideration of a spherical torus magnetic geometry for FNSF. The five-year operation of DIII-D provides optimal investigation of transient mitigation and plasma control for ITER.

It is crucial that scientists and engineers from the MIT Plasma Science and Fusion Center take leadership roles in the proposed Initiatives.

Panel explored various funding scenarios to derive credible funding profiles for the highest priority research activities.

- 2014 Modest Growth –Vision 2025 has an acceptable probability of being achieved. The U.S. features prominently in four areas: Transients, Interface, Predictive, and importantly FNS.
- 2014 Cost of Living – Vision 2025 can be met, but with lower probability, with probable consequence for one of the two remaining major facilities or for DPS funding. The U.S. features prominently in at least three Initiative areas (Transients, Interface, Predictive), with the possibility of featuring prominently in the FNS Initiative. U.S. prospects for FNS-frontier leadership diminish.

Focused effort on 4 highest-priority initiatives, with U.S. strengths in diagnostics, experiment, theory, simulation, and computation, can support a vibrant program and sets stage for world leadership in emerging key fusion nuclear science research.

Panel explored various funding scenarios to derive credible funding profiles for the lowest priority research activities.

- 2014 Flat – Vision 2025 only partially met, earlier next-closure of a major facility, and reduction to DPS. Neutron-irradiation facility may not be possible, but linear divertor simulator and the upgraded tokamak-divertor are operating. The U.S. fusion program features prominently in two (Transients, Interface) Initiatives, possibly also in the Predictive Initiative.

- 2015 C.O.L – Vision 2025 only partially met, and the second Tier 2(Predictive) Initiative is lost. DPS funds get reduced slightly and linear divertor simulator and/or the upgraded tokamak divertor may not be possible in spite of a 2020 next-closure of a major facility. The U.S. would be in a weak position to proceed as an innovative center of fusion science beyond 2025.

New facilities are required for Vision 2025 Initiatives

During Phase 1, both NSTX -U and DIII-D should be available for ITER-related research, for assessing FNSF magnetic geometry, and for Transients Initiative. New international partnership arise.

During Phase 2, at least one of NSTX-U/DIII-D is required for ITER-related research and for Interface and Predictive Initiatives. New international partnerships on superconducting tokamaks and stellarators flourish.

After ~2025, 1 facility is required both for programmatic research and, operating as a User Facility, for DPS. The best facility for beyond ~2025 is not necessarily the same as the best facility for the ~5 years prior to ~2025. If this is the case, then cold storage, i.e., mothballing, should be considered.

Between 2015 and 2025, the DPS program is strengthened by peer-reviewed univ., national lab, and industry collaborations. These collaborations will be enhanced by partnering with federal agencies and by cost-sharing collab-orative, intermediate-scale facilities in order to realize the broadest range of plasma science discoveries.

With such collaborations in place, DPS will able to train the next generation of plasma scientists to ensure continuing U.S. leadership in plasma science.

Timeline for Facilities and Initiatives

Phase I:

- Alcator C-Mod operation ends
- DIII-D operating and providing info on transient mitigation, boundary physics, plasma control, and other ITER-related research
- NSTX-U operating and providing information on potential path to a FNSF-ST, boundary physics, and on ITER-related research
- Linear divertor simulator is under construction
- Predictive Initiative is launched and grown
- FNS subprogram is initiated
- Partnerships on leading international superconducting tokamaks and stellarators are increased with intentions of supporting long-term engagements
- Expanded integration of DPS elements facilitate the effective stewardship of plasma science

Phase II:

- Partnerships are centered on leading international superconducting tokamaks and stellarators
- Minimum of one domestic facility (DIII-D, NSTX-U) operating and providing information for the Interface Initiative
- Linear divertor simulator operating and providing information for the Interface Initiative
- Predictive Initiative is fully underway and providing information in support of all Initiatives
- FNS Initiative underway and expanding science and technology for fusion materials, including a new neutron-irradiation capability
- Priority increasing for fusion power extraction, and tritium sustainability
- DPS partnerships advancing the frontiers of DPS knowledge enhanced by cost-sharing on intermediate-scale collaborative facilities.

2025: Either DIII-D or NSTX-U operating as a national user facility for Discovery Plasma Science as well as for programmatic objectives.

Thank you for your input to this report. Please support the community workshops being planned.