A Strategic Plan for U.S. Burning Plasma Research

Status and Comments

Mike Mauel, Columbia University, Co-Chair
Mel Shochet, University of Chicago, Co-Chair

December 5, 2018

39th Meeting of the Fusion Power Associates

Washington, D.C.

http://nas.edu/fusion

Outline

- Appreciation for your Input and Engagement
- Statement of Task
- Report Status
- Progress since the 2004 Burning Plasma Study
- Some Additional Comments

Committee Membership

Michael Mauel, Columbia University, Co-Chair

Melvyn Shochet (NAS), Univ Chicago, Co-Chair

Christina Back, General Atomics

Riccardo Betti, University of Rochester

Ian Chapman, UK Atomic Energy Authority

Cary Forest, University of Wisconsin, Madison

T. Kenneth Fowler (NAS), Univ of California, Berkeley

Jeffrey Freidberg, MIT

Ronald Gilgenbach, University of Michigan

William Heidbrink, University of California, Irvine

Mark Herrmann, LLNL

Frank Jenko, IPP Garching and University of Texas, Austin

Stanley Kaye, Princeton University

Mitsuru Kikuchi, Nat. Inst. Quantum Radiological Sci & Tech

Susana Reyes, LBNL

C. Paul Robinson (NAE), Advanced Reactor Concepts, LLC

Philip Snyder, General Atomics

Amy Wendt, University of Wisconsin, Madison

Brian Wirth, University of Tennessee, Knoxville

Chris Jones, David Lang, NRC Study Director

Fusion Community Input (Thank you! Part 1 of 2)

- ***Seven meetings 39 presentations**:* Mohamed Abdou, Hans-Henrich Altfeld, Michl Binderbauer, Amitava Bhattacharjee, Bernard Bigot, Richard Buttery, Tony Donné, Gianfranco Federici, Phil Ferguson, Stefan Gerhardt, Chuck Greenfield, Martin Greenwald, Sibylle Guenter, Richard Hawryluk, Dave Hill, Amanda Hubbard, Yong-Seok Hwang, Thomas Klinger, Mike Jaworski, Sam Lazerson, Gyung-Su Lee, Jiangang Li, Tim Luce, David Maurer, Jon Menard, Bob Mumgaard, Yuichi Ogawa, Stewart Prager, Soren Prestemon, Juergen Rapp, Ned Sauthoff, Oliver Schmitz, Ed Synakowski, Tony Taylor, Jim Van Dam, Mickey Wade, Dennis Whyte, and Mike Zarnstorff.
- **> 100 White Papers**

Fusion Community Input (Thank you! Part 2 of 2)

- Report of the FESAC Subcommittee on ***Transformative Enabling Capabilities Toward Fusion Energy*** (Rajesh Maingi and Arnie Lumsdaine; February 2018). This report describes several "*revolutionary*" ideas that would dramatically increase the rate of progress through increased performance, simplification, reduced cost or time to delivery, or improved reliability and/or safety.
- Two weeklong community **Workshops on Strategic Directions for U.S. Magnetic Fusion Research**, hosted by the University of Wisconsin at Madison (July 2017) and by the University of Texas at Austin (December 2017)
- Thank you to leadership of the workshop co-chairs, **David Maurer, Jon Menard, Hutch Neilson, and Mickey Wade**.
- ***16 technical summaries***: Strategic Elements, Strategic Approaches, Working group Summaries.

Statement of Task: *Two Reports*

A committee… will **study the state and potential of magnetic confinement-based fusion research in the U.S. and provide guidance on a long-term strategy**…

✓ **Interim Report**:

- **Assess the current status of U.S. research** that supports burning plasma science
- **Assess the importance of U.S. burning plasma research** to fusion energy development, plasma science, and other science and engineering disciplines.

➡ **Final Report:** *In two separate scenarios in which, after 2018,*

(1) the United States is a partner in ITER, and

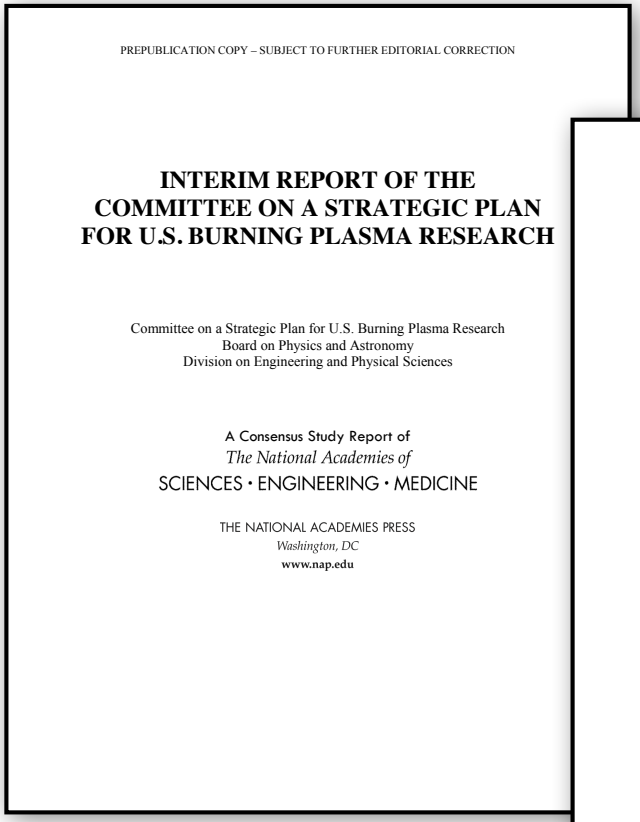
(2) the United States is not a partner in ITER

provide guidance on a long-term strategic plan (***covering the next several decades***) for a national program … given the U.S. strategic interest in realizing **economical fusion energy in the long term**.

Status

- *Interim Report* released on December 21, 2017
- *Final Report* "expected" in December 2018

Interim Report: https://doi.org/10.17226/24971



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INTERIM REPORT OF THE COMMITTEE ON A STRATEGIC PLAN FOR U.S. BURNING PLASMA RESEARCH

Committee on a Strategic Plan for U.S. Burning Plasma Research
Board on Physics and Astronomy
Division on Engineering and Physical Sciences

A Consensus Study Report of
The National Academies of
SCIENCES • ENGINEERING • MEDICINE

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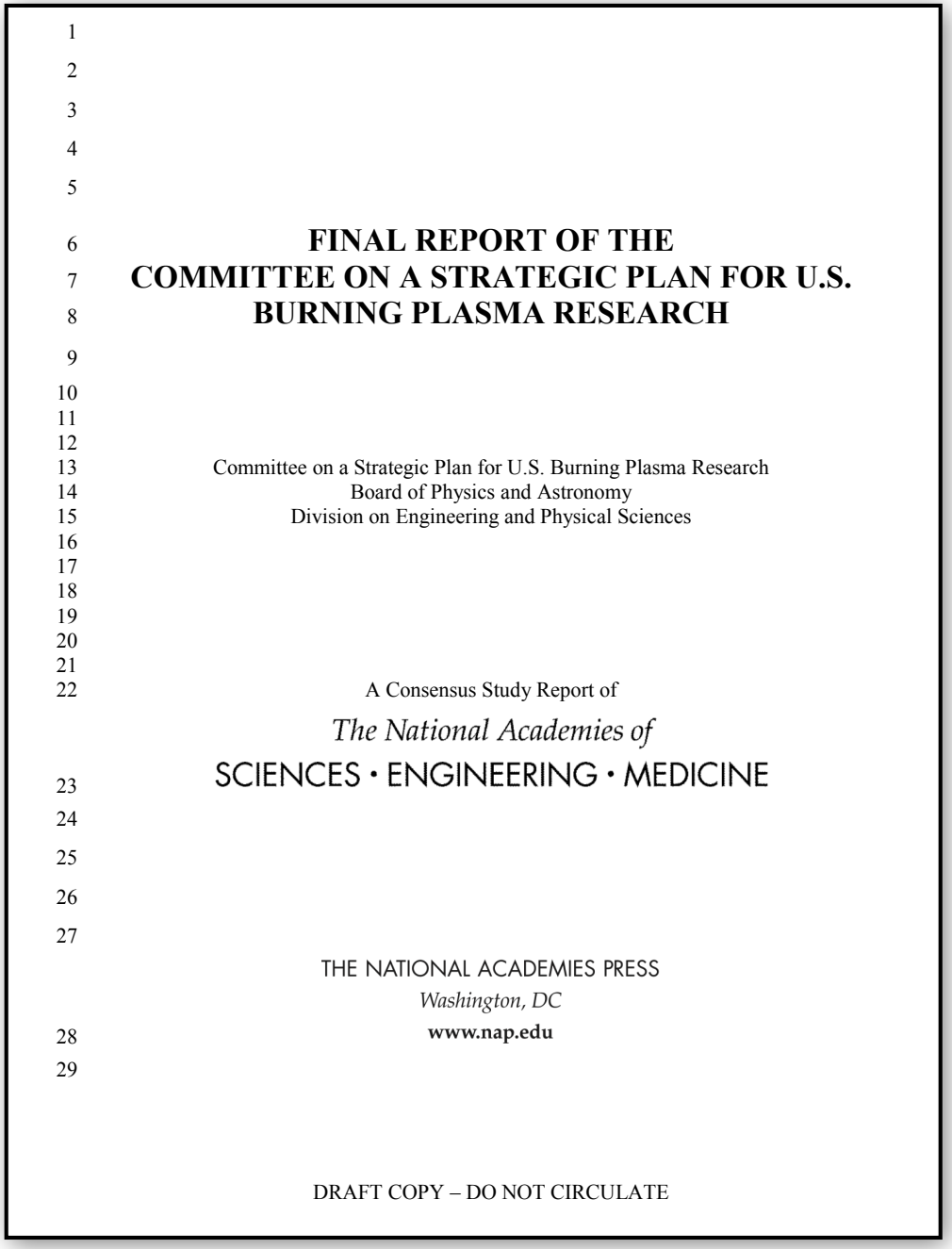
Contents

Draft Final Report



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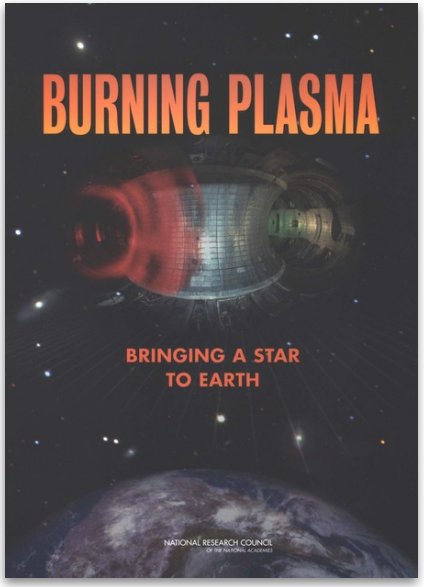
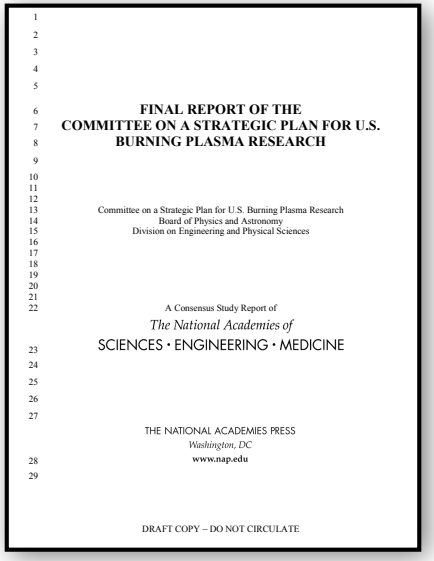
>165 pages,
>36 figures,
> 300 technical references,
plus appendices

As compared with *BP2004*, *BPStrategy* is tasked with an Explicit Long-Term Energy Goal

- ***NAS BP2004*** Task:
  - "assessment of scientific and technical readiness"
  - "strategy aimed at **maximizing the yield of scientific and technical understanding**"
  - "The committee is not asked to evaluate fusion as an energy option."
- ***NAS BPStrategy*** Task:
  - "consider the scientific and engineering challenges and opportunities associated with advancing magnetic confinement fusion as an energy source"
  - "The committee may **assume that economical fusion energy within the next several decades** is a U.S. strategic interest."

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Assessments from the 2004 BPStudy

- (p. 3) “DOE has not yet established a clear program strategy for fusion [as a power source] …, in part because the plans for an international burning plasma experiment have been in flux for the past few years.”

- (p. 4) “The committee concludes that the progress made in fusion science and fusion technology has increased overall confidence in the readiness to proceed to the burning plasma step, …”

  and

  “**The United States should participate in a burning plasma experiment.**”

Scientific and Technical Readiness (2004)
(Chapter 3)

- **Scientific readiness:** (1) Confinement projections, (2) Operational boundaries, (3) Mitigation of abnormal events, (4) Maintenance of plasma purity, (5) Characterization techniques, and (6) Plasma control techniques.

  "*… are sufficiently well understood to proceed with a burning plasma experiment.*"

- **Technical readiness:** (1) Fabrication of necessary components, (2) Component lifetime in a nuclear environment, (3) Lifetime of plasma-facing components, (4) Tritium inventory control, (5) Remote maintenance, and (6) Fueling, heating, and current drive control.

  "*Significant progress has been made in the development of the technology needed to implement a fusion machine of the scale and nature of ITER.*"

Tremendous Progress since 2004

- **ELM control** with weak 3D magnetic fields (*Fenstermacher, Moyer, Evans 2018 Dawson Prize*)
- Simultaneous **control of detachment and core radiation** (*DIII-D-2015 and ASDEX-U-2012*)
- **Predictive models** to optimize the H-Mode pedestal (*Snyder NF Award 2014*); leading to World pressure records (*C-Mod*) and Optimized fusion gain, $Q_{DT,eq} \rightarrow 0.54$ (DIII-D)
- **Full bootstrap current operation achieved** (*TCV-2008*)
- **ILW** experiments (*JET, WEST*) and significant progress understanding the science and technology of the integrated "Core-Pedestal-SOL-Divertor" magnetic fusion system
- (*Reiman and Fisch, **PRL Friday!***) "Suppression of Tearing Modes by Radio Frequency Current Condensation" improving the efficiency of ECCD NTM control.
- Rapid **growth of international effort;** sustained operation using large superconducting experiments: LHD, EAST (2006-), KSTAR (2008-), WEST (2016-)/Tore Supra, W-7X (2015-)
- (***FESAC TEC 2018***) High-field superconducting magnets, advanced manufacturing, intelligent control, novel tritium technologies (and industries innovating in fusion-relevant technology)
- "First-of-a-kind fusion" construction **license** (2012), and (*ITER Council, November 15, 2018*) **ITER first plasma construction is nearly 60% complete (!)**

Three Assessments from 2017 Interim Report

- (*Assessment 2*) "Our ***confidence*** that a burning plasma experiment such as ITER will succeed" has substantially improved

- (*Assessment 3*) "Operation of a burning plasma experiment is a critical, ***but not sufficient***, next step toward the realization of commercial fusion energy. In addition, further research is needed …"

- (*Assessment 7*) "If the U.S. seeks to continue its pursuit for abundant fusion power, the development of ***a national strategic plan for fusion*** energy that spans several decades is necessary"

"The **time is right** to initiate an activity with the community and with FESAC to develop a new long-range strategic plan for the FES program" – *Jim Van Dam (November 5, 2018)*

(*Interim Report,* p. 4) the committee views the following elements as important to its guidance on a long-term strategic plan:

- Continued progress towards the construction and operation of a burning plasma experiment leading to the **study of burning plasma**,
- Research beyond what is done in a burning plasma experiment to **improve and fully enable commercial fusion power**,
- **Innovation in fusion science and technology** targeted to improve the fusion power system as a commercial energy source, and
- **A mission for fusion energy research that engages the participation of universities, national laboratories, and industry in the realization of commercial fusion power for the nation.**

A Strategic Plan for U.S. Burning Plasma Research

On behalf of the committee: Thank you for your expert input

http://nas.edu/fusion