

Perspectives and Plans for the US Fusion Program and General Atomics' Part in It

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Fusion Power Associates
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General Atomics Embraces the Spirit and Recommendations of the National Academies' Report

“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.”

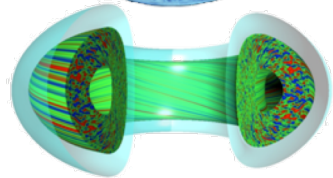


Two top-level recommendations:

- **Remain a partner in ITER**
- **Start a national R&D program leading to the construction of a electricity-producing pilot plant at the lowest possible capital cost**

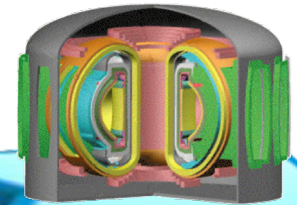
How do We Get There?

Experiments Worldwide

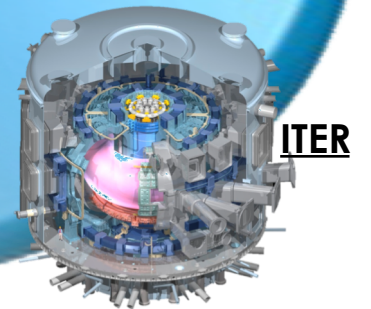


Theory and Computation

???

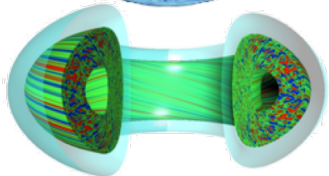


Cost-attractive Pilot Plant/FNSF



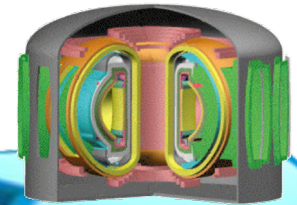
The Key Question to Ask is ...

Experiments
Worldwide



Theory and
Computation

What R&D will enhance the
attractiveness, timeliness of the
pathway and/or end product?



Cost-attractive
Pilot Plant/FNSF

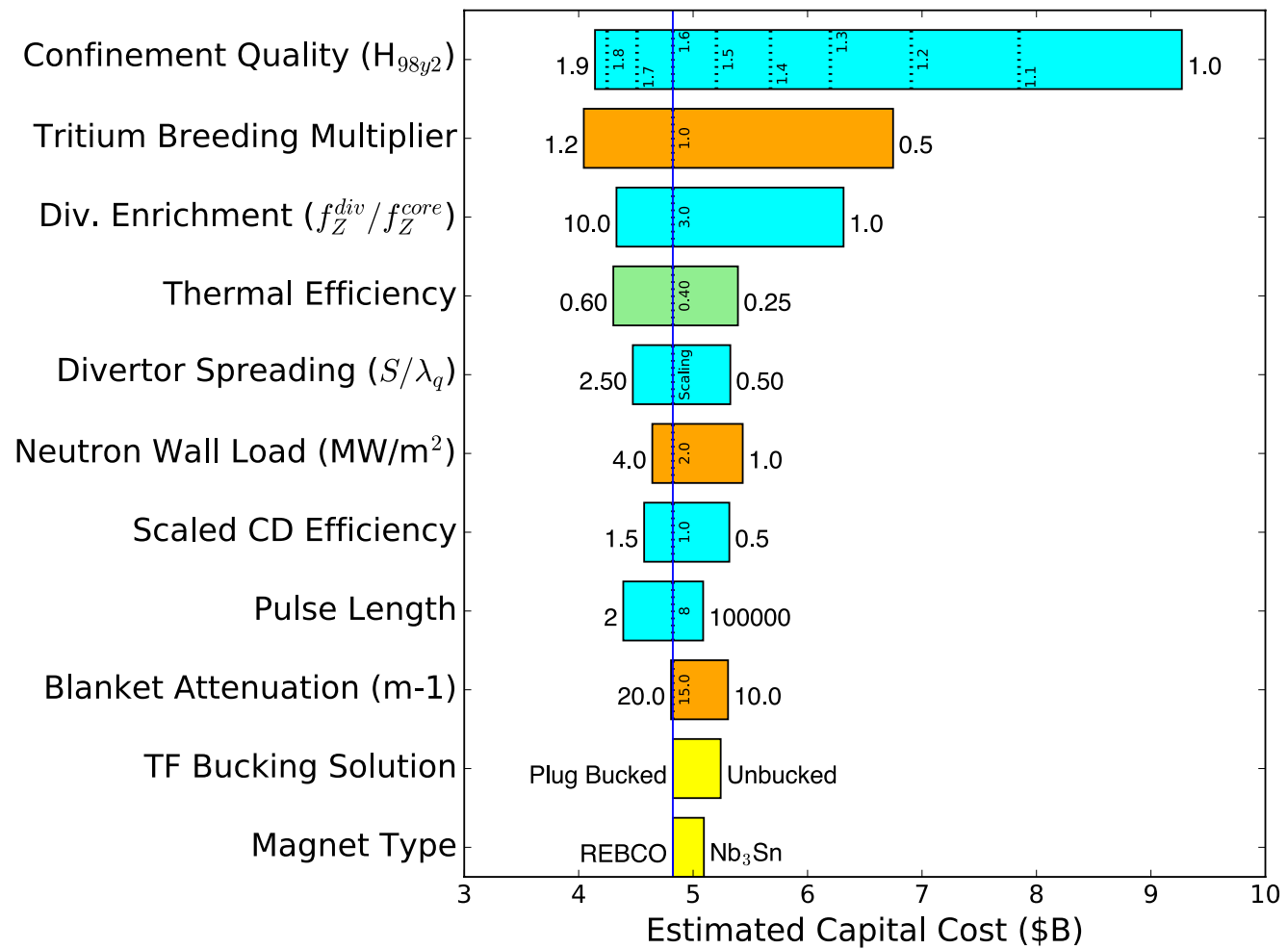


ITER

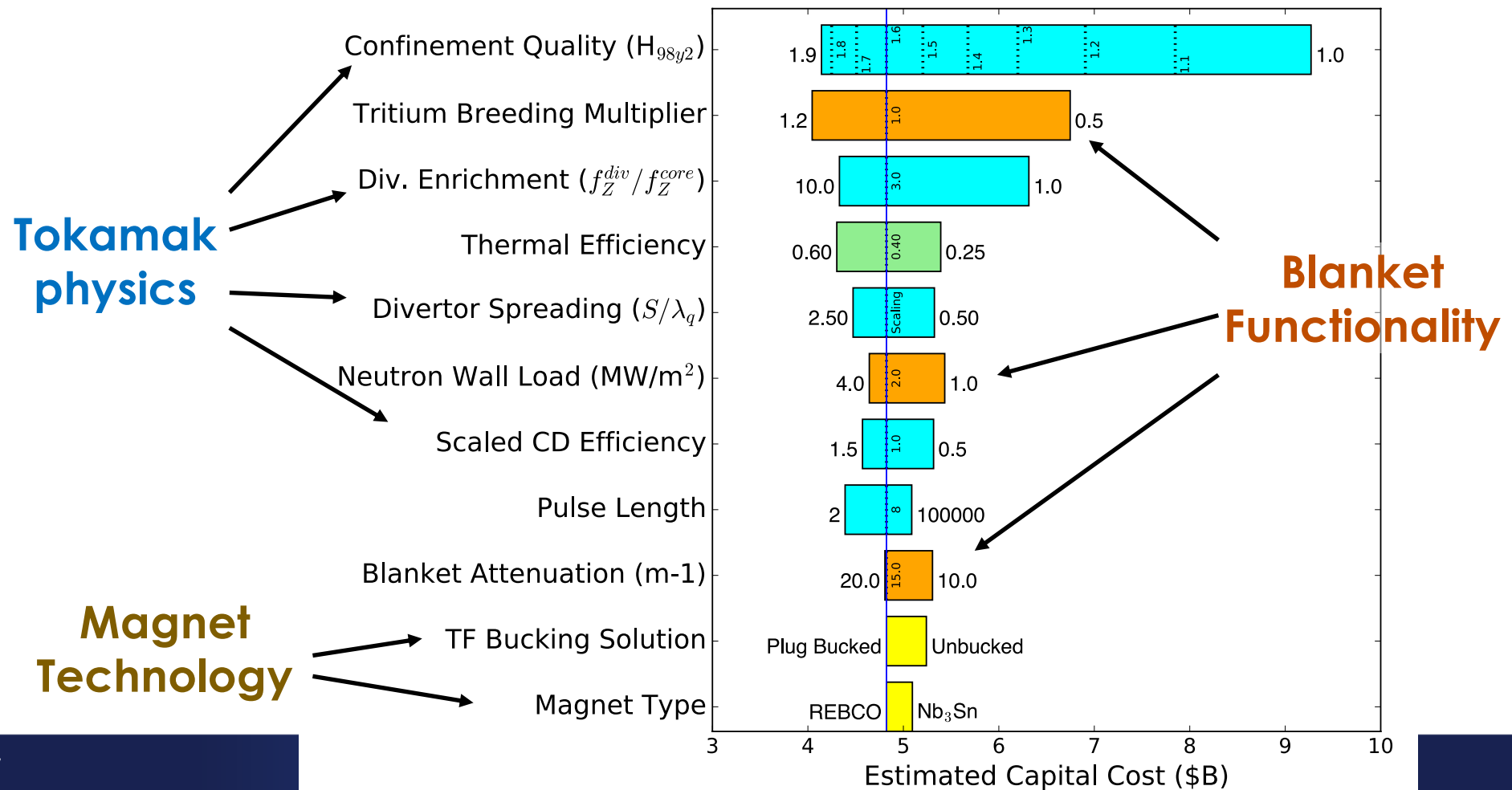
Let's Look Ahead to What a Cost-Attractive Pilot Plant Would Look Like

- **At present, no agreed upon technical requirements for a CFPP**
- **My assumptions for those requirements:**
 - 1) Produce 200 MW-e
 - 2) Must produce (or purchase) sufficient tritium for its operation
 - 3) Must operate for a 2-year calendar lifetime
 - 4) Capital costs to construct should be minimized; operating costs is secondary consideration; COE not important at all
- **Note that these assumptions significantly reduce potential impact of material lifetime and availability requirements**

“Tornado Chart” Reveals Most Sensitive Parameters with Regard to Capital Cost

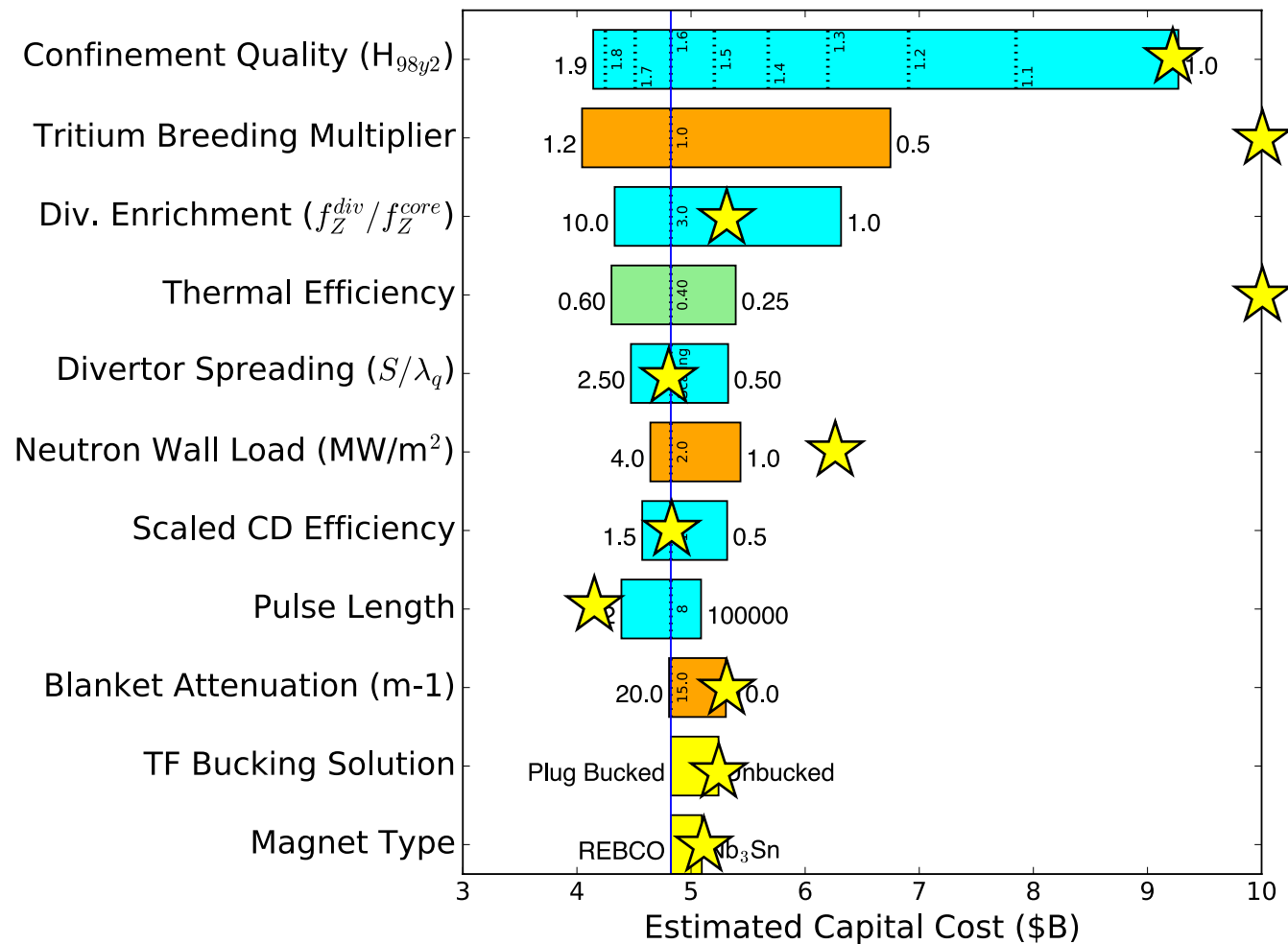


Minimizing Capital Cost Demands High Confinement with Adequate Power Exhaust, TBR ~ 1, and $\eta_{th} > 33\%$



Improvement Needed Beyond ITER Design Basis in Several Areas

★
Nominal
ITER
Design

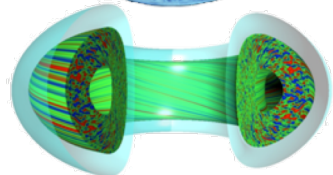


Outline of Talk

Develop Foundation for Tokamak Approach to Fusion

Experiments Worldwide

1



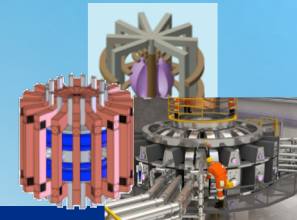
Theory and Computation

Secure Benefit of ITER Construction and Operation

2

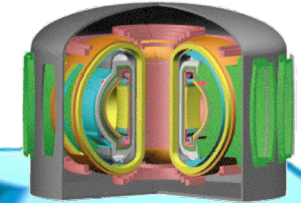


New fusion facilities
(incl. materials,
magnets, blankets)



Enhance Attractiveness, Timeliness of Pathway and/or End Product

3



Cost-attractive
Pilot Plant/FNSF

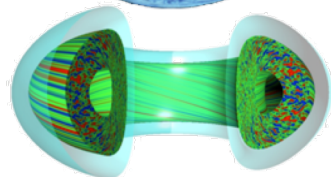
GA Perspective: Near-Term R&D Should Focus on Delivering Foundation for High Confinement, Power Exhaust, and Current Drive

Develop Foundation for Tokamak Approach to Fusion

Experiments Worldwide

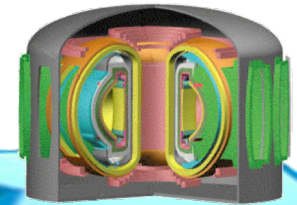


1



Theory and Computation

- Highest leverage on reducing capital cost is sustained high confinement
- ... Consistent with a dissipating divertor
- ... Utilizing CD tools with high combined plug/CD efficiency

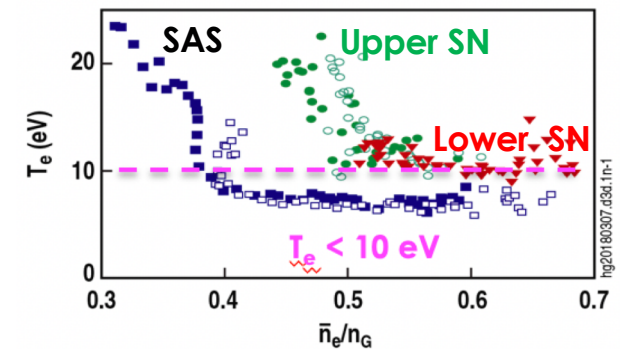
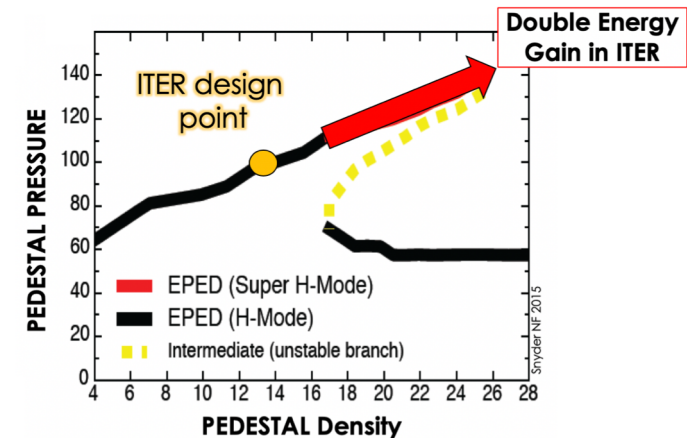
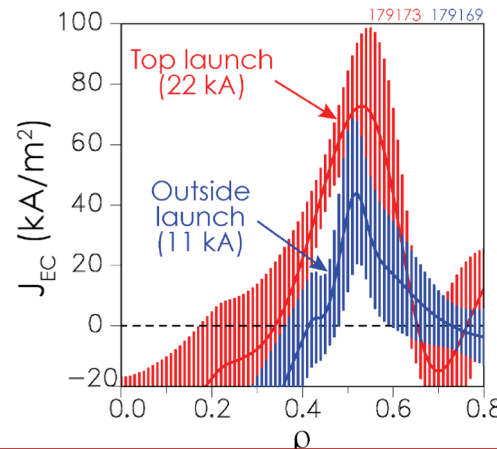


Cost-attractive Pilot Plant/FNSF

Possibly challenging to do this simultaneously in any existing facility, but can (and should) develop physics basis

DIII-D Continues to Deliver 'Factor of Two' Improvements In the Physics Basis for Future Devices

- Super H-mode \rightarrow x2 increase in energy gain in ITER
- Vertical Launch ECCD \rightarrow x2 increase in CD efficiency
- SAS divertor \rightarrow x2 decrease density at detachment



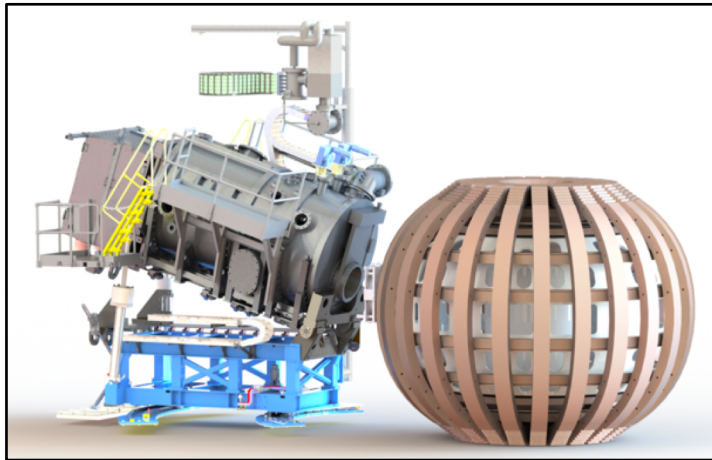
Productivity driven by continuing upgrades,
comprehensive diagnostic set, and diverse,
experienced staff

Plan: Exploit DIII-D to Deliver Physics Basis For Enhanced Performance for ITER and a Cost-Attractive Pilot Plant

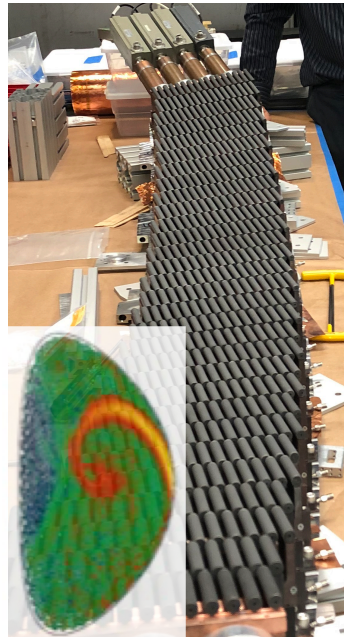
- Program now executing DIII-D 2019-24 plan
- Key areas of research:
 - Disruption Avoidance and Mitigation
 - ELM control
 - Sustained high-confinement scenarios for ITER and future reactors
 - Physics basis of the dissipative divertor
 - Assessment of new current drive tools
 - ...Many more



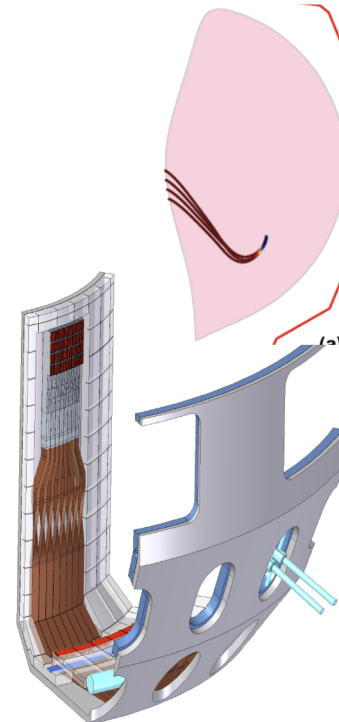
Facility Upgrades Will Provide New Opportunities for Breakthroughs in Fusion Performance and Physics Understanding



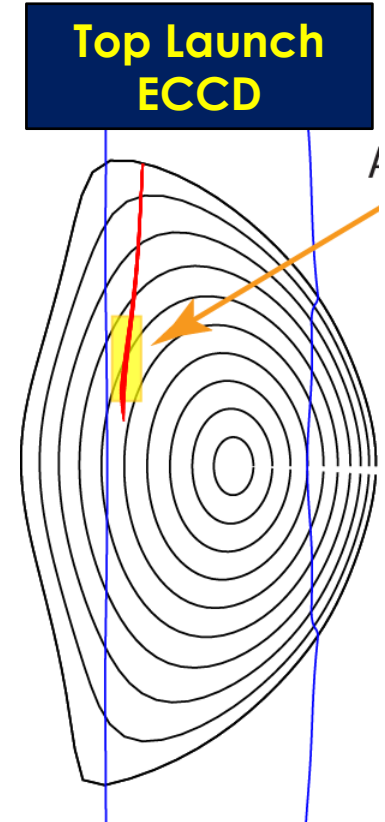
**Off-axis
Steerable NBI**



Helicon



**High Field Side
Lower Hybrid**



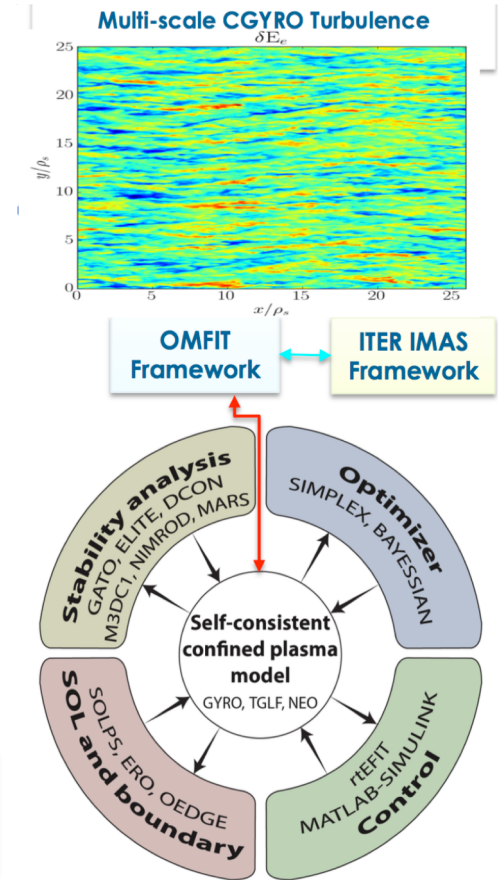
**Top Launch
ECCD**

GA Theory Program Focused on Delivering Impactful Predictive Capabilities for Fusion Development

Multi-Prong Approach

- New theoretical/computational approaches
- High performance computing (HPC) applications
- Integrated predictive modeling using a hierarchy of models
 - HPC simulation codes for calibration
 - Reduced models for large dataset validation
 - Ultra-fast neural networks driven by machine learning on extensive data sets

Goal: Guide present experiments and design of future devices through 'predict first' methodology



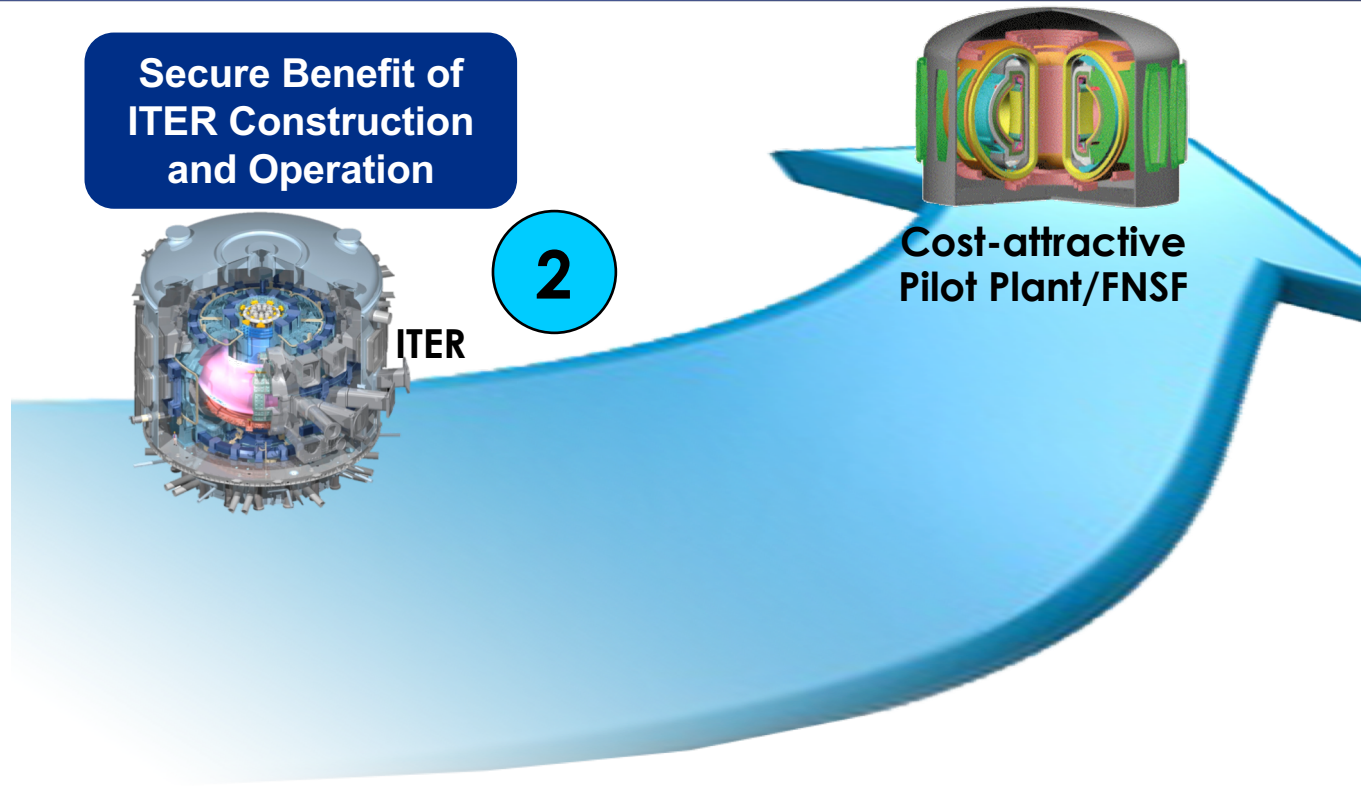
GA Perspective: ITER is a Critical Element In Expediting the Pathway to a Cost-Attractive Pilot Plant

Physics

- Understand burning plasma dynamics

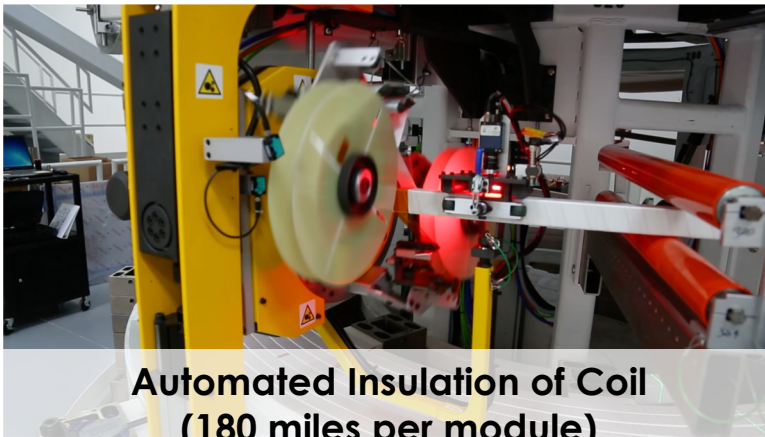
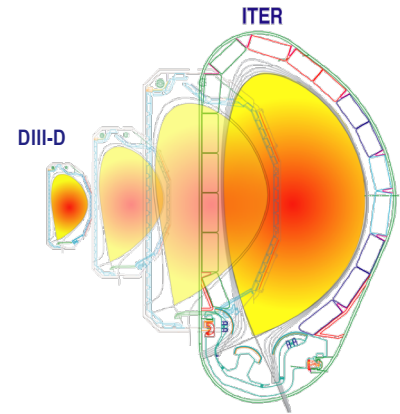
Technology

- Learn how to build a fusion reactor

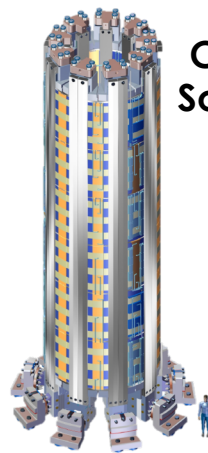


Plan: Ensure success of ITER Through Improved Physics Basis and High Quality Fabrication of ITER Central Solenoid and Key Diagnostics

- DIII-D/Theory: Resolve baseline questions & provide basis for exceeding expectations
- ITER Project: Timely delivery of key components
- Collaborate internationally in key areas
- Participate in early US research team development



Automated Insulation of Coil
(180 miles per module)



ITER
Central
Solenoid



ITER CS
Team

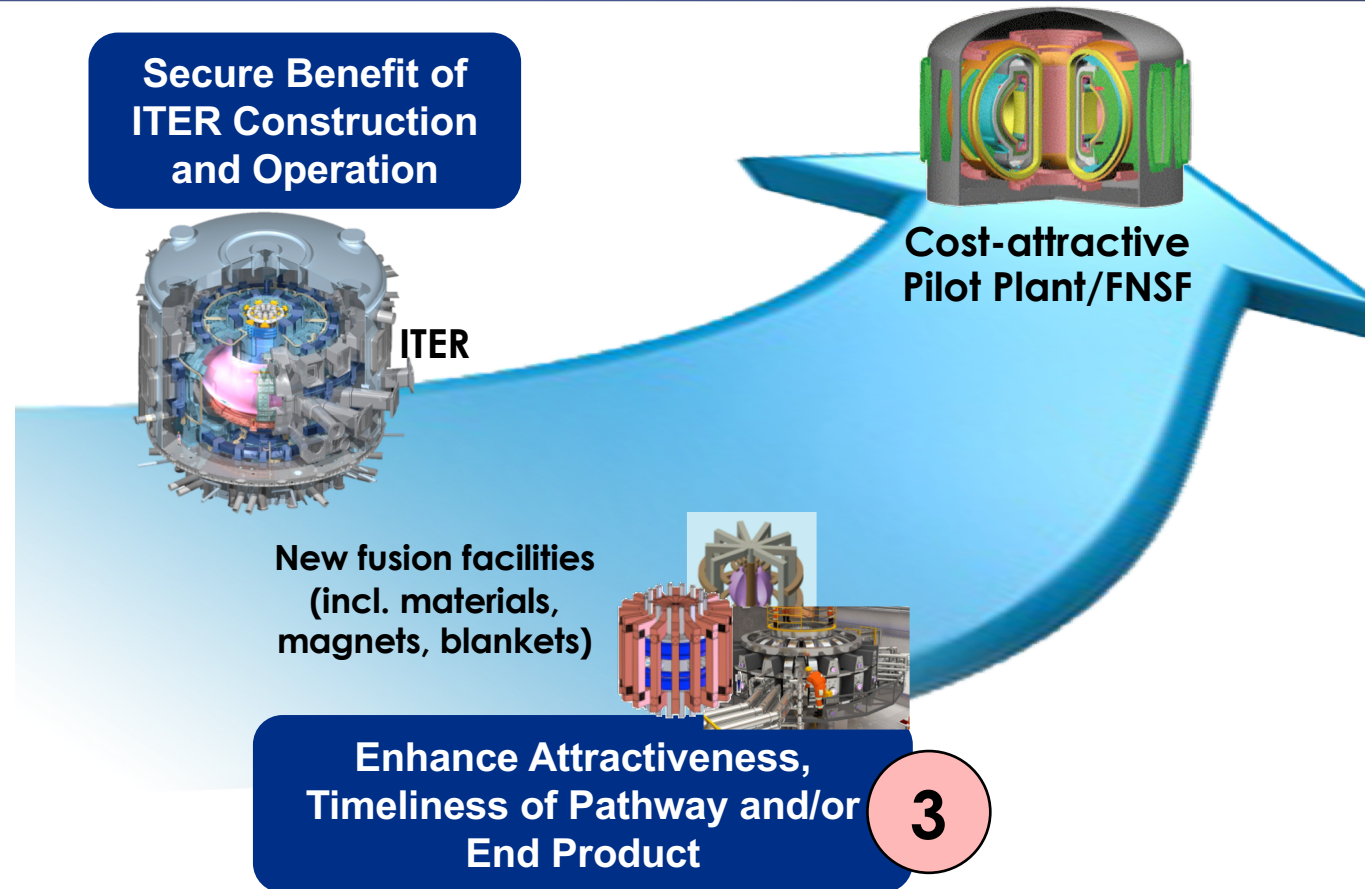
GA Perspective: New Facilities Are Required to Prepare the Design Basis for a Cost-Attractive Pilot Plant

Physics

- Understand burning plasma dynamics
- **Demonstrate sustained high confinement at reactor scale**

Technology

- Learn how to build a fusion reactor
- **Solve technology challenges**



New Tokamak Facility Should Target Key R&D Needs Identified by 'Tornado Chart' Analysis

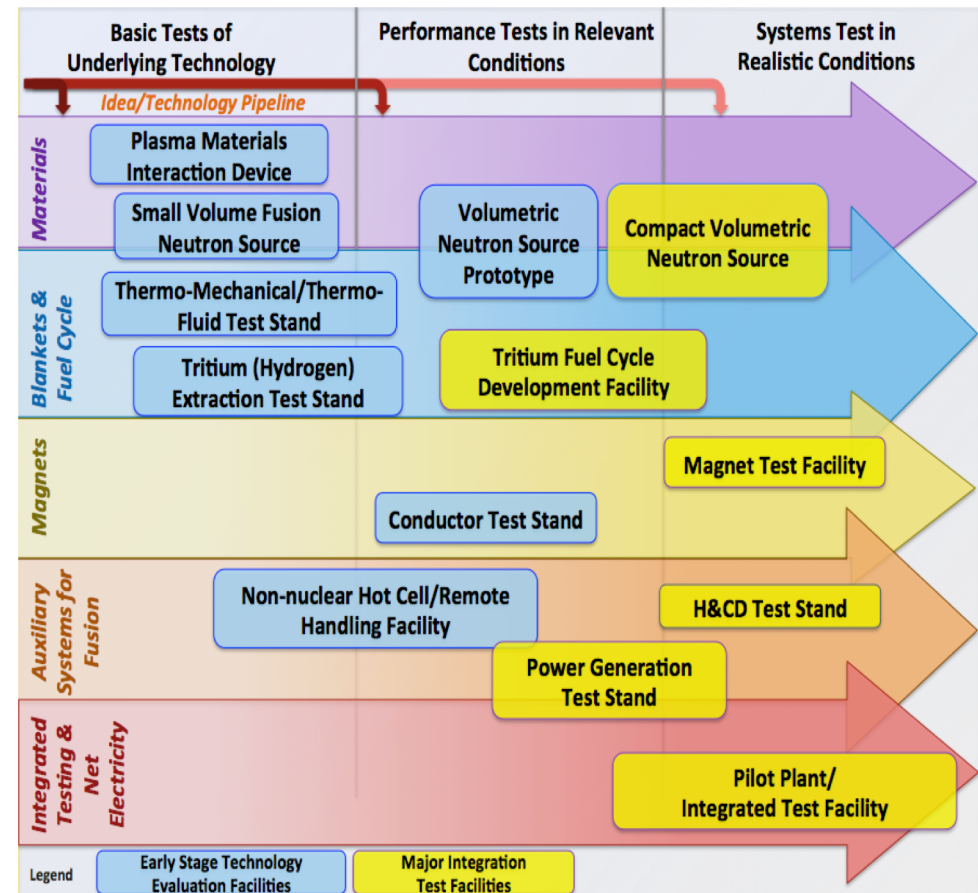
Three Main Mission Elements

- Sustained high confinement operation at as close to reactor conditions as possible (ρ^* , v^* , β , pressure, power flow)
- Plasma exhaust solutions consistent with sustained high confinement (not just a divertor test bed)
- Physics integration of as many key elements as possible (e.g., core-edge, current drive/transport/stability, fueling & exhaust)

Scoping studies indicate a modest-size (~ 1.25 m), modest-field (~4-7 T) device could address these missions

Near-Term Technology Initiatives Should Focus on Early-Stage Technology Evaluation Facilities

- Fusion technology “pipeline” will require multiple programs/facilities
 - *More extensive than is practical in the near term*
- Jump-start US technology program with programs targeting:
 - Plasma material interaction (MPEX)
 - Neutron material interaction (PFNS)
 - Blanket non-nuclear tests
 - Magnet technology
 - Tritium Fuel Cycle

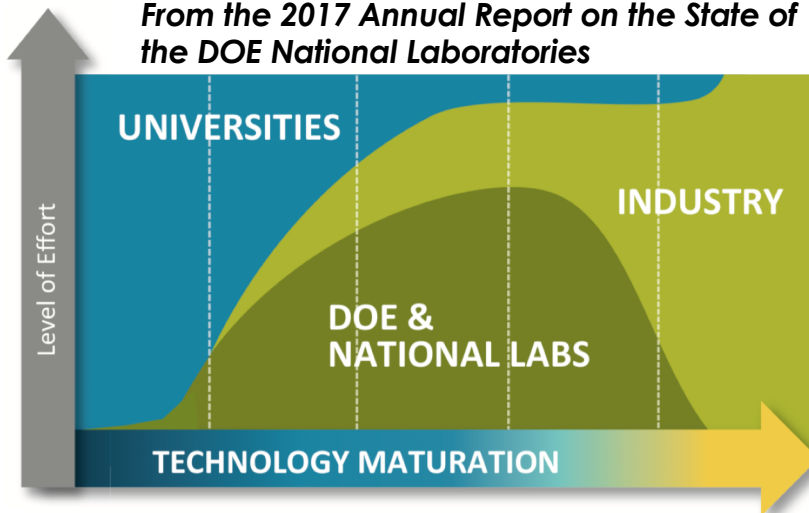


From Wade presentation APS-DPP Comm. Wkshp-Madison 2019

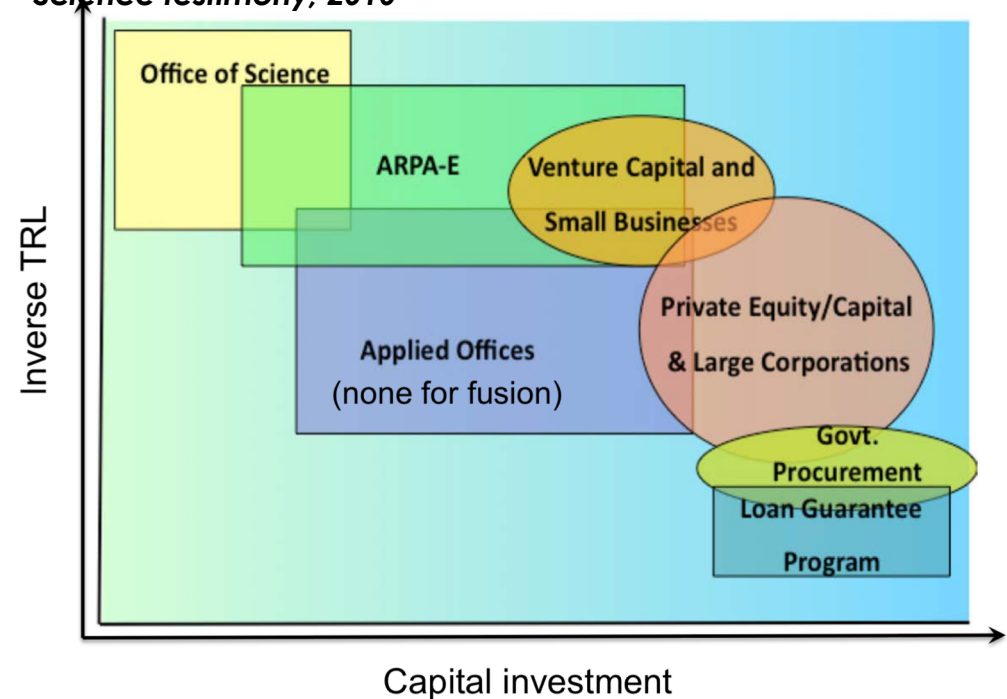
GA Perspective: Public-Private Partnership Important for Timely Fusion Energy – Need to Establish Effective Mechanism

- Present private sector engagement is not typical for DOE partnerships
 - Private TRL < Public TRL

From the 2017 Annual Report on the State of the DOE National Laboratories



Adapted from former ARPA-E director A. Majumdar's House Science testimony, 2010

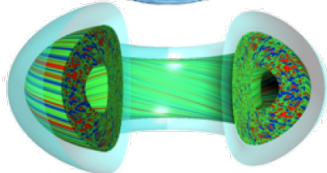


Need New Engagement Modalities that Leverage Private Interests While Maintaining Consistency with DOE Mandates for R&D

GA is Excited About the Prospects of Fusion Energy Development in the Coming Decade

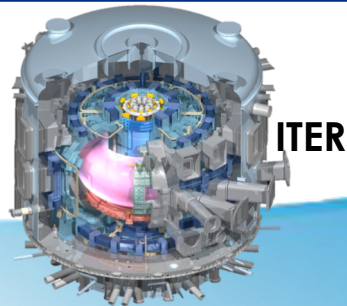
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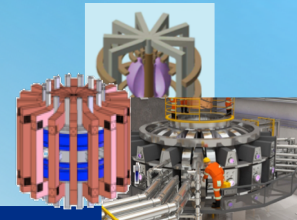
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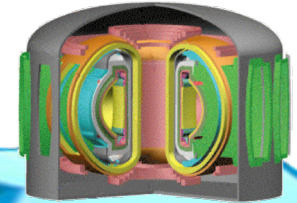


ITER

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Enhance Attractiveness, Timeliness of Pathway and/or End Product

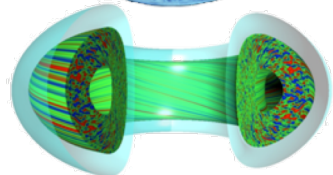


Cost-attractive Pilot Plant/FNSF

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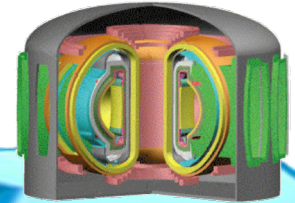


Theory and Computation

Secure Benefit of ITER Construction and Operation

A Bold Plan for Fusion Electricity - Let's take on this challenge together!

Enhance Attractiveness, Timeliness of Pathway and/or End Product



Cost-attractive Pilot Plant/FNSF