

Summary and Perspectives from the NAS Burning Plasma Strategy Report

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NAS Committee on Key Goals and Innovations Needed for a U.S.
Fusion Pilot Plant
September 2, 2020 — Zoom

Containing some personal views, not necessarily reflecting the NAS Committee.



Outline

- Context and Background
- Two main recommendations (focus on second recommendation)
- FESAC/TEC: “Game changing” technical opportunities make possible a lower-cost pathway to fusion electricity
- Closing comments

Today, Fusion Energy Science Enjoys Remarkable Consensus (but, this hasn't always been the case)

Then (2013-2015)

ITER Cost/Schedule Concerns:

- U.S. Senate Leaders Request GAO Study (May 2013)
- GAO-14-499 (June 2014) *Actions Needed to Finalize Cost and Schedule Estimates for U.S. Contributions to an International Experimental Reactor*

FESAC Strategic Planning:

- “As evidenced in the public record, there is partial consensus, and significant disagreement, within the community regarding the top-level FES Program vision, strategy and associated priorities.”
C. Keane, Acting Chair (Dec 2014)

Now (2016-2020)

ITER Updated Long-Term Schedule:

- Bigot reforms management; sets baseline (June 2016)
- U.S. DOE/OS Approves ITER Project Plan (Jan 2017)
- ITER Assembly Phase Begins (July 2020)

FESAC Strategic Planning:

- APS-DPP-CPP delivers comprehensive plan (March 2020) “A success, not only by yielding the presented plan, but also bringing a diverse community together”
- FESAC Long Range Planning underway
T. Carter, Chair (June 2020 –)

Study Origin

CONSOLIDATED APPROPRIATIONS ACT, 2016

PUBLIC LAW 114–113—DEC. 18, 2015

(129 STAT. 2410) That not later than May 2, 2016, the Secretary of Energy shall submit to the Committees on Appropriations of both Houses of Congress **a report recommending either that the United States remain a partner in the ITER project after October 2017 or terminate participation**, which shall include, as applicable, an estimate of either the full cost, by fiscal year, of all future Federal funding requirements for construction, operation, and maintenance of ITER or the cost of termination.



U.S. Department of
ENERGY

U.S. Participation in the ITER Project

May 2016

United States Department of Energy
Washington, DC 20585

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

The Department of Energy requested two reports:

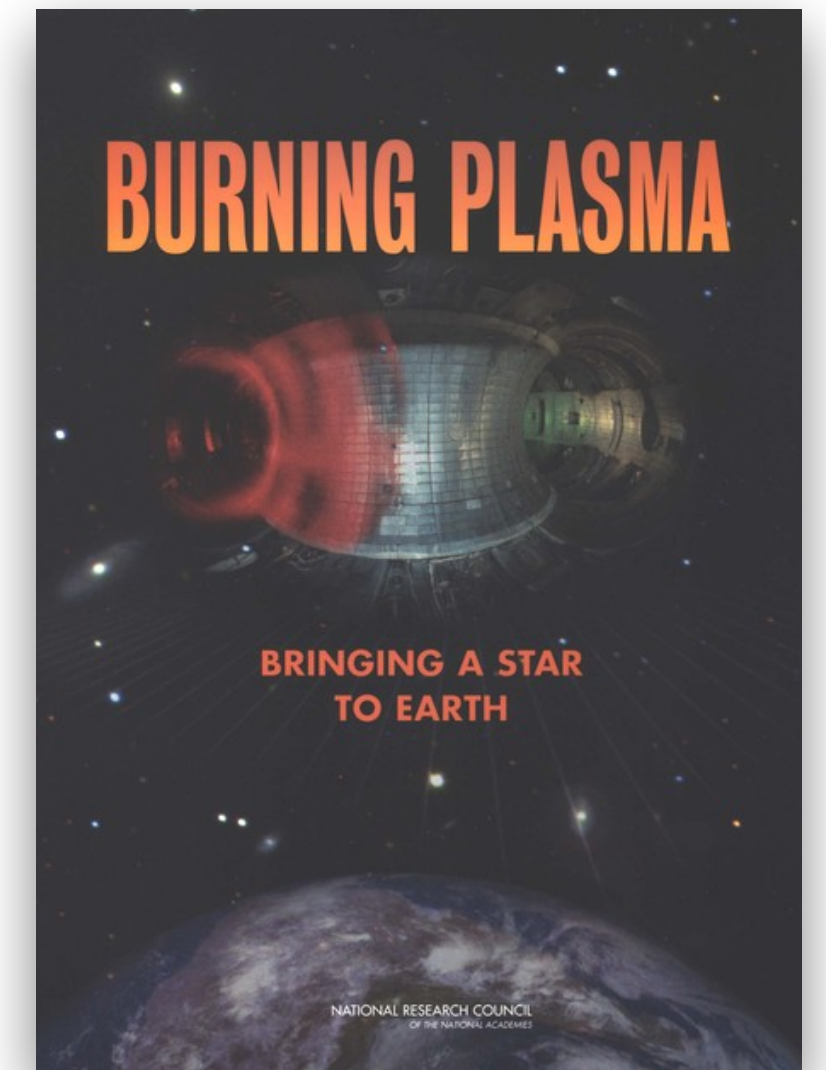
Interim Report (Dec 21, 2017): assessment of the **current status** of United States fusion research and of the **importance of burning plasma research** to the development of fusion energy and other science and engineering disciplines.

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.

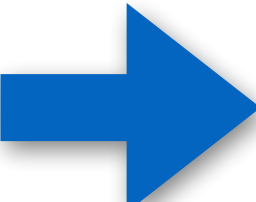
(See Full Report and Statement of Task at: <https://www.nap.edu/25331>)

Unlike *BP-2004*, *BPStrategy-2019* was tasked with an **Explicit Long-Term Energy Goal**

- ***NAS-2004 BP* 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-2019 BP-Strategy* 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.”



The Committee's unanimous conclusion is ...

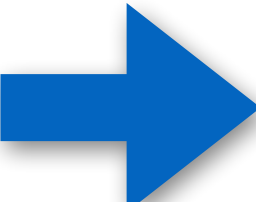


*Now is the right time **for the U.S. to develop plans to benefit from its investment in burning plasma research and take steps towards the development of fusion electricity***

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

- *First, the **U.S. 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 U.S. **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.***

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Why now?

Conclusion is based on:

- Significant progress in predicting and controlling high-pressure plasma (*Ch. 2*)
- ITER construction is more than half complete and confidence has improved (*Ch. 3*)
- Growth of the international and private sector research programs (*Ch. 5*)
- **New technologies (*Ch. 4*)**, 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

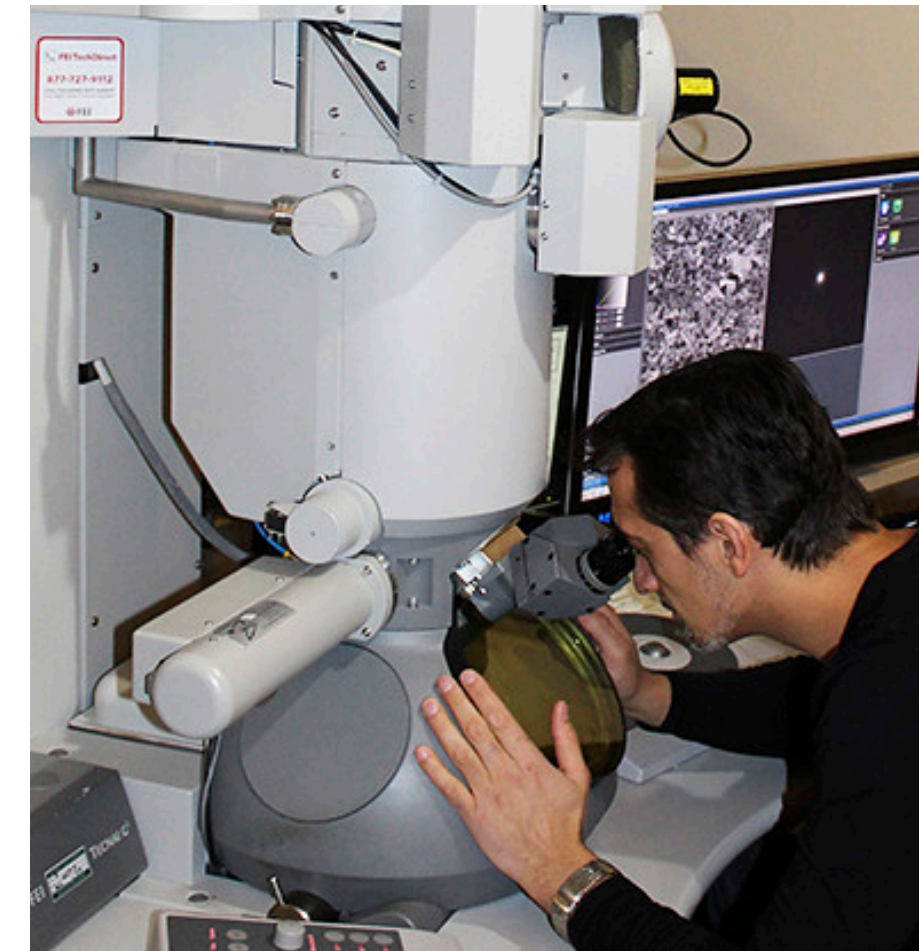
Better Control



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

Applied Math, AI,
Machine learning, and
Exascale computing

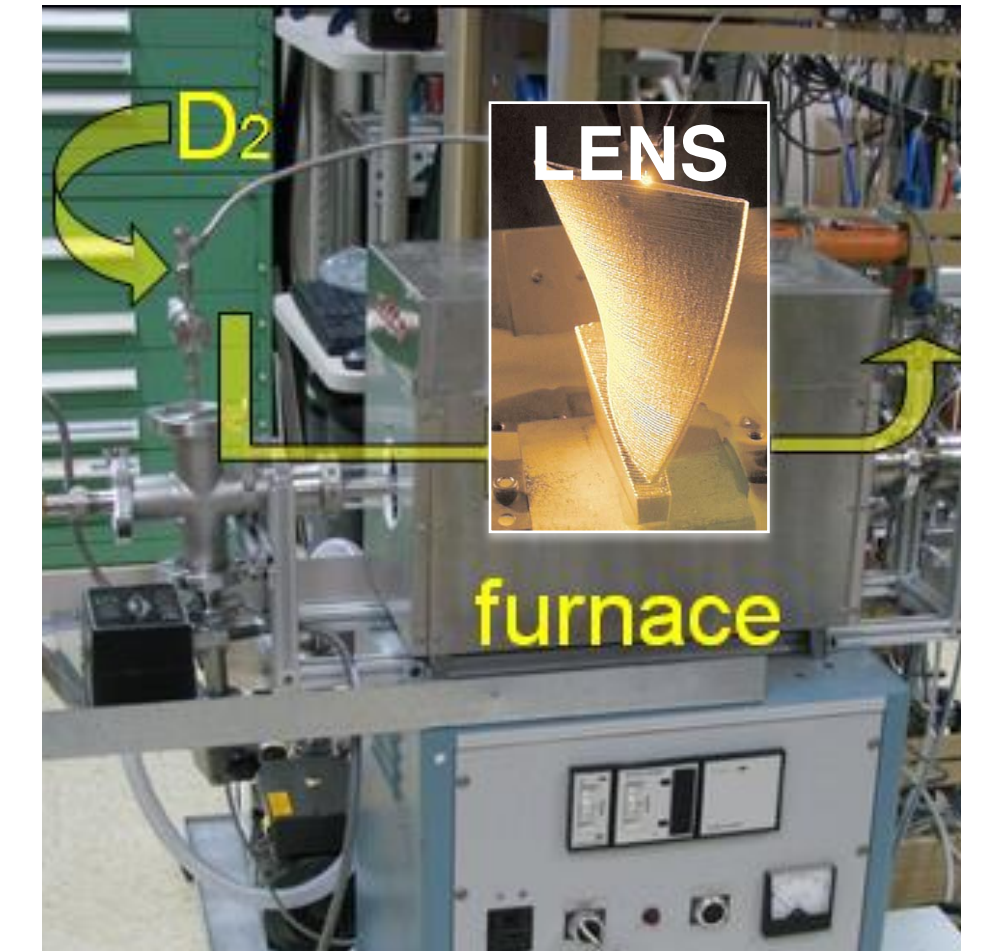
Better Materials



Osman El Atwani, Enrique Martinez (LANL) et al, develop **new tungsten-based alloy** withstands fusion radiation
(*Science Advances*, Mar 2019)

Materials-by-design,
new fusion nuclear
materials.

Better Tritium Tech



Richard Karnesky (**Tritium Barriers and Diffusion**) and David Gill (**Laser Engineered Net Shaping**) at Sandia National Lab; and **significant national expertise** (SRNL, ...)

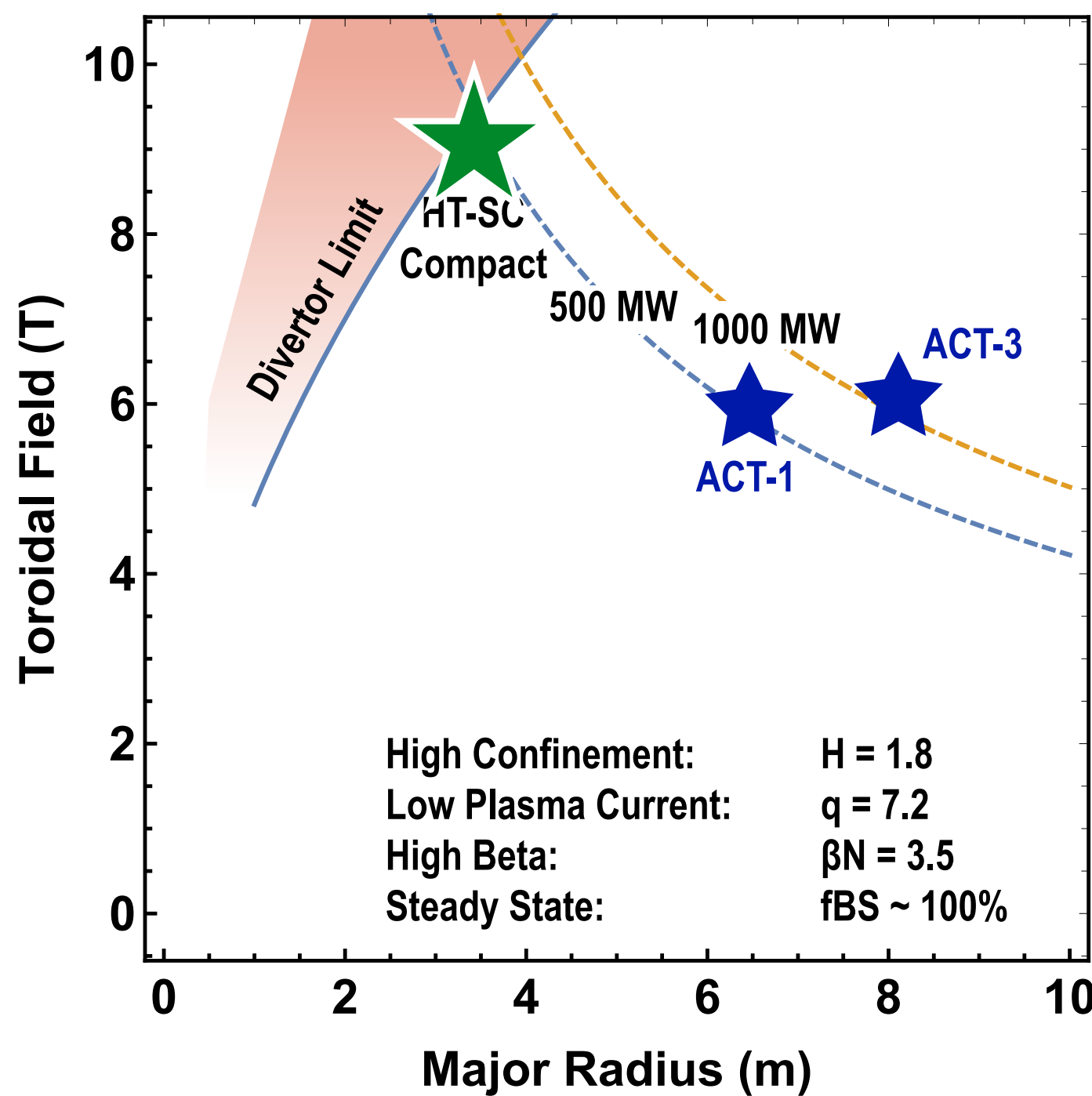
Fusion fuel production,
extraction, and recycle-
process

One example (Fig. 4.4):

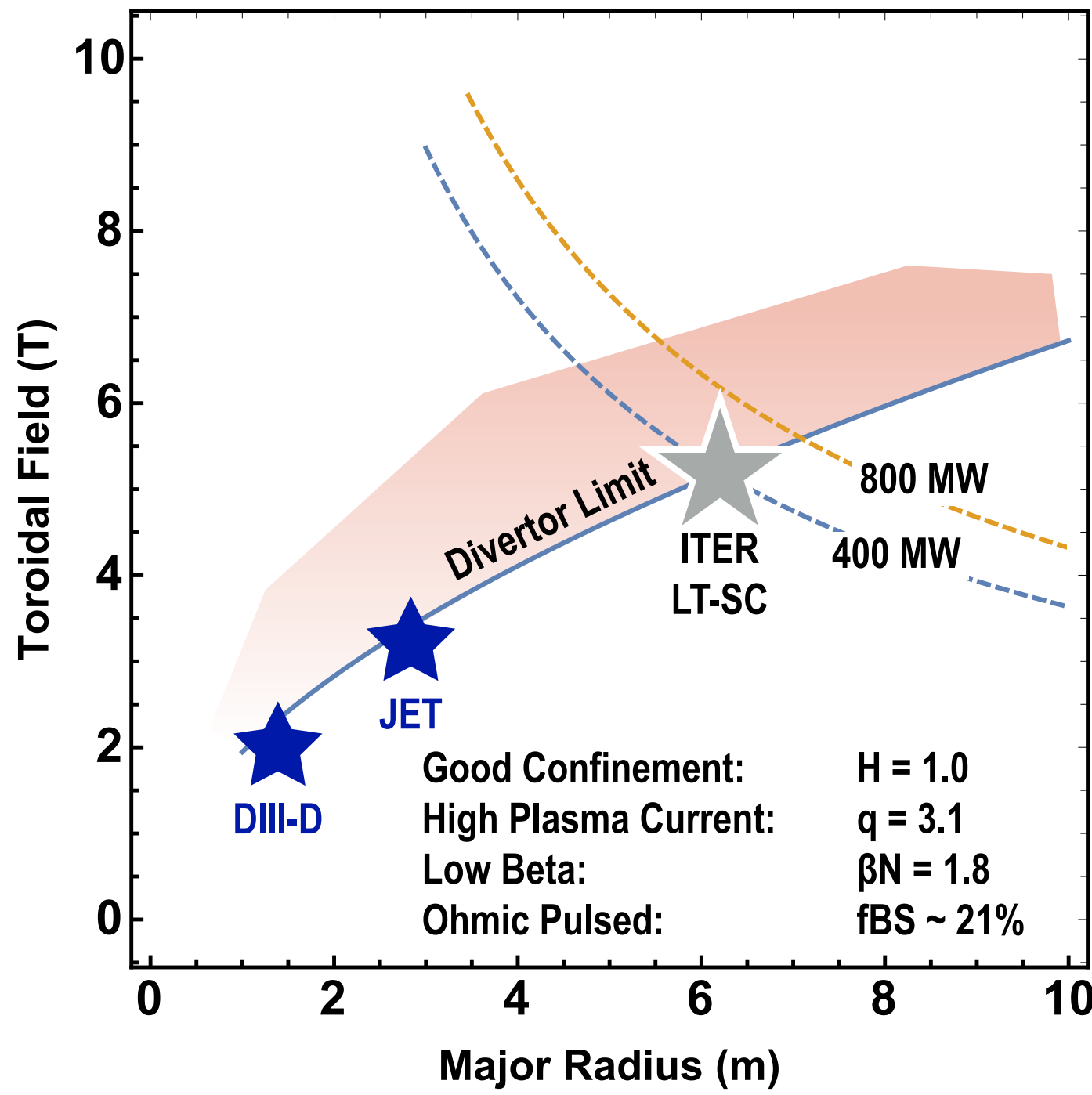
Better magnets make possible a compact less costly pathway to fusion electricity

COMPACT ← Recommended EXPERIMENT → Not Recommended LARGE DEMO

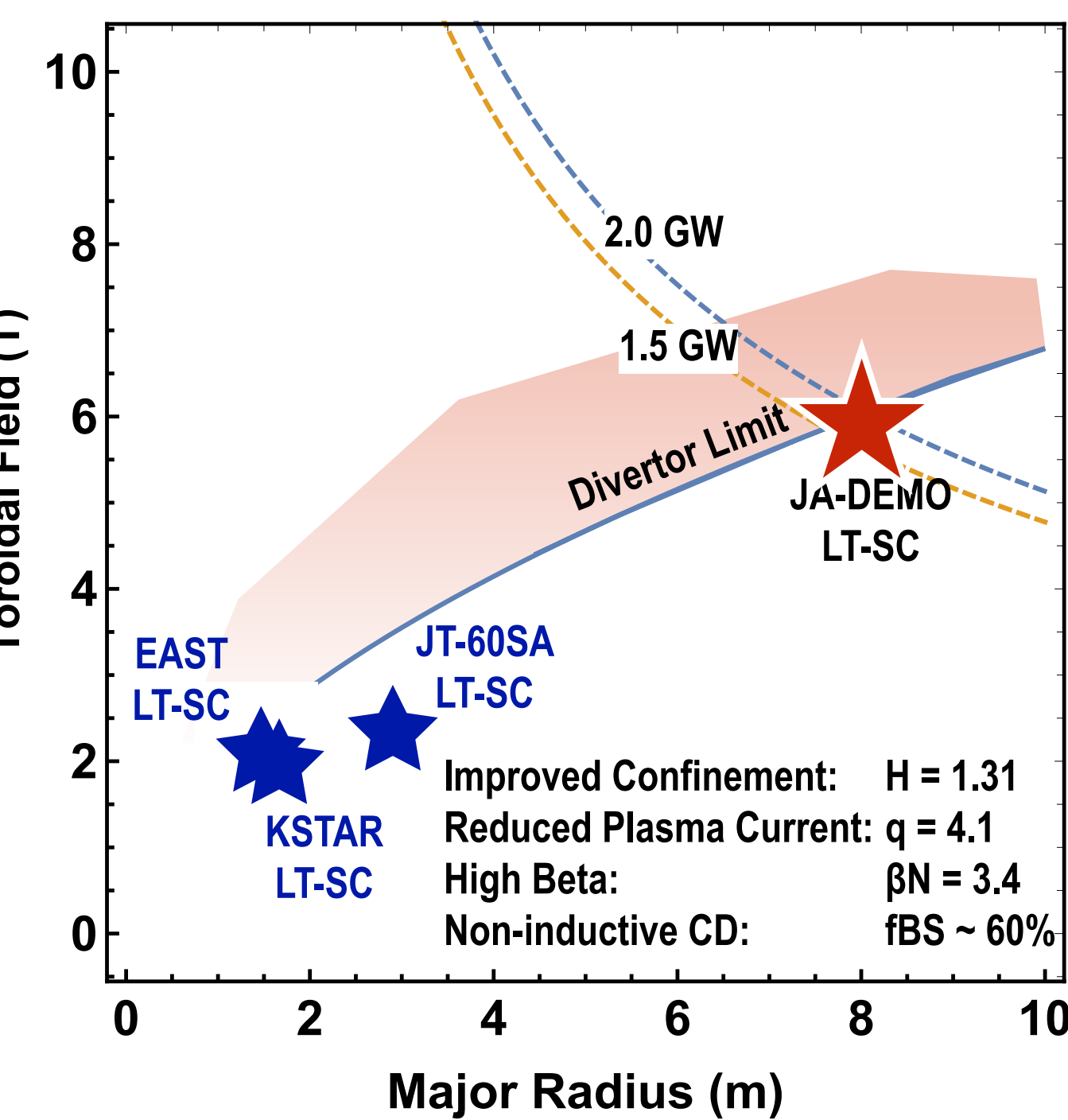
(a) Compact, High-Performance, Steady-State



(b) Pulsed, Burning Plasma Experiment



(c) Large, Steady-State DEMO with Current Drive



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, $R^3 B^4$; 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) .

Main Recommendation #2

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

- **Finding:** Recent advances motivate a new national research program leading to the construction of a compact fusion pilot plant at the lowest possible capital cost ... Significant progress ... **now make a compact device technically possible, affordable, and attractive for industrial participation.**
- **Recommendation:** In the near- and mid-terms, the U.S. DOE should **resolve critical research needs for the construction of a compact fusion pilot plant ...**
- **Recommendation:** In addition to ITER, **new research facilities should be built** to increase the technical and scientific readiness of critical capabilities needed to construct a compact fusion pilot plant. This will require retiring one or more existing facilities as they complete their most important goals.

Setting a National Goal

Characteristics of U.S. Fusion Pilot Plant:

- Produce fusion power similar to ITER but in **a device much smaller in size and cost** and employing design improvements to allow net electricity production.
- This compact fusion pilot plant would be a pre-commercial research facility.
- In addition to the production of fusion electricity, **it would be staged** and ultimately be capable of uninterrupted operation for weeks and produce tritium.
- As a pilot plant, **its purpose will be learning**, but the knowledge obtained would be sufficient to design the first commercial fusion power systems.

A compact fusion pilot plant is a different pathway as compared with DEMO or FNSF

- The U.S. pilot plant targets **lowest possible capital cost** (*not levelized C.O.E., availability, maintenance, decommissioning, ...*) to reduce the cost of the development pathway.
- The U.S. pilot plant would be “compact”: **smaller than ITER**; not a DEMO **larger than ITER**.
- The U.S. pilot plant **advances both fusion physics and fusion technology** to demonstrate fusion electricity production without a large intermediate FNSF facility.
- The recommended strategy ***entails more technical uncertainty*** than our international partners because it requires research to reduce the capital cost of fusion through the **integrated progress in burning plasma science, materials science, and fusion engineering science**.

Two-Phase Approach to the Compact Fusion Pilot Plant

Recommendation: In recognition of the significant challenges that needs to be addressed for the construction of a compact fusion pilot plant facility capable of electricity production, the U.S. DOE OFES **plan for a pilot plant should have a two-phase approach.**

- ***In the first phase***, the pilot plant should be capable of demonstrating fusion electricity production for periods lasting minutes and establish the feasibility of electricity production **including the assessment of plasma material interactions, tritium safety, pumping, recycling, breeding, and extraction.**
- ***In the second phase***, the pilot plant should be capable of uninterrupted operation for many days **allowing fusion materials and component testing** consistent with a commercial power plant, including **full fuel cycle blanket testing.**

Resolving technical uncertainties will necessitate the design and operation of new facilities

Two most significant research challenges:

- The **control of a continuous high-pressure compact plasma**, which will require a design and construction of new intermediate-scale research facility in the United States, or a significant upgrade to an existing facility, to establish its feasibility. (*CPP recommended a new facility, NTUF.*)
- The **qualification of the materials and components** that surround the plasma and are exposed to fusion irradiation. (*CPP recommended a FPNS.*)

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

In addition to ITER partnership...

- **Immediately begin new program elements to develop the materials and technologies** needed to extract the heat and recirculate tritium
- **Promote the industrial development** of very-high-field superconducting magnets for fusion.
- **Increase the fusion power density** beyond that obtainable in ITER
- Learn 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.

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.

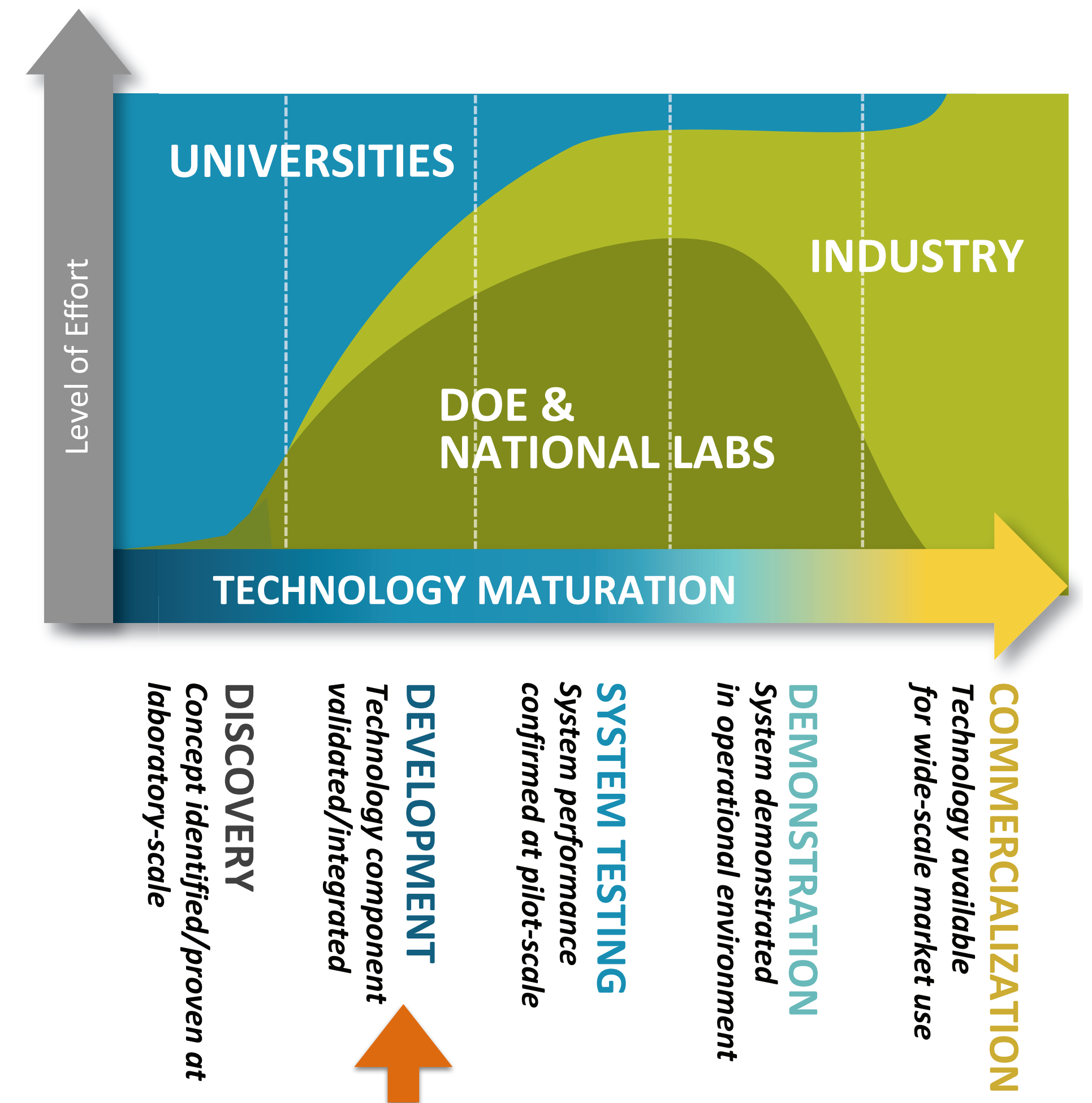
Engineering and costing studies for the low-cost pilot plant are essential to guide the integrated fusion research and engineering program. (CPP RecA: Establish a multi-institutional, multidisciplinary program to develop fusion pilot plant concepts.)

- **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 BES, NE, NRC, NNSA, 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. Public awareness is a critical element in maintaining support.

INFUSE



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*.

Recap

Now is the right time to benefit from our investment in burning plasma research and take steps towards the development of fusion electricity.

- *First, the U.S. should remain an ITER partner...*
- *Second, the U.S. 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*

A new national focus on low-capital cost fusion electricity **sets priorities for the near and mid-term research programs**, and

Necessitates **reconsideration of management and planning for integrated progress** in *burning plasma science, materials science, and fusion engineering science.*

NAS-2019 BPStrategy and NAS-2020 KGINUSFPP

“The NAS shall assemble a committee to provide guidance to DOE and others that are aligned with the objective of constructing a pilot plant in the U.S. that produces electricity from fusion at the lowest possible capital cost (“Pilot Plant”).”

Comments:

- Lowest cost pathway to fusion electricity is *the key goal*.
- Explain how our success predicting and controlling a burning plasma can be integrated with transformational new technologies to achieve the lowest possible capital cost.
- Explain how the new national focus sets priorities for the near and mid-term research programs.
- In addition to ITER, NAS-2019 recommended five specific near- and mid-term research directions ...
- Guide FES as the research portfolio is expanded to include materials science and fusion engineering science.
- Provide your views for new management and planning processes that strengthen private sector and inter-agency efforts.

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

*The National
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ENGINEERING
MEDICINE

Final Report of the Committee on a Strategic Plan for

BURNING PLASMA RESEARCH

Download the report at [nap.edu/25331](https://www.nap.edu/25331)