Fusion Energy Development Strategies

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Outline/Summary

- ITER is an essential element for fusion energy development → burning plasma science and fusion technologies
- A broader fusion development path should include:
  - Focused scientific/technical efforts to prepare for burning plasmas and fusion energy
  - Fusion nuclear science program to develop materials suitable for a fusion environment
- The tokamak concept is best positioned to advance fusion energy, world-leading science and scientific innovation
- International collaboration will accelerate fusion energy development and scientific understanding

Vision of the Fusion Program Highlights the Importance of ITER and Fusion Energy Development

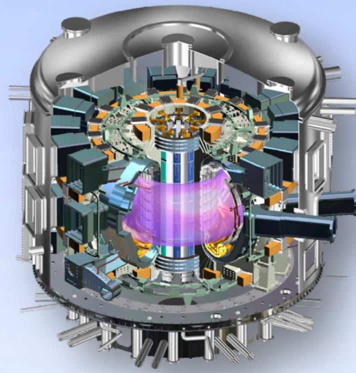
10 Yr Vision (Fonck, FESAC Pres., June 2014)

- "The U.S. is prepared to play a leading role in the scientific exploration of burning plasmas as ITER begins operations"
- "The U.S. is ready to move into a fusion energy development program"
- "The U.S. has an established steward of plasma science in the federal complex"

The fusion research program should focus on preparing for this future:

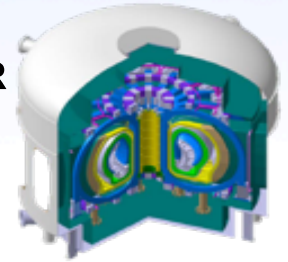
~2025

ITER



ITER has begun operation
US is playing a leading scientific role

CFETR



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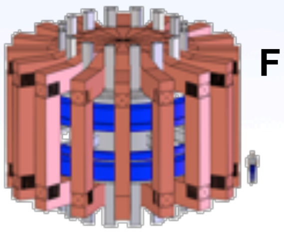


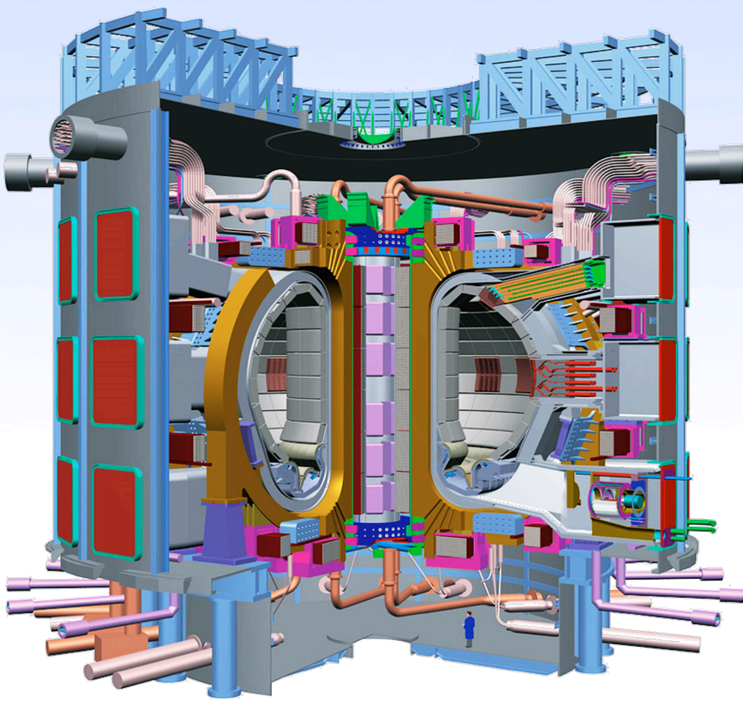
Integrated Fusion Nuclear Test Facility
Is being Designed/Constructed

ITER Is an Essential Element of the Path to Fusion Energy

- **ITER is a partnership between U.S., EU, Japan, Russia, China, Korea and India**
- **The community effort in developing a consensus in support of ITER was extensive culminating with → Snowmass, FESAC, NRC**
  - A burning plasma experiment is a "crucial and missing element in the Fusion Energy Sciences program"
- **ITER enables frontier fusion science in burning plasmas**
- **ITER provides good progress in fusion nuclear science/technologies**
- **ITER is highly leveraged: 9% US financial contribution → access to science and technology gained from ITER**
- **An international partnership provides the <u>science, technology</u> and financial base required for a burning plasma experiment**

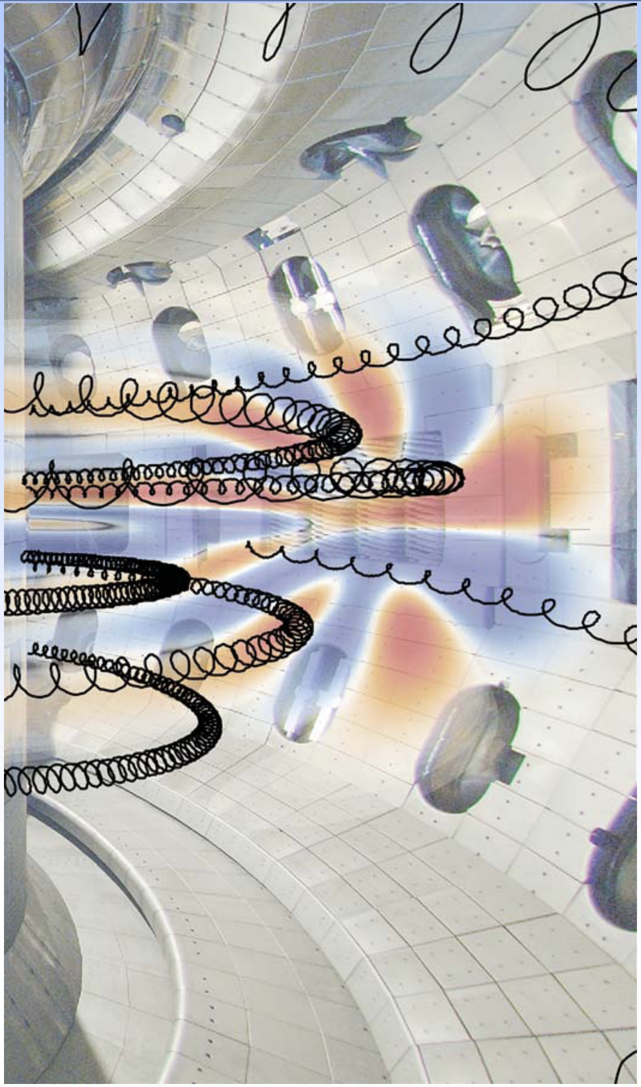
Mission

"To demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes."



ITER Enables New and Frontier Science in Burning Plasmas

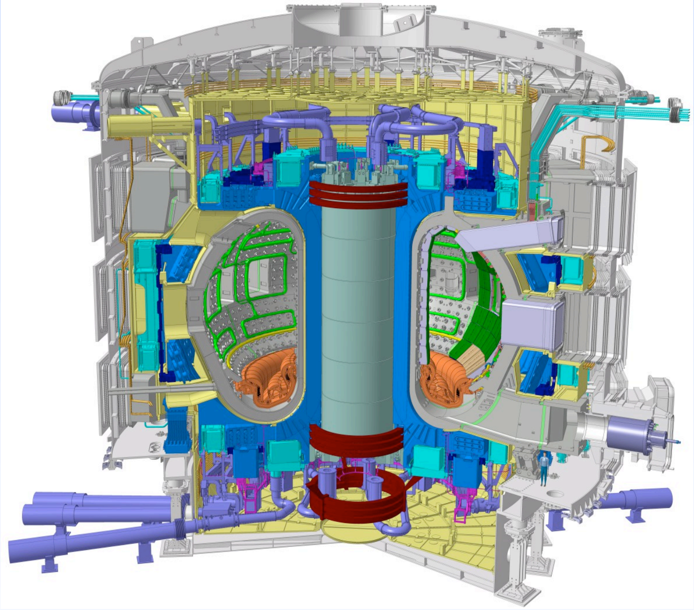
- **Sustained, thermonuclear plasma temperatures and pressures (high gain)**
- **Self heating, impacts profiles (heating + pressure + magnetic fields) → strong non-linear complex behavior**
- **Fast alpha population → unique and interesting instability physics**
- **Extends transport and stability physics to lower ρ^* and the self-heated regime**
- **Grand challenge for theory and predictive simulation**
  - Opportunity and requirement for whole device modeling
- **Exciting boundary science and control for new high heat flux divertor regimes**
- **Science and control of transients in a high current burning plasma evironment**



Energetic particle trajectories, DIII-D

ITER Has and Will Continue to Enable Advances in Fusion Technologies

- Large, high field superconducting magnets
- Remote maintenance and handling
- Test blankets for tritium breeding
- Tritium processing systems
- Hardened diagnostics
- High heat flux energy removal systems
- Long pulse, high power density heating and current drive systems
- Plasma current quench detection/ remediation systems
- Integrated control systems for the nuclear plant and plasma, including burn control
- …



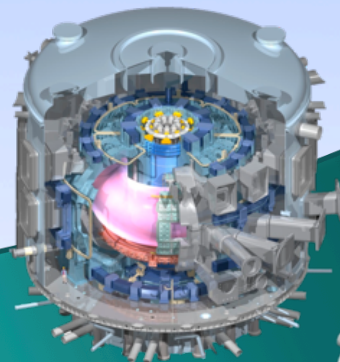
Support ITER as an essential Element of the U. S. Fusion Energy Science Program

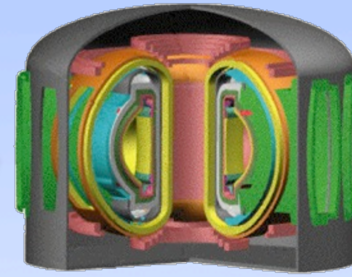
Fusion Energy Development Requires Key Elements Beyond ITER

Challenges/Initiatives
- BP scenarios
- Integrated Simulation ✓
- Boundary and PMI ✓
- Steady-State
- Disruptions and ELMs ✓

High Gain Burning Plasma Physics

ITER





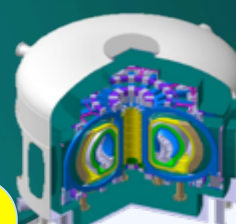
DEMO

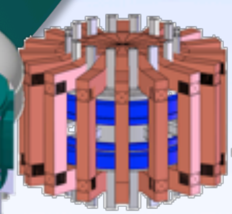
Electrical Energy Demonstration

Scientific and Technical Basis

New facilities
- Blankets (MT³F)
- Materials (MPEX)
- Nucl. Irrad. (FMITS)

Fusion Nuclear Science Program





CFETR FNSF

Integrated Fusion Nuclear Test Facilities

Near Term Initiatives: Optimize the Success and Benefit of ITER and Prepare for Fusion Energy

**(Fonck, FESAC presentation, June 2014)

- **Burning Plasma Scenarios:** Develop integrated scenarios suitable for optimal exploitation of ITER

  "position the U.S. to play a leading role in the scientific exploration of burning plasmas through the ITER experiment."*

- **Integrated Simulations:** Making optimal use of high performance computing, develop integrated models of the plasma system validated against experiments
- **Boundary and PMI:** "Produce solutions for the plasma material interface suitable for entry into a fusion energy development program"**
- **Steady State:** "Establish the scientific basis for high performance, steady-state operation"**
- **Disruptions and ELMs (Transients):** Understand and mitigate disruptions and ELMs to minimize their impact on ITER operation

Makes use of existing world facilities, with facility enhancements as needed

Opportunity for innovative and world - leading science

Fusion Energy Requires Two Major Elements

- **A reliable and sustained source of neutrons**
  - Plasma confinement & stability
  - Plasma heating & current drive
  - Plasma performance, $NT\tau$, scenarios
  - Density and Impurity control (PMI)
  - Transient control

Tokamak appears ready; ITER will demonstrate feasibility

- **Proven method to turn the neutrons into fuel and electricity**

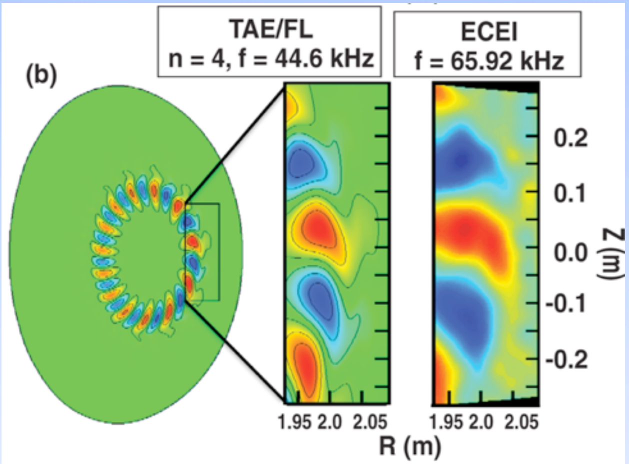
  ------- The greater challenge -------

  - High temperature and neutron resilient materials
  - Breeding blankets
  - High heat flux and erosion resistant materials (PMI)
  - Remote nuclear maintenance
  - → choices here impact the plasma and source of neutrons
  - → "Assess structural materials and nuclear technologies for initial experiments in a fusion nuclear environment" (Fonck, FESAC presentation, June 2014)

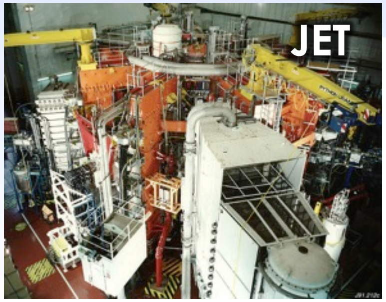
It is time to move forward with a fusion nuclear science program to address the more difficult challenge

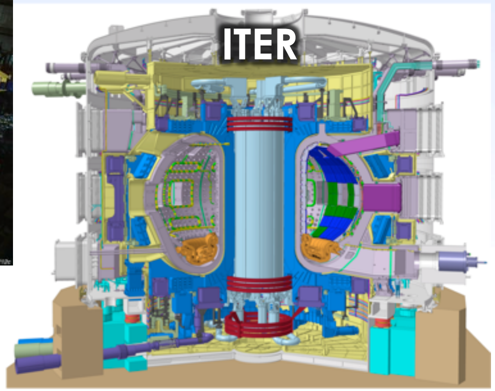
The Tokamak Concept Provides a Strong Scientific and Technical Base for Developing Fusion Energy

- **Tokamak confinement system has most advanced scientific base**
  - Theory & Modeling
  - Diagnostics and Control
  - Large experienced work force
  - Highest performance (T, $nT\tau$, …)



- **Tokamak has made extensive progress (10 and 16 MW of fusion power)**
- **ITER will significantly advance the science and technology of fusion**
- **Tokamak is ready – no other magnetic concept is ready**
- **Tokamak research has a history of scientific innovation and excellence**

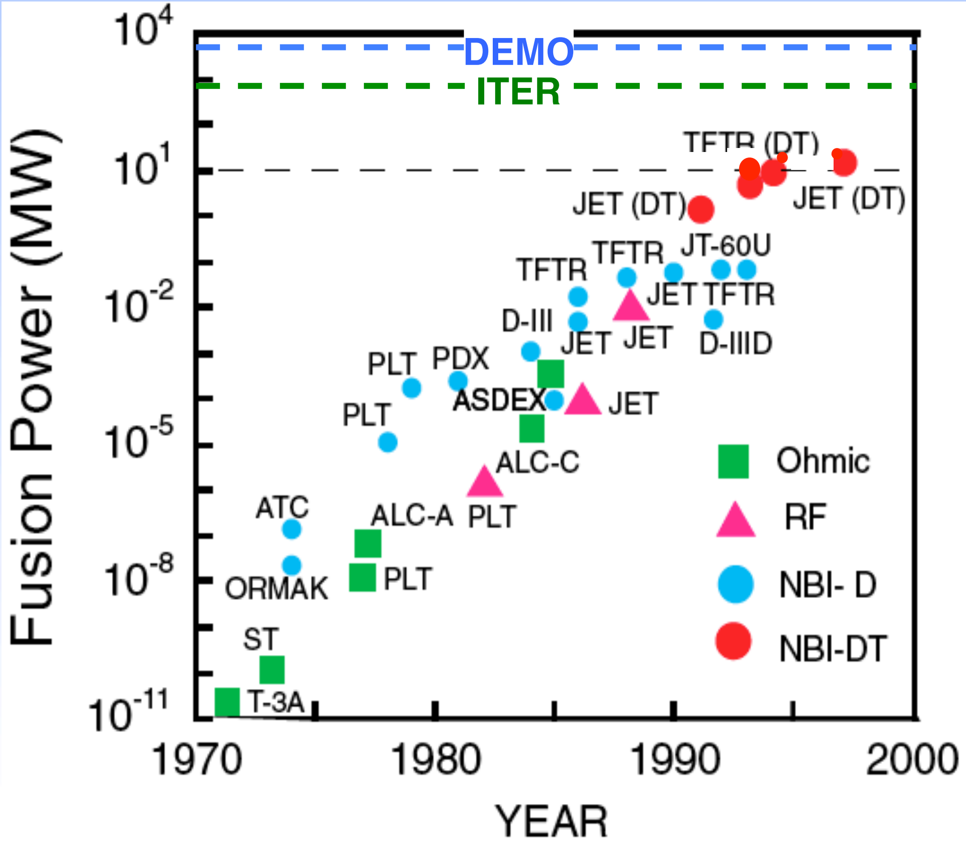




A robust US tokamak program provides the best opportunity to advance fusion energy and for world leading science

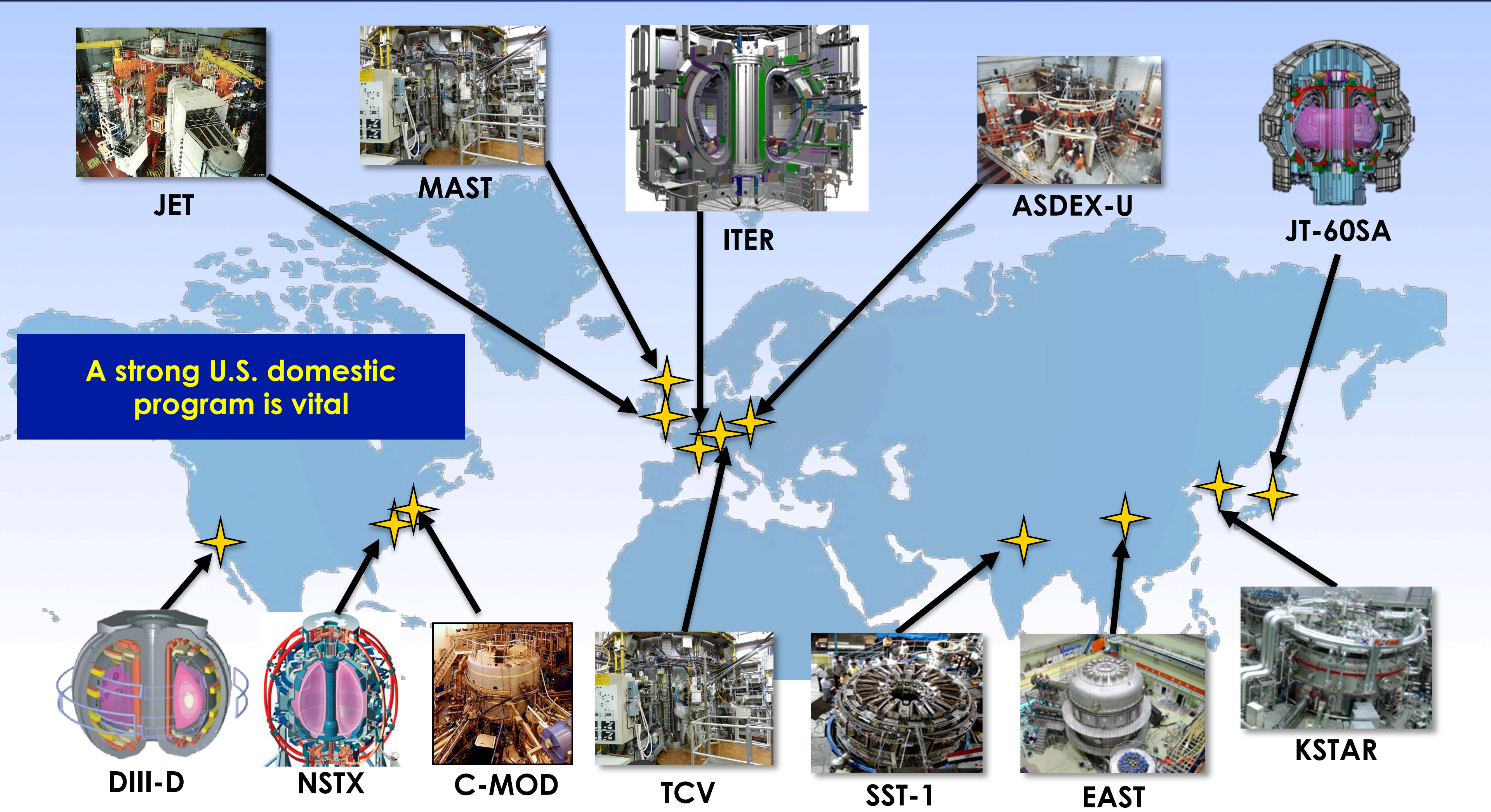
Tokamak Has Provided Rapid Progress

- **Progress in tokamak fusion has been rapid since the tokamak was introduced, T3, 1969**
- **NTτ has increased 4 orders of magnitude in 30 years, fusion power has increased 12 orders of magnitude**
- **No progress in NTτ/power over the last 15 yrs**
  - No new major facility built in since the 1980s aimed at increasing NTτ



Progress in tokamak absolute performance (NTτ) and fusion energy development is limited by lack of funding and new major facilities

International Collaboration Will Accelerate Fusion Energy Development and Scientific Understanding



The world fusion program must work together to prepare for ITER and the future

Credibility of the Fusion Enterprise

- **For many energy producers and non-fusion professionals, there is skepticism about the viability of the fusion enterprise**

- **Credibility will be gained by:**
  - Demonstrating that power-plant levels of power can be produced and sustained → ITER
  - Showing that potentials solutions exists for generic implementation issues such as tritium breeding, materials, and heat flux handling

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