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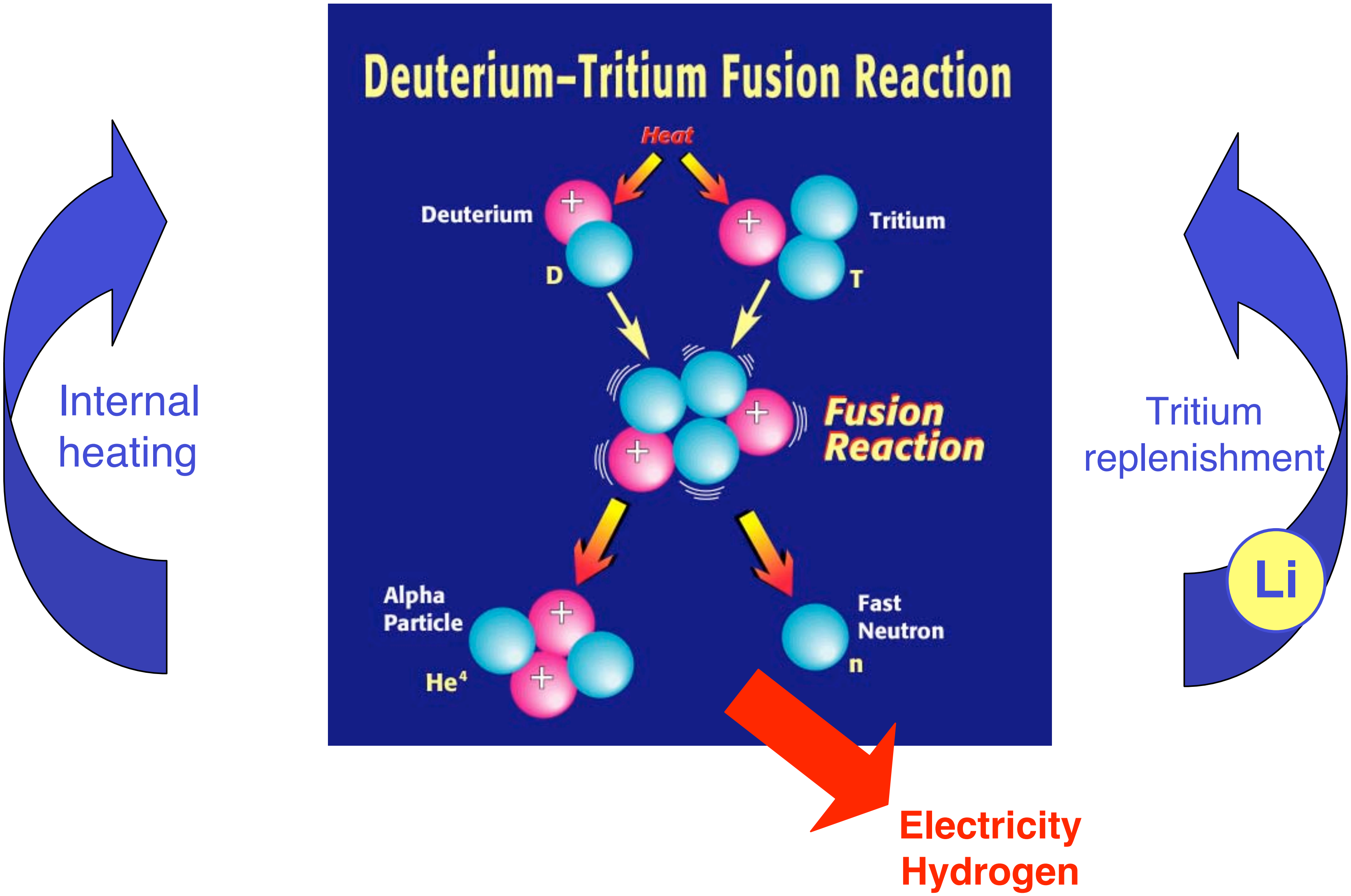
Director, DOE Princeton Plasma Physics Laboratory

Congressional Research and Development Caucus

December 7, 2005

PPPL
PRINCETON PLASMA PHYSICS LABORATORY

Fusion is an Attractive Long-term Form of Nuclear Energy

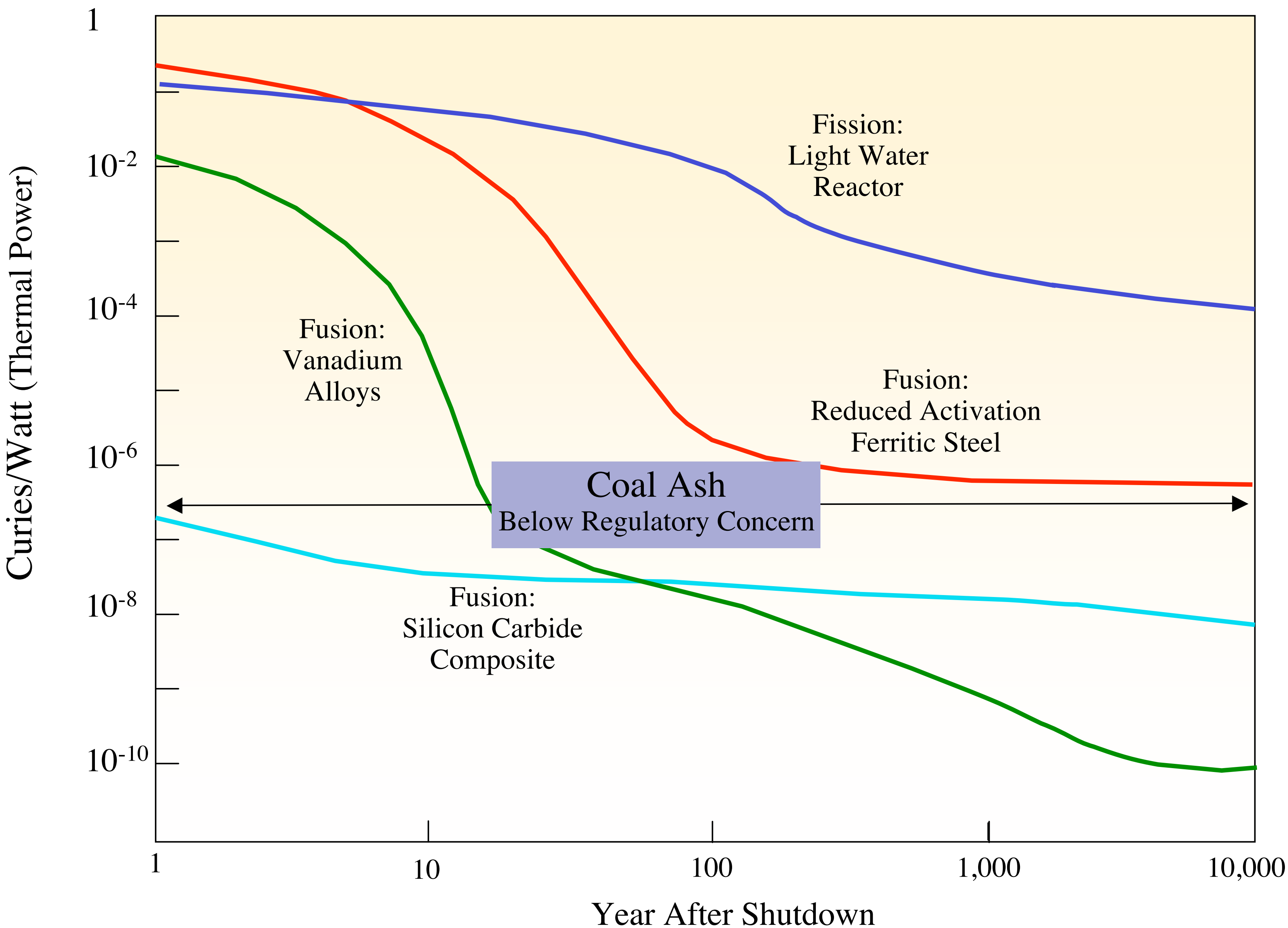


Fusion can be an Abundant, Safe and Reliable Energy Source

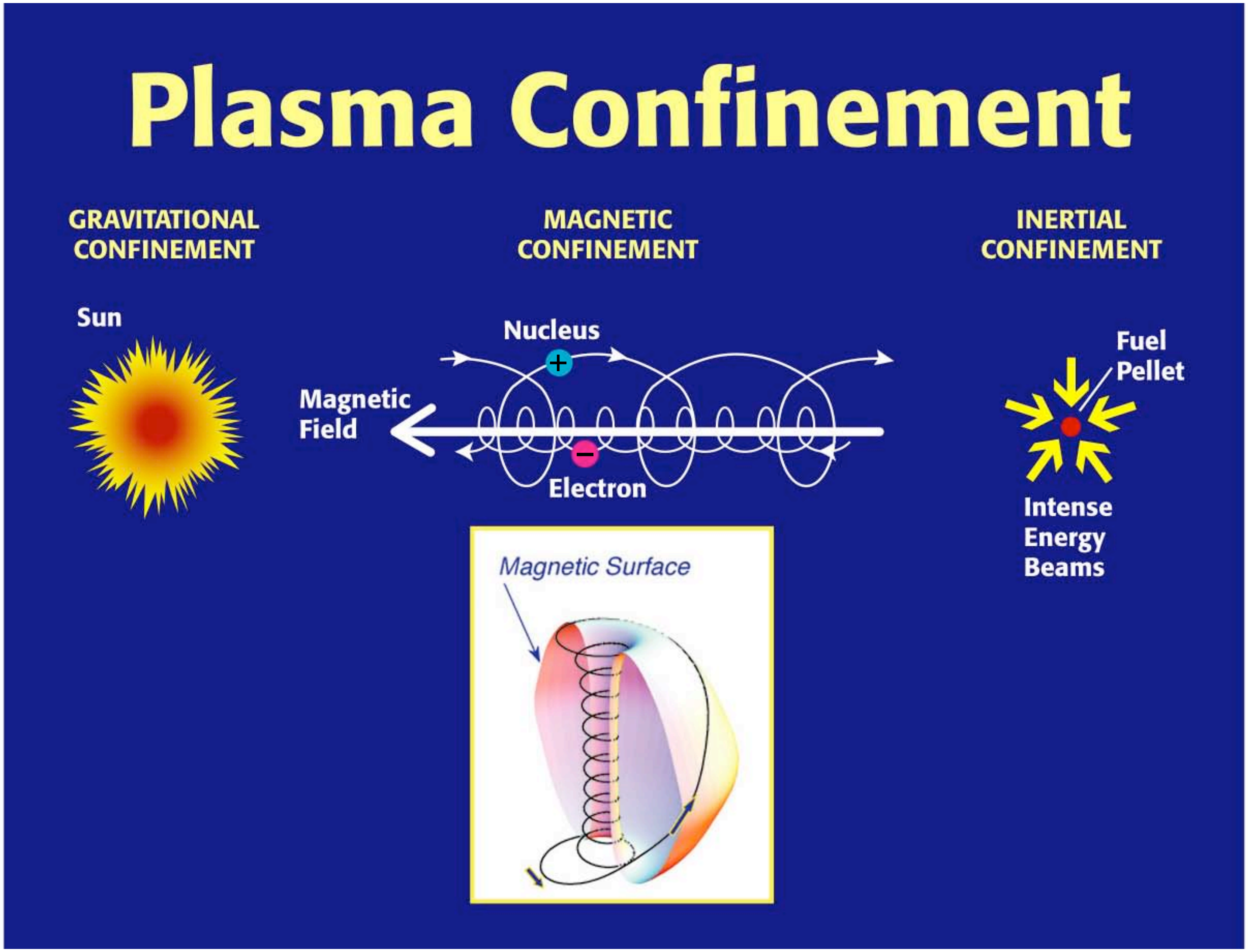
- **Worldwide long-term availability of low-cost fuel.**
- **No acid rain or CO_2 production.**
- **No possibility of runaway reaction or meltdown.**
- **Short-lived radioactive waste.**
- **Low risk of nuclear proliferation.**
- **Steady power source, without need for large land use, large energy storage, very long distance transmission, nor local CO_2 sequestration.**
- **Estimated to be cost-competitive with coal, fission.**

Complements nearer-term energy sources.

Fusion has Low Long-Lived Waste

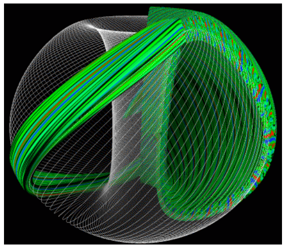


Magnetic Fields Confine Hot Plasmas



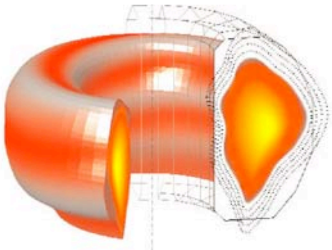
Fusion Science: Challenges and Advances

- **Energy Gain**
  - Internal heating by fusion must largely sustain the high plasma temperature against turbulent heat loss, giving high gain = fusion heat / input power.
  - Theory and experiment support the projection that ITER will exceed gain of 10.



Turbulence Calculation

- **Power level**
  - Fusion power must be maximized for given cost.
  - Plasma shaping and active field control allow higher plasma pressure / magnetic field, so higher power level.



Plasma Instability Control

- **Sustainment**
  - Fusion output must be sustained steadily, with low external power for sustainment.
  - Self-sustaining plasma currents have been discovered, and compact configurations have been invented that do not require external drive.

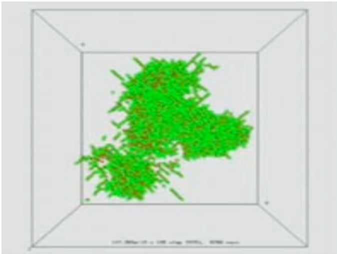
Sustained Configuration

Fusion Technology: Challenges and Advances

- **Heat handling**
  - Fusion vessel must be able to handle sustained high heat loads.
  - Means have been developed to spread heat in space and time, and handle high loads.

Tungsten Brush

- **Materials**
  - Materials are needed that can handle high fluence of energetic neutrons.
  - New low-activation ferritic steels, evolved from fission, are promising.

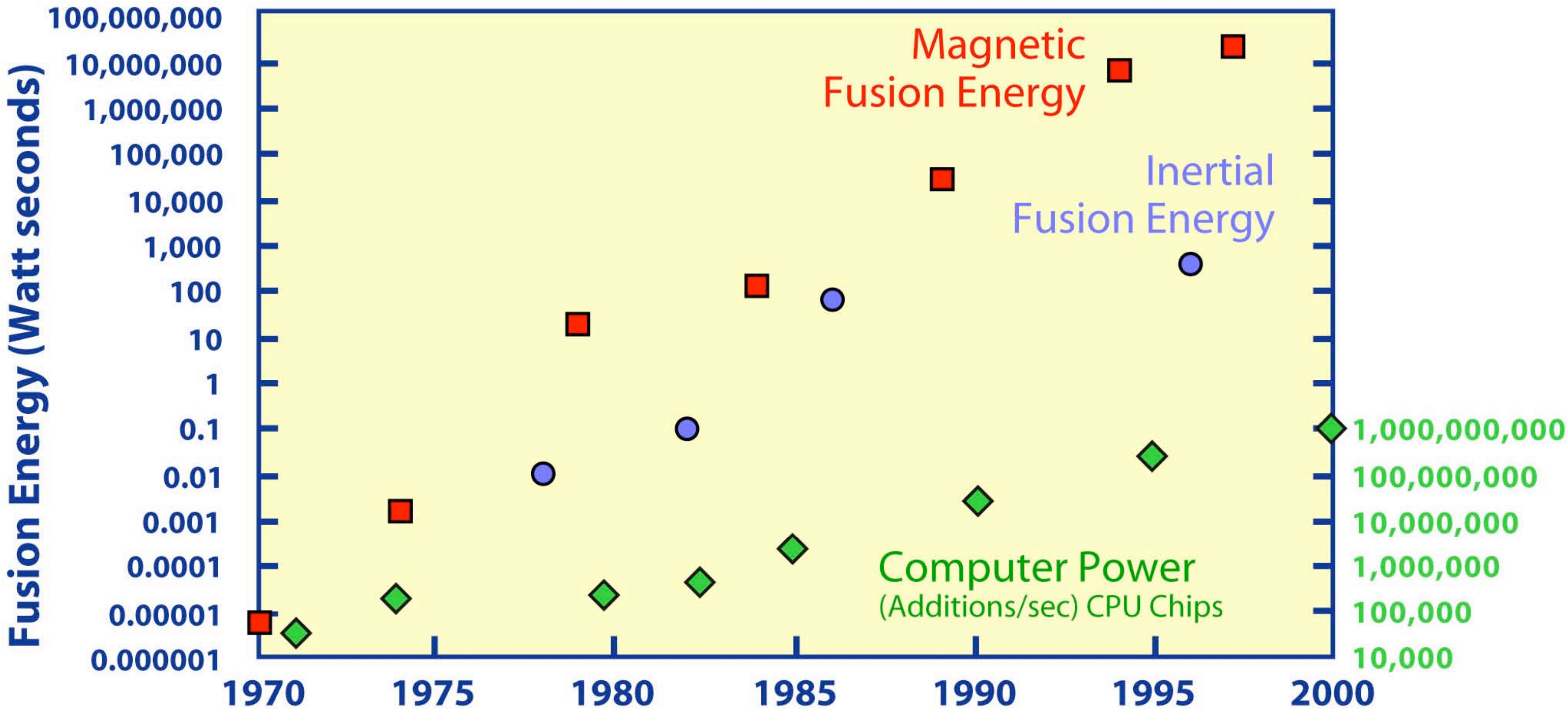


Neutronics Calculation

- **Major Components**
  - Example: Large superconducting magnets.
  - ITER R&D has already demonstrated magnets at about half power plant scale.

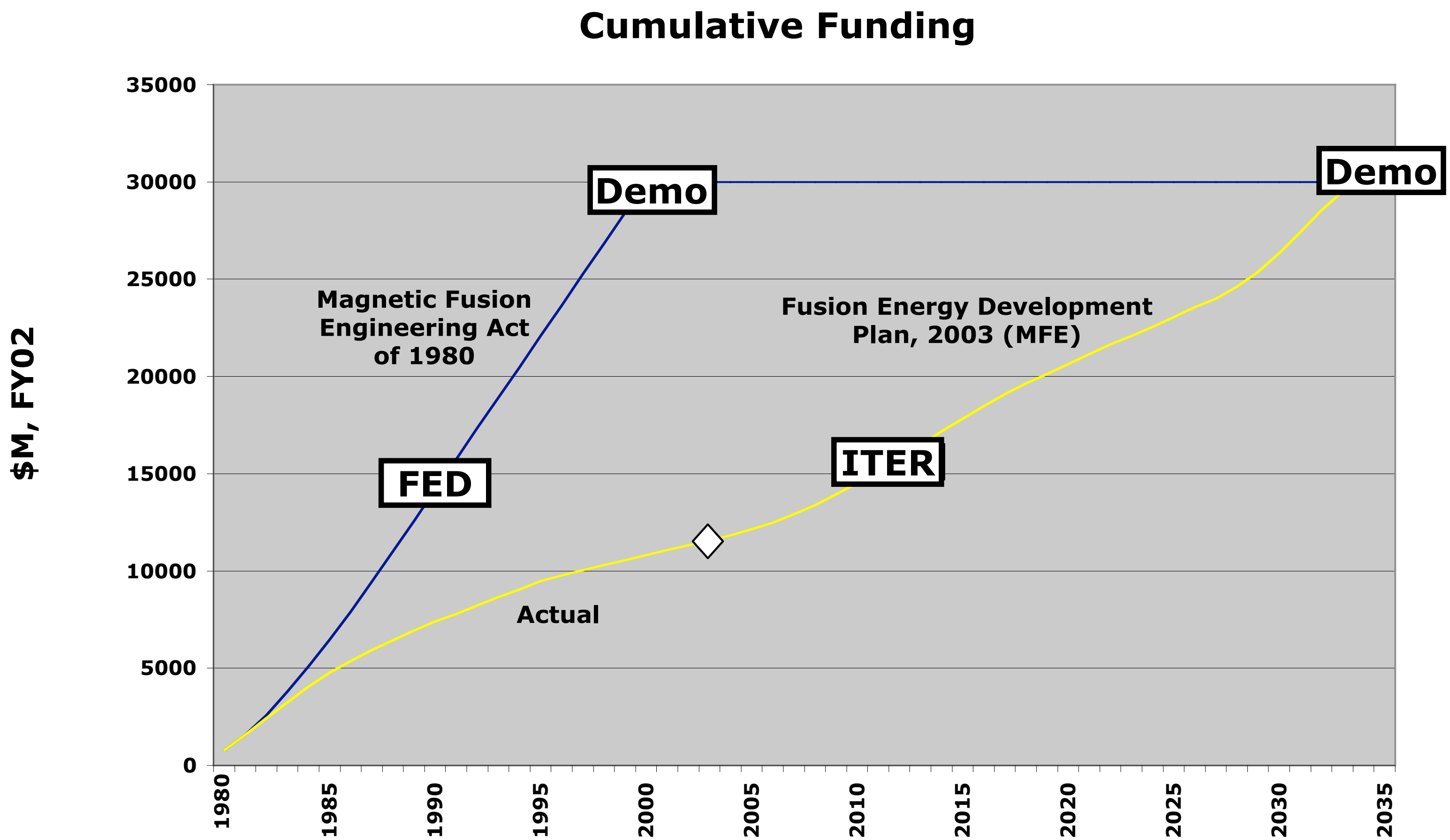
ITER R&D Magnet

Progress in Fusion has Outpaced Computer Speed



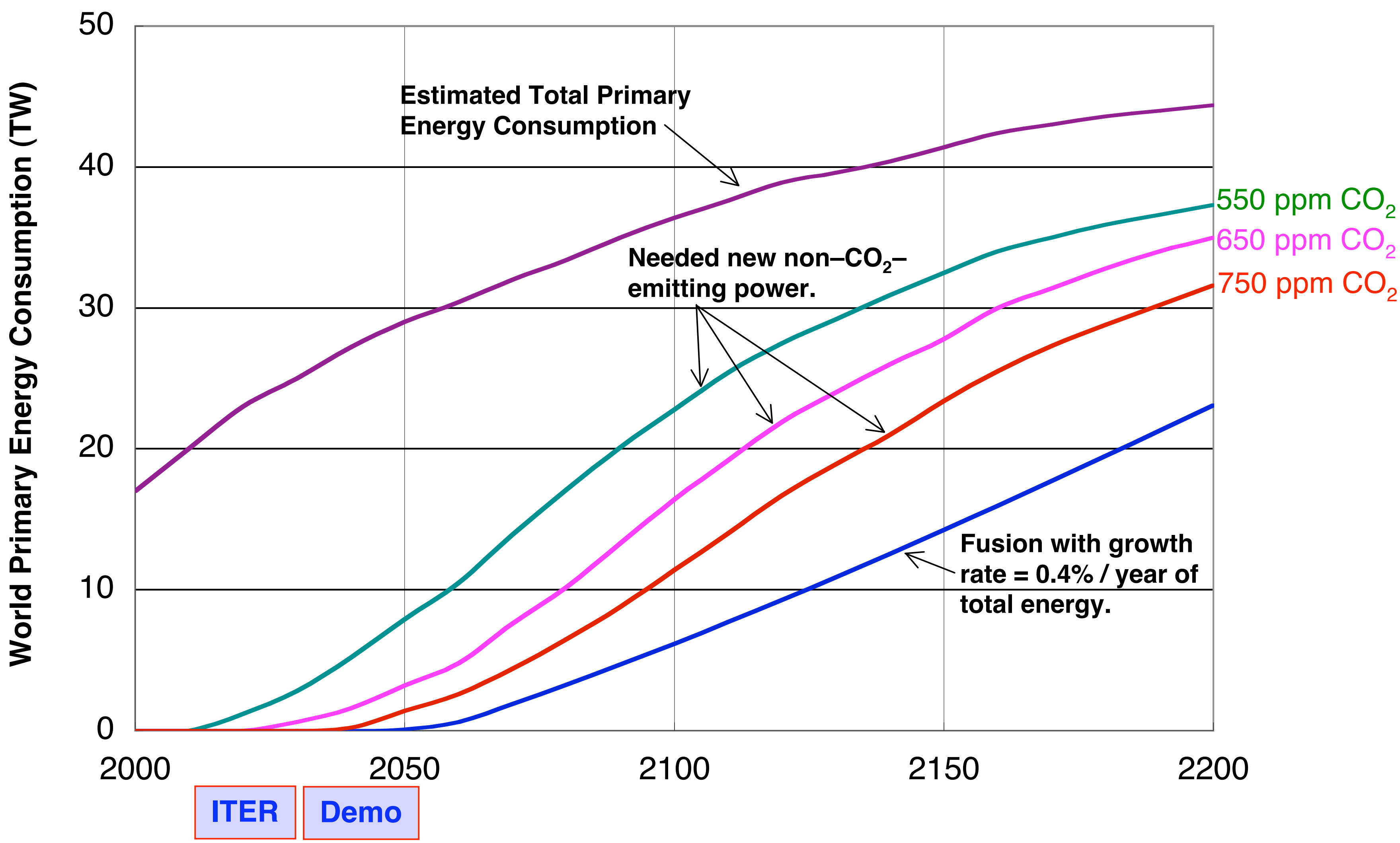
ITER will produce over 200,000,000,000 Watt seconds of heat from fusion, demonstrating the scientific and technological feasibility of magnetic fusion. NIF will produce over 2,000,000 Watt seconds of fusion heat, demonstrating the scientific feasibility of inertial fusion.

Magnetic Fusion can be Brought on Line at the Cost Projected in 1980, on a Timescale to Address the Long-term Issue of Climate Change

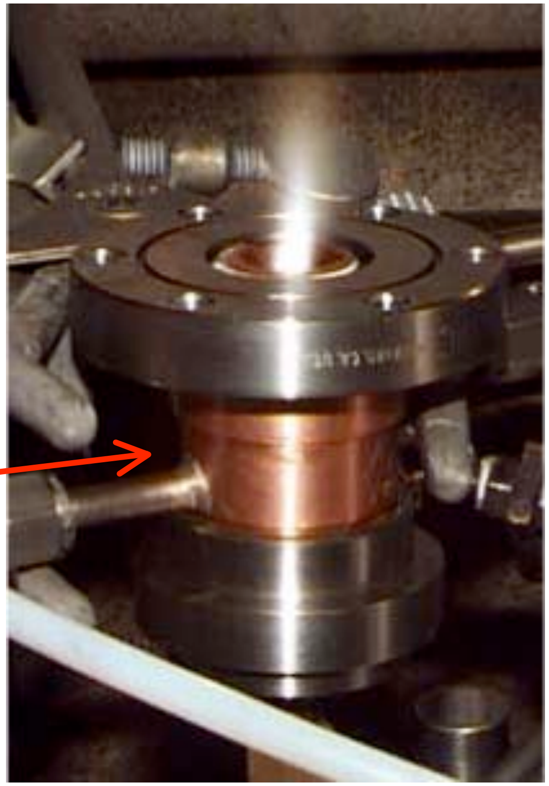


NAS "Gathering Storm" report emphasizes importance of U.S. science and engineering, as well as the need for clean, affordable and reliable energy.

Fusion can be an Important Element in Addressing Climate Change



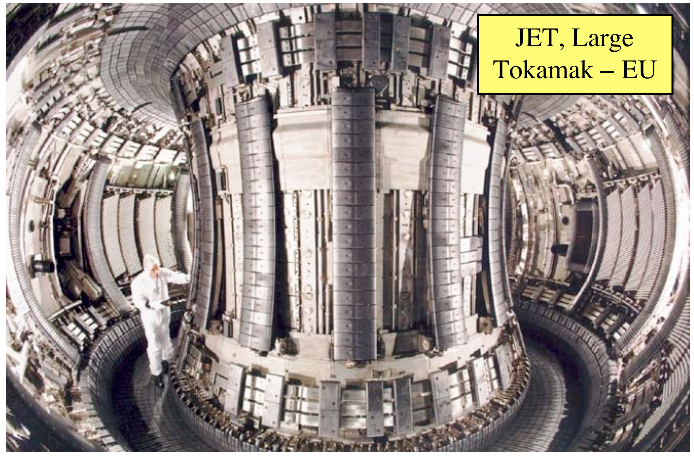
Fusion Research has Major Spinoff Benefits



- **Plasma Processing of Chips and Circuits**
  - **Plasmas are used to etch the narrow features on modern computer chips.**
- **Coatings and Films**
  - **Plasmas provide hardened surfaces and corrosion resistance.**
- **Plasma Electronics**
  - **Plasma science is central to development and improvement of plasma TV's.**
- **Clean and Efficient Engines**
  - **Plasmatron fuel reformer for higher efficiency and cleaner exhaust.**
- **Plasma Sterilization**
  - **Plasmas for low-temperature sterilization.**
- **Plasma Thrusters for Satellites**
  - **Plasma thrusters require less fuel for station-keeping.**
- **Scientific Advances**
  - **Fusion science contributes to understanding near-Earth space, the sun, and the galaxies. Most of the visible universe is plasma.**

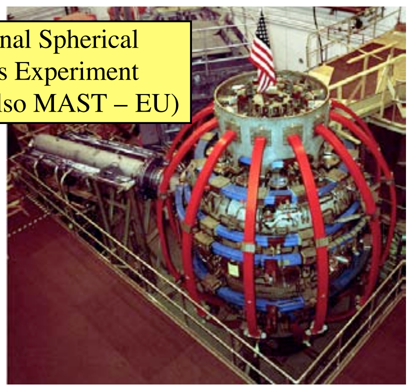
Magnetic Fusion Research is a Worldwide Activity: Optimizing the Configuration for Fusion

C-Mod, Tokamak MIT

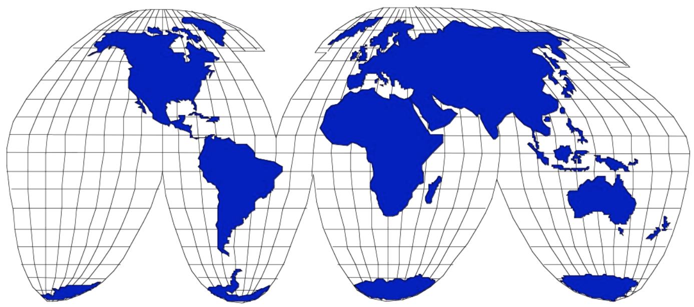


JET, Large Tokamak – EU

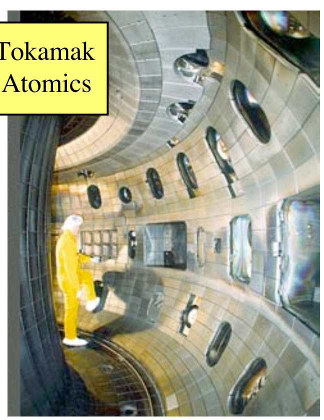
W7-X, Large Superconducting Stellarator – EU



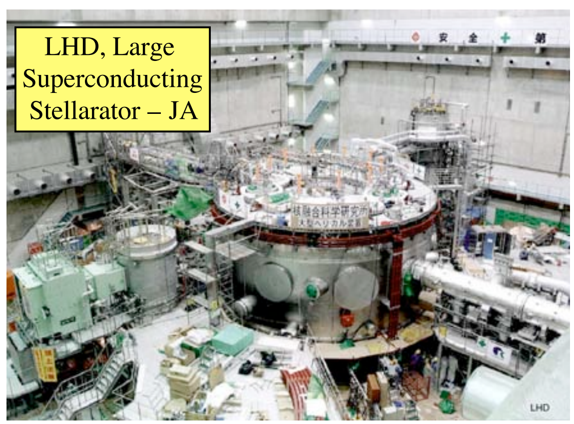
National Spherical Torus Experiment PPPL (also MAST – EU)



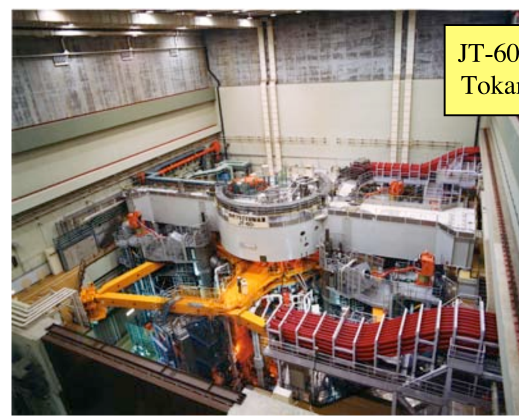
KSTAR, EAST, SST-1 Superconducting Tokamaks, – Korea, China, India



DIII-D, Tokamak General Atomics



LHD, Large Superconducting Stellarator – JA



JT-60U, Large Tokamak– JA

China is Making Dramatic Advances in Fusion

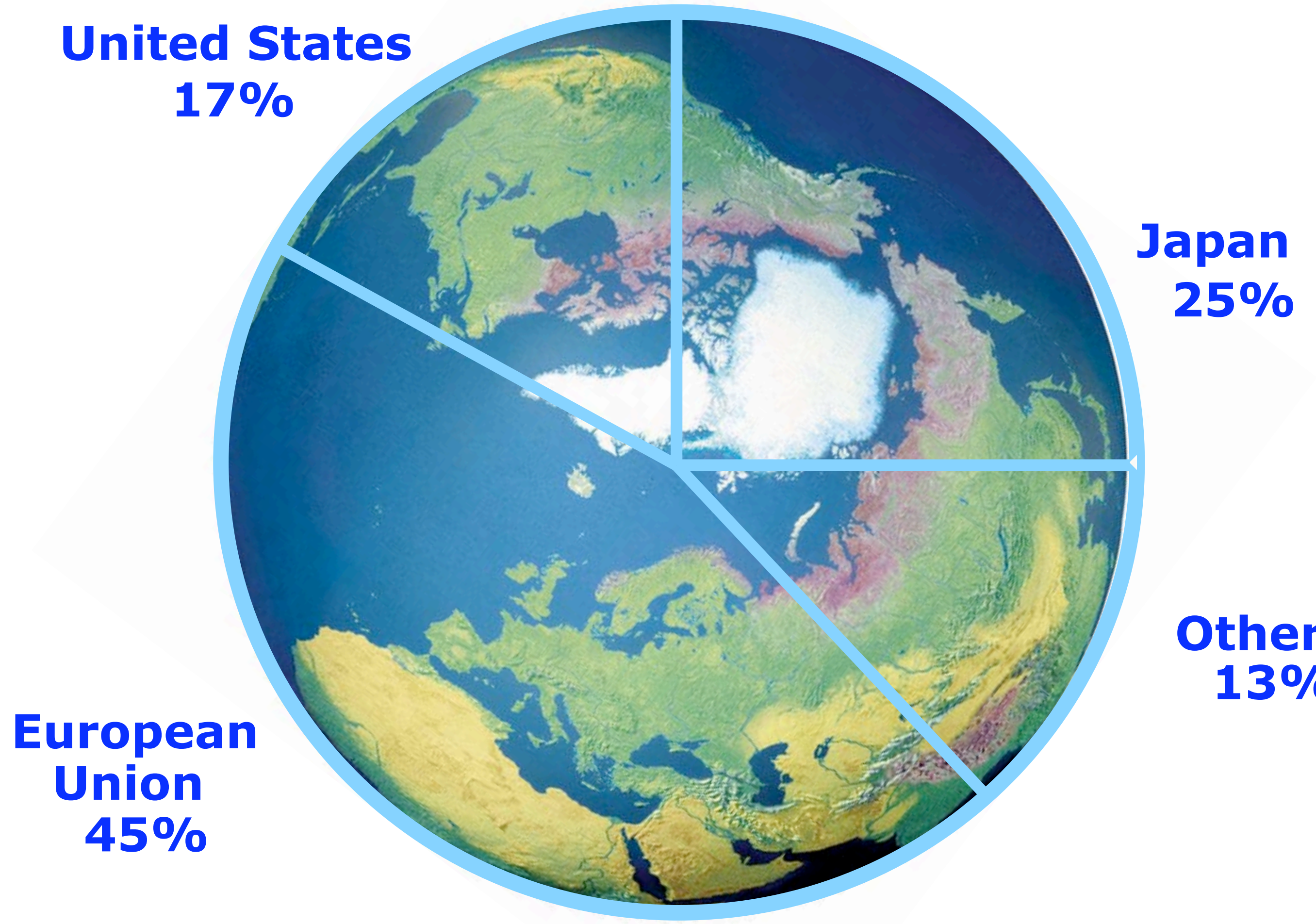
EAST will be on line in May

Superconducting magnets

Magnet facility

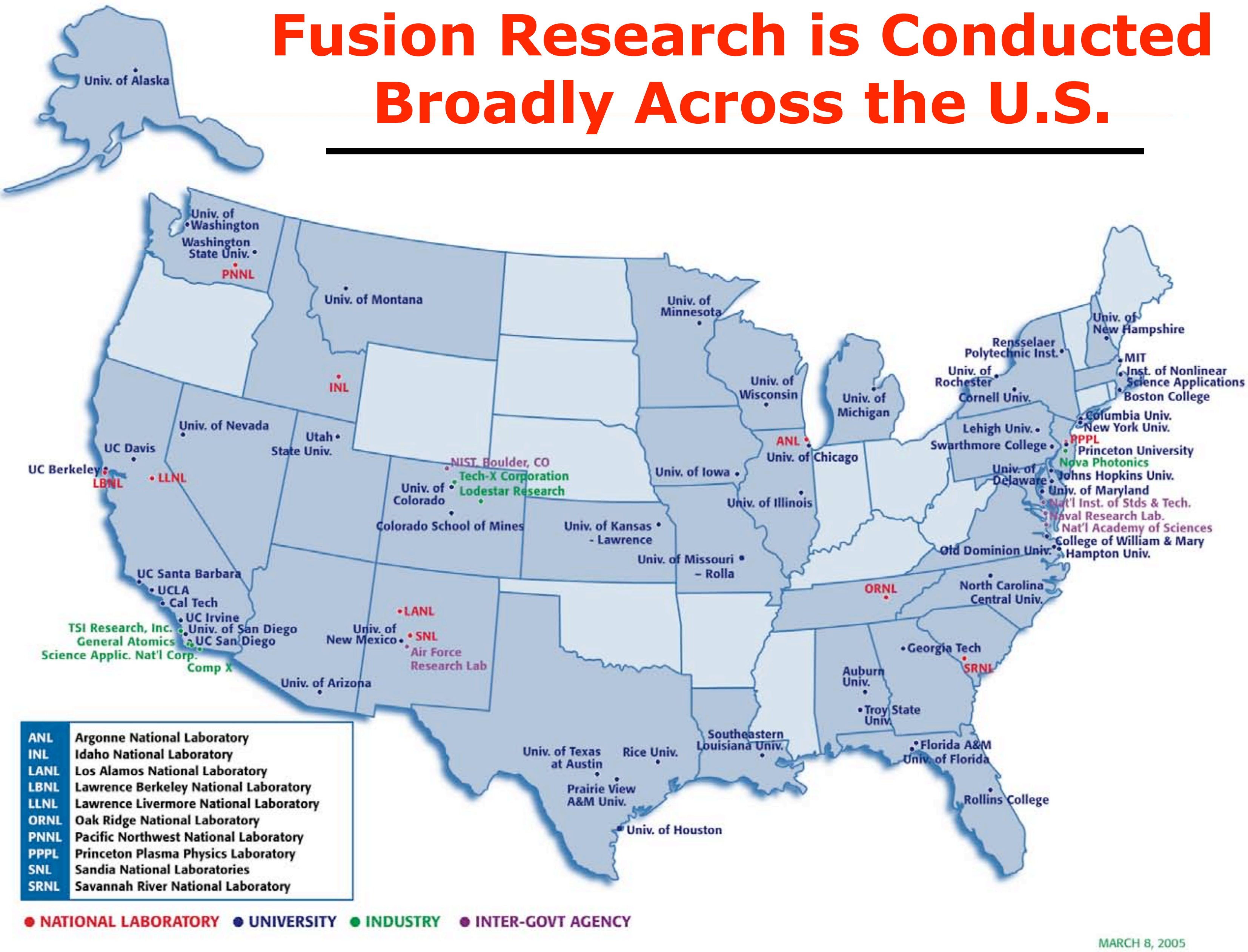
Inside vessel

The U.S. is about 1/6 of the World Magnetic Fusion Effort



US: $260M/yr
World: ~$1.5B/yr
(FY 2005)

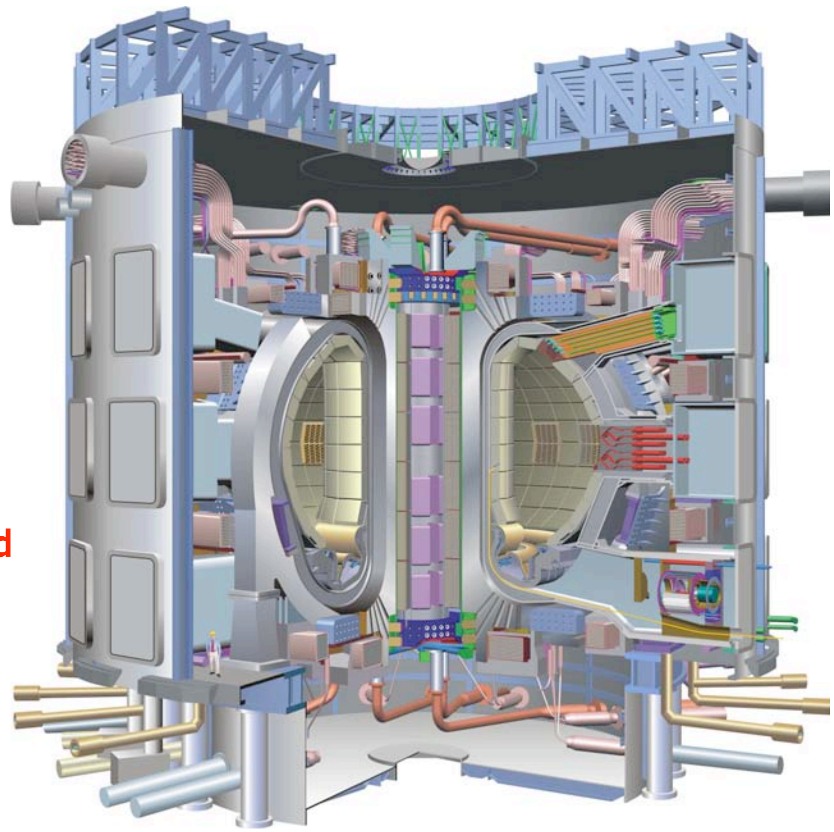
Fusion Research is Conducted Broadly Across the U.S.



ITER Negotiations:

Europe, Japan, Russia, US, China, South Korea, India

- The site and Director General have been selected:
  - Cadarache, France, near Aix-en-Provence.
  - Kaname Ikeda; JA Ambassador to Croatia, nuclear engineer with experience in large-scale international projects.
- The finances add up:
  - Europe pays 50% – spending 10 of these 50% in Japan (!).
  - Each of the other five pays 10%.
  - Europe pays for 1/2 of "broader approach" additional fusion facilities in Japan, valued at 16% of ITER.
  - India has joined, now >1/2 the world
- ~~There are key issues for resolution:~~
  - ~~Management of a major international construction project with contributions "in kind."~~



Joint Press Release
TWELFTH ITER NEGOTIATION MEETING
Jeju, Korea, 6th December 2005

- At the start of the Meeting, the Delegations unanimously and enthusiastically welcomed India as a full Party to the ITER venture. A Delegation from India then joined the Meeting and participated fully in the discussions that followed. With this exciting new development, over half of the world's population is now represented in this global endeavour.
- The seven ITER Delegations also welcomed to the Meeting the newly designated Nominee Director-General for the prospective ITER Organisation, Ambassador Kaname IKEDA, who is to take up his duties as leader of the project.
- Based on the results of intensive working level meetings held throughout the previous week, the Delegations have succeeded in clearing the remaining key issues such as decision-making, intellectual property and management within the prospective ITER Organisation and adjustments to the sharing of resources as a result of India's participation, including in particular cost sharing and in-kind contributions.
- With this achievement, the Delegations are pleased to declare that their work is finished, opening the way towards concluding the negotiations at political level.

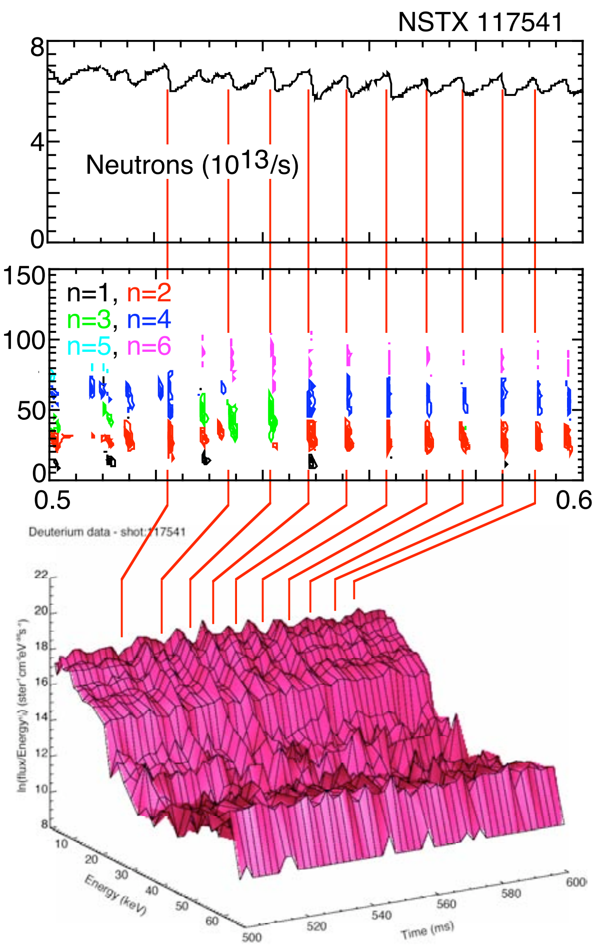
ITER will Test Magnetic Fusion Science at Power Plant Scale

- **Energy Gain:** **Study – *for the first time* – self-sustained internal plasma heating by energetic helium fusion products.**
  Extend the study of turbulent heat loss to much larger plasmas, providing a strong test of how turbulent structure size varies with system size.

- **Power level:** **Extend the understanding of plasma pressure limits to much larger size systems, where particle trajectories are smaller compared with the plasma.**

- **Sustainment:** **Study external sustainment of plasma electrical currents at high temperature.**

These results can be extrapolated via advanced computing to related magnetic configurations.

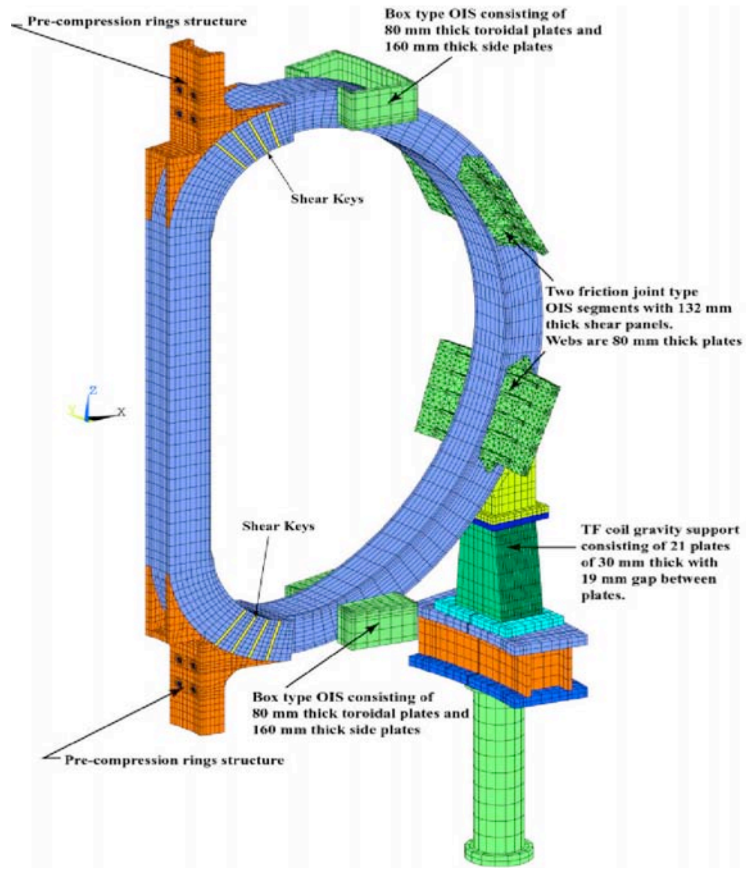


External heating in current experiments.

ITER will Test Fusion Technologies at Power Plant Scale

- **Plasma Vessel Components**
  - 5 MW/m^2 steady heat flux
  - 20% duty factor during operation
- **Nuclear Components**
  - Initial test of tritium replenishment by lithium-bearing modules in vessel wall.
- **Superconducting Magnets**
  - Power plant size and field, 40 GJ

These technologies are applicable to all configurations.



ITER Toroidal Field Coil

ITER is the Last Large Step before National Demonstration Power Plants

- **ITER is truly a dramatic step. For the first time the fusion fuel will be sustained at high temperature by the fusion reactions themselves.**
  - **Today:** ***10 MW(th) for 1 second with gain ~1***
  - **ITER:** ***500 MW(th) for >400 seconds with gain >10***

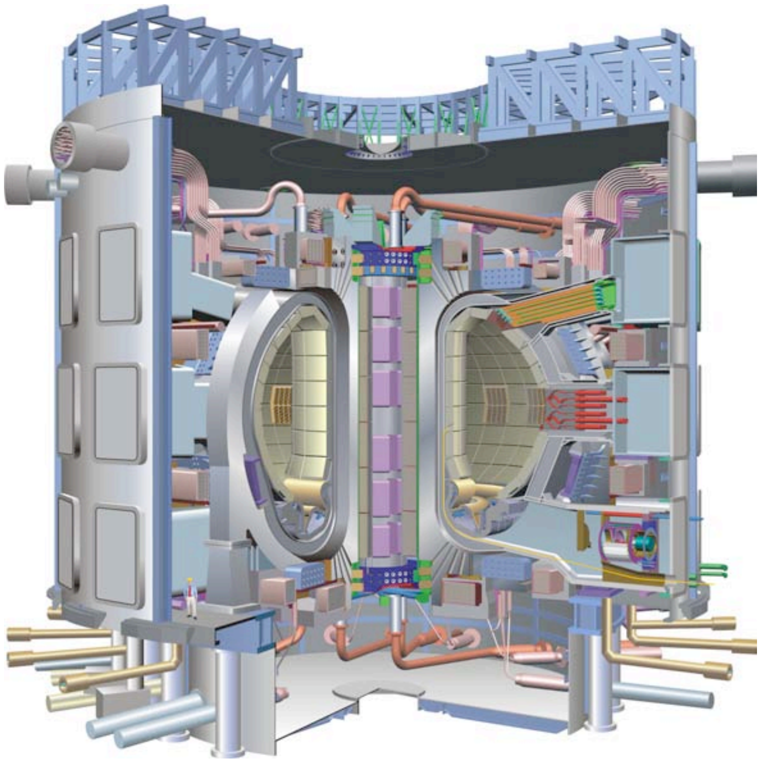
- **Further science and technology are needed.**
  - **Demo:** ***2500 MW(th) continuous with gain >25, in a device of similar size and field as ITER***

    ⇒ **Higher power level**

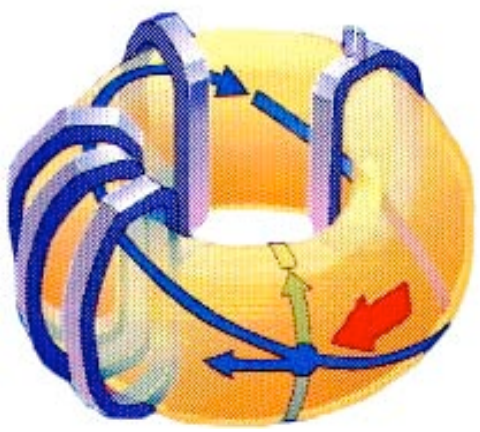
    ⇒ **Efficient continuous operation**

- **Strong, innovative research programs focused around ITER are needed to address these issues.**
  - **Experiments, theory/computation and technology that support, supplement and benefit from ITER.**

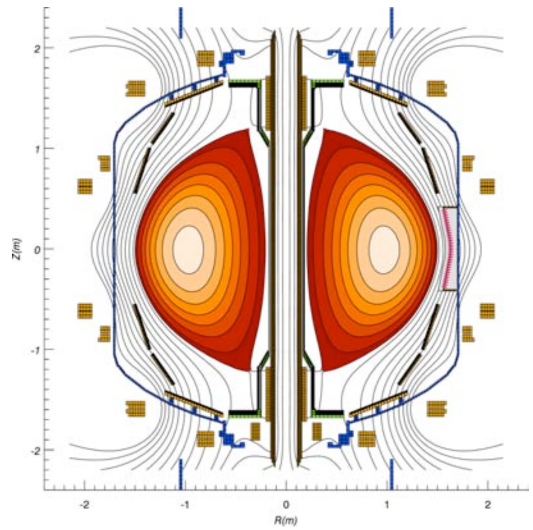
- **ITER will provide the science needed at the scale of a Demonstration Power Plant.**
  - **Whether Demo is configured as an Advanced Tokamak, a Spherical Torus or a Compact Stellarator.**



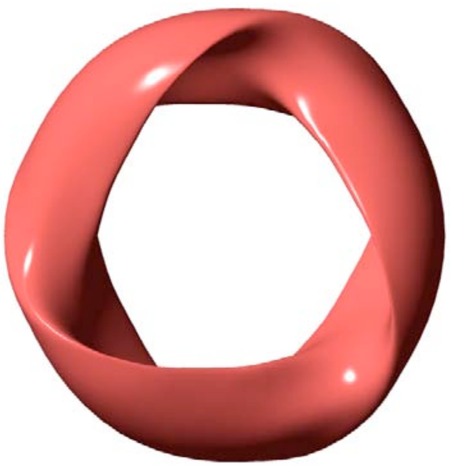
Research is Needed in ITER, and in Parallel with ITER, for Practical Fusion



Advanced Tokamak
Active instability control and driven continuous operation.



Spherical Torus
High fusion power at given size and magnetic field.

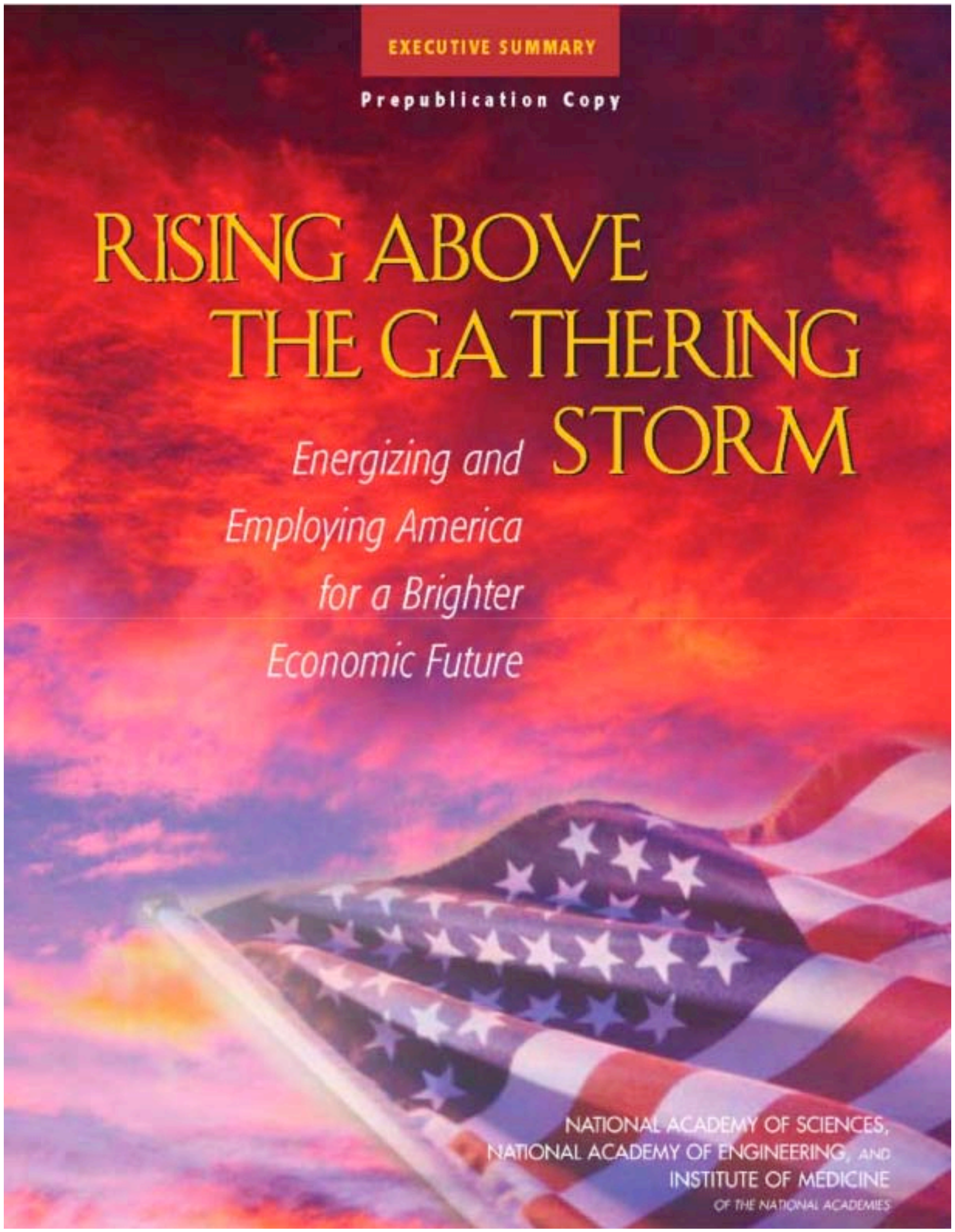


Compact Stellarator
Passive stability and efficient continuous operation.

Practical fusion requires high power and efficient continuous operation.

Other Nations are Leveraging ITER Strongly

- **Major New Plasma Confinement Experiments**
  - China, South Korea, India, Europe, JA-EU in Japan
  - Each is more costly than anything built in the U.S. in decades.
- **Major Fusion Computational Center**
  - Japan - Europe in Japan
  - Next generation beyond Japan’s Earth Simulator
- **Engineering Design / Validation Activity for Fusion Materials Irradiation Facility**
  - Japan - Europe in Japan
  - Critical for testing of materials for fusion systems.
- **A new Generation of Fusion Scientists and Engineers is being Trained around the World.**
  - China plans to have 1000 graduate students in fusion.



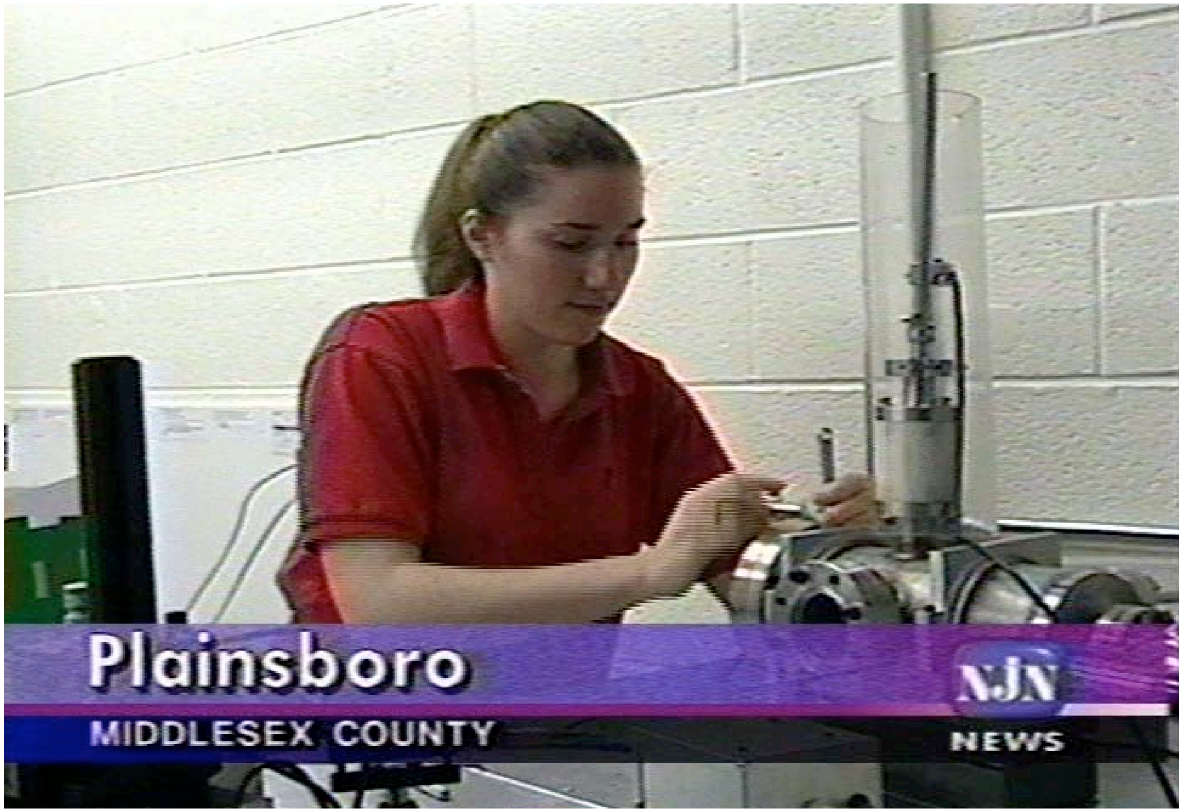
"Having reviewed trends in the United States and abroad, the committee is deeply concerned that the scientific and technical building blocks of our economic leadership are eroding at a time when many other nations are gathering strength. … we are worried about the future prosperity of the United States."

"The committee identified two key challenges that are tightly coupled to scientific and engineering prowess: creating high-quality jobs for Americans and responding to the nation's need for clean, affordable, and reliable energy."

Fusion Excites Students about Science and Technology

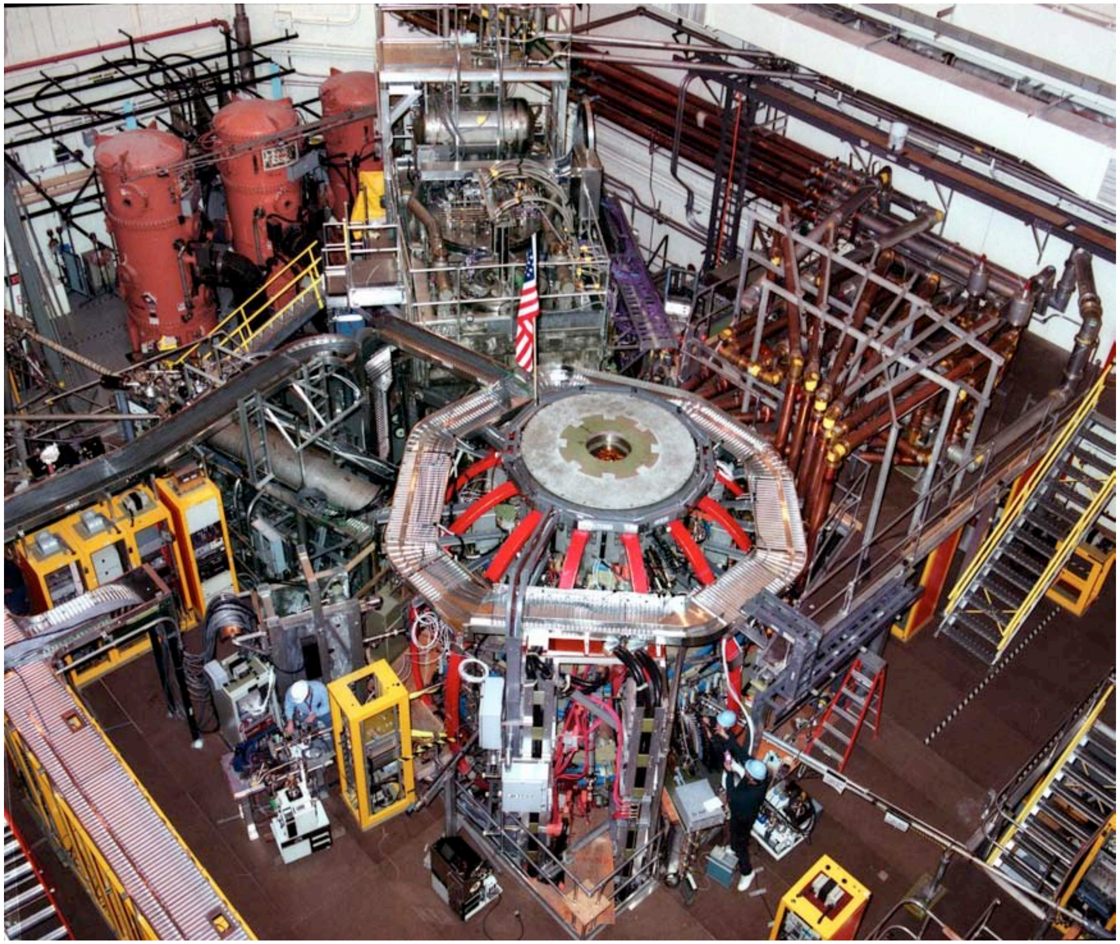
- **54 Universities Nationwide Participate in Fusion Research**
  - **50 Ph.D. students are produced each year**
  - **Some continue in fusion research, some contribute to other fields of science and technology.**

- **Each of the major fusion groups has a strong educational outreach program. These programs reach K-12 students, their teachers and undergraduate students.**



- **Fusion is an attractive, long-term form of nuclear energy.**
- **Fusion can have an important impact on climate change.**
- **S&T challenges are significant and progress has been dramatic.**
- **Over half of the world is negotiating to construct ITER.**
- **ITER will demonstrate the scientific and technological feasibility of magnetic fusion energy.**
- **ITER needs to be leveraged to get to practical fusion energy.**

Come Visit PPPL !



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