Technical R&D Perspectives and Opportunities for ARPA-E from the NAS BP Strategy Report

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ARPA-E FUSION WORKSHOP
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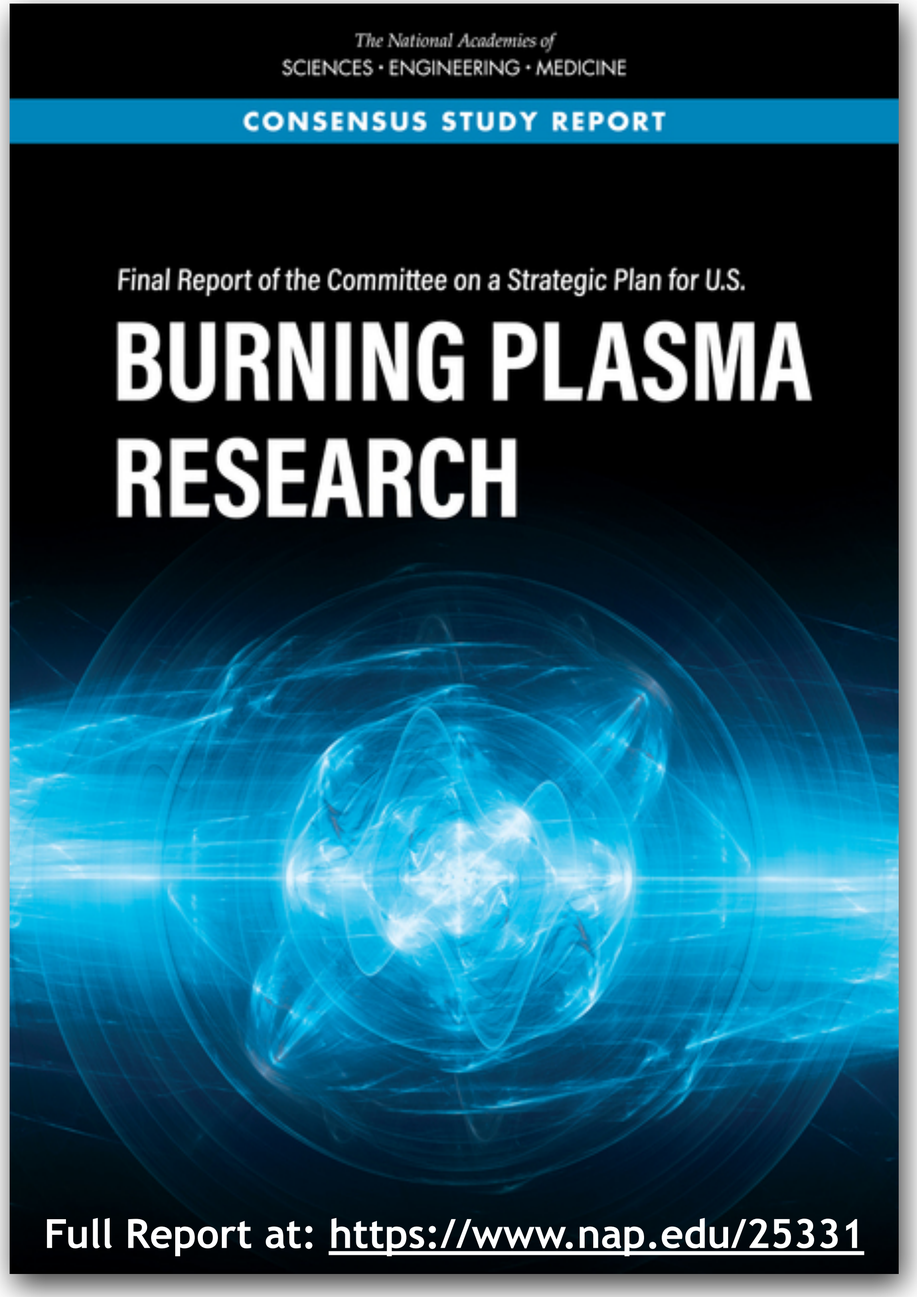
Containing some personal views, not necessarily reflecting the NAS Committee.



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- Two primary recommendations: (1) remain an ITER partner as the most cost-effective way to gain experience with a burning plasma, and (2) **start a national program of accompanying research and technology leading to a compact fusion pilot plant**
- **FESAC/TEC: "Game changing" technical opportunities** make possible a lower-cost pathway to fusion electricity
- **<u>Promoting discovery in fusion science and enginerring</u>**, *an important role for **ARPA-E**, P4, and DOE/FES (from Ch. 5, pp. 145-147)*

Committee on a Strategic Plan for U.S. Burning Plasma Research

The Department of Energy requested two reports:

Interim Report (Dec 21, 2017): assessment of the **current status** of United States fusion research and of the **importance of burning plasma research** to the development of fusion energy and other science and engineering disciplines.

Final Report (Dec 12, 2018): guidance on a **strategic plan for a national program of burning plasma science and technology research** given the U.S. strategic interest in realizing economical fusion energy in the long-term.

(See Full Report and Statement of Task at: https://www.nap.edu/25331)

The Committee's unanimous conclusion is …

Now is the right time ***for the United States to develop plans to benefit from its investment in burning plasma research and take steps towards the development of fusion electricity for the nation's future energy needs.***

The implementation of these plans should be guided by two main recommendations:

- *First, the **United States should remain an ITER partner** as the most cost-effective way to gain experience with a burning plasma at the scale of a power plant.*

- *Second, the **United States should start a national program of accompanying research and technology** leading to the construction of a compact pilot plant which produces **electricity from fusion at the lowest-possible capital cost**.*

Why now?

Conclusion is based on:

- Significant progress in predicting and controlling high-pressure plasma,
- ITER construction is more than half complete and confidence has improved,
- Growth of the international and private sector research programs,
- **New technologies**, such as high-field superconducting magnets, advanced manufacturing and new materials, ***make possible a less costly pathway to fusion electricity.***

Transformational "Game Changing" Enabling Technologies

Transformational Enabling Capabilities for Efficient Advance Toward Fusion Energy (FESAC Feb 2018)

Better Magnets

Brandon Sorbom (*CFS*) compares **REBCO superconducting** tape to copper buss

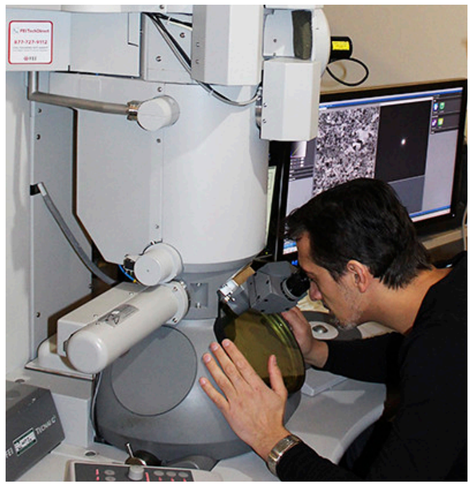
MIT *TechReview* 2019: 35 inventors under 35

Better Control

Julian Kates-Harbeck (*Harvard*) applies **deep-learning** for fusion control (*Nature*, **561**, 526 (2019))

Applied Math, AI, Machine learning, and Exascale computing

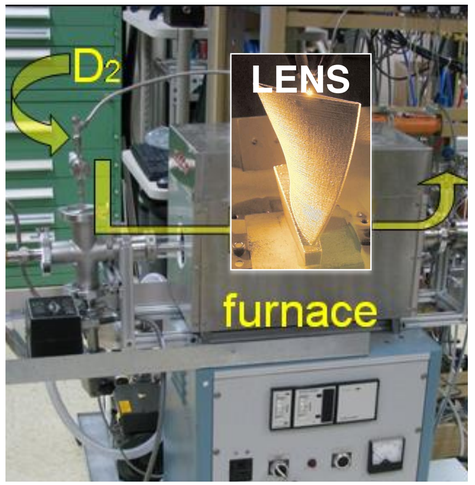
Better Materials



Osman El Atwani (LANL) et al, develop **new tungsten-based alloy** withstands unprecedented fusion radiation without damage (*Science Advances*, Mar 2019)

Materials-by-design, new fusion nuclear materials, AdManf for complex systems.

Better Tritium Tech



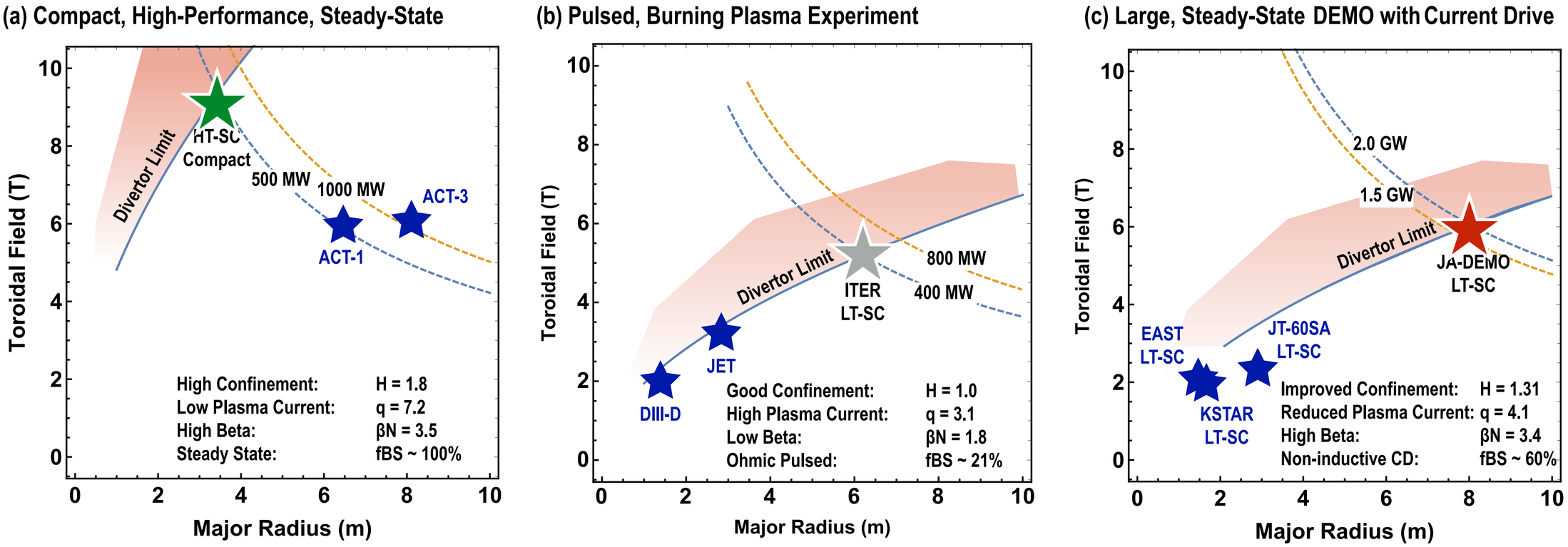
Richard Karnesky (**Tritium Barriers and Diffusion**) and David Gill (**Laser Engineered Net Shaping**) at Sandia National Lab

Fusion fuel production, extraction, and recycle-process

One example (Fig. 4.4):
Better magnets make possible a compact less costly pathway to fusion electricity

Recommended *Not Recommended*

COMPACT ← EXPERIMENT → LARGE DEMO



Magnetic fusion as a function of magnetic field strength, B, and toroidal major radius, R. The fusion power increases rapidly with both size and magnetic field, R^3B^4; the plasma current increases linearly, RB/q; and the power flux to the divertor is assumed to scale as the product of the plasma thermal power and (B/Rq).

Features of the national program leading to the construction of a compact pilot plant at the lowest-possible capital cost

- A compact fusion pilot plant is **a different pathway** as compared our international partners.
- The U.S. pilot plant targets **lowest possible capital cost** (***not levelized C.O.E.***) to reduce the cost of the development pathway.
- The U.S. pilot plant would be **smaller than ITER**; not a DEMO **larger than ITER**.
- The recommended strategy ***entails more technical uncertainty*** than our international partners because it requires research to reduce the capital cost of fusion through the ***development of promising innovations*** ***in burning plasma science, materials science, and fusion engineering science.***

The focus on low-capital cost fusion electricity sets priorities for the near and mid-term research programs

- **Immediately begin new program elements to develop the materials and technologies** needed to extract the heat and recirculate tritium and, also,

  Promote the industrial development of very-high-field superconducting magnets for fusion.

- **Increase the fusion power density** beyond that obtainable in ITER

- Demonstrate uninterrupted operation while also learning how to handle reliably the high levels of escaping heat from the plasma

- **Encourage promising innovations** in burning plasma science and fusion engineering science to simplify maintenance and lower construction cost.

(Ch. 5, pp. 145-147)

Promoting Discovery in Fusion Energy Science and Engineering

- ***To reduce risk and encourage discovery,*** the long-term research strategy should develop promising innovations in burning plasma science and fusion engineering science that can accelerate fusion development or improve and reduce the cost of fusion as a source of electricity.

- New insights and discoveries are expected to occur in all parts of the program. ***But the committee feels that research on less developed and therefore more speculative topics should continue to be a feature of the U.S. program.***

- **ARPA-E strengthens the national program** by supporting research with greater technical "uncertainty", and potential for breakthrough, than DOE/FES.

- **ARPA-E achieves success** when innovations become "main-stream" and accelerate fusion development at DOE/FES and in the private sector.

Organizational Structure and Program Balance

- **Finding:** The recommended ***expansion in scope*** and interconnected programs within DOE/FES will necessitate reconsideration of management and planning to ensure coordination between programs and efficient progress

- **Recommendation:** The committee recommends a new division within U.S. DOE/FES to manage and organize research in developing technologies needed to improve and fully enable the fusion power system.

  Engineering and costing studies for the low-cost pilot plant are essential to guide the integrated fusion research and engineering program.

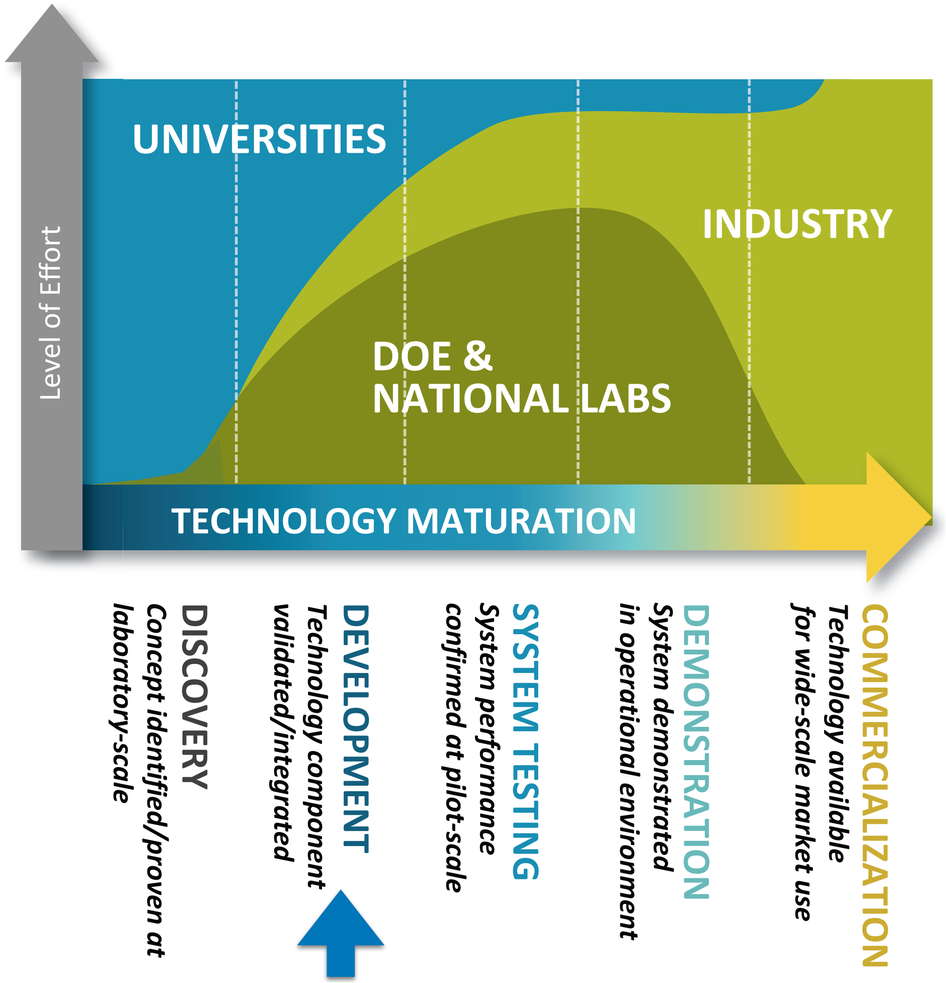
- **Recommendation:** The U.S. DOE Office of Fusion Energy Sciences (FES) should establish formal structures for regular communication with and among leaders of the research communities, ***including ARPA-E***

Opportunities to Encourage and Support Private Sector

- **Finding:** Opportunities exist to encourage and support private investment in fusion energy development and the focused, goal-oriented approach from U.S. industry, which is beneficial to fusion energy development.

- **Recommendation:** The U.S. DOE OFES should define mechanisms to manage assignment of intellectual property as a means to encourage both private and publicly funded researchers to establish mutually beneficial partnerships.

- **Recommendation:** The U.S. DOE OFES should conduct outreach initiatives that engage the fusion research community and inform the nation. <u>Public awareness is a critical element in maintaining support.</u>

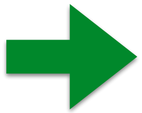


The institutional balance of science and technology research evolves with maturity and technical readiness of the technology. From the 2017 *Annual Report on the State of DOE National Laboratories.*

Summary

- **New technologies,** such as better magnets, better control, better materials, and better tritium technology, **make possible a less costly pathway to fusion electricity.**

- To reduce technical risk and encourage discovery, **all parts of the program should develop promising innovations**, but



The committee feels that research on less developed and therefore more speculative topics should continue to be a feature of the U.S. program.

- **ARPA-E strengthens the national program** by supporting more speculative research, and potential for breakthrough, than DOE/FES.

- **ARPA-E achieves success** when innovations become “main-stream” and accelerate fusion development at DOE/FES and in the private sector.

- The recommended ***expansion in scope*** and interconnected programs within DOE will necessitate reconsideration of **management and planning**.

Committee and report information at: https://www.nap.edu/25331