Presented to

**National Research Council**
**Burning Plasma Assessment Committee**

By

**Dr. Anne Davies**

Associate Director  
for Fusion Energy Sciences  
Office of Science  
Department of Energy

September 17, 2002  

**www.ofes.fusion.doe.gov**

---

**Excellent Science in Support of Attractive Energy**
Deuterium-Tritium Fusion Reaction

Deuterium + Tritium → Fusion Reaction → Hot Alpha Particle + Fast Neutron + Heat

Energy Multiplication
About 450:1
Magnetic Fusion Power Plant

Deuterium fuel (from seawater)

Tritium Breeding Blanket

Fusion Plasma

Turbine

Generator

Electric Power
"The NEPD Group recommends that the President direct the Secretary of Energy to develop next-generation technology--including hydrogen and fusion."
Why Develop Fusion Energy

Fusion is a unique energy option with:

- **Secure inexhaustible fuel reserves**
  - Fuel obtained from seawater
  - One pound of fusion fuel = 25,000 barrels of oil

- **Multiple end uses**
  - Electricity
  - Fissile fuel
  - Hydrogen production

- **Attractive environmental and safety features**
  - No long-lived reaction products
  - Radioactive structure is relatively easy to manage
  - No combustion pollutants are produced
  - No possibility of runaway reaction

- **Ancillary Benefits**, such as, advanced science and technology/spinoffs/education
Comparison of Fission and Fusion
Radioactivity After Shutdown

![Graph showing comparison between fission and fusion radioactivity after shutdown.](image_url)
Fusion Can Contribute to Carbon Management on a Timely Basis

Estimated Total Primary Energy Consumption

Needed new non-emitting power. $750B / year market (today’s dollars).

Fusion with growth rate = 0.4% / year of total energy.

650 ppm WRE Scenario

World population growth will be in cities and “megacities,” requiring large new power stations.
Progress in Fusion Energy has been Dramatic

- MFE data
- IFE Data
- ITER-FEAT (BPX)
- NIF

Fusion Energy (Joules/pulse) vs. Years (1970-2015)
The Tokamak -- The Workhorse of Fusion Science

Science Issues
Configuration Stability
Confinement and Transport

Heating, Fueling, Current Drive
Boundary Physics

Integration

Burning Plasma Physics
Massachusetts Institute of Technology
C-MOD Started Operations in October 1991

Princeton Plasma Physics Laboratory
Alcator C-MOD

General Atomics
Doublet III Started Operations In 1978

National Spherical Torus Experiment
NSTX started Operations in 1999

Princeton Plasma Physics Laboratory
DIII-D Tokamak

National Compact Stellarator Experiment
NCSX Fabrication: FY 2003-2007
Burning Plasma Physics
The Next Frontier

Three Options
(Different Scales)

FIRE

ITER

IGNITOR
Upcoming ITER Decision is Crucial for Fusion World-wide

Merging of Fusion Science and Fusion Energy
Burning Plasma Physics & Power Plant Relevant Technologies

- ITER Parties (EU, JA and RF) have completed design for reduced cost (~$5B) and technical objectives (same mission)
  - ITER would be first burning plasma physics device

- ITER Parties (now EU, JA, RF and Canada) want the U.S. to join negotiations

Fusion Power: 500MW
Burn Pulse: 400-3600 sec
Why the U.S. Left ITER

- “ITER won’t work” --“Science” article, 12/96
  - Physics of Plasmas paper, 3/00 -- extensive analysis showed critical 12/96 article was wrong

- “ITER costs too much” -- $10B
  - Now $5B after revision to reduce costs through reduction in detailed technical objectives, thereby--reduced size, mass, power and cost.

- “Partners will never agree to move forward” -- EDA extension
  - Negotiations underway
  - Multiple sites offered
Four Thrust Areas are Required for Practical Magnetic Fusion Energy

Areas defined by the Fusion Energy Sciences Advisory Committee.

- Burning Plasmas (ITER)
- Fundamental Understanding
- Configuration Optimization
- Materials and Technology

Cost-Effective Fusion Energy
Scientific Understanding of Fusion Plasmas has Increased Dramatically

Advanced Computing

Plasma Measurements

Simulation of turbulence in magnetic fusion plasma.

Fast imaging of plasma turbulence.

Goal: Practical fusion energy through high-quality science.
A New Era in Plasma Control: 
Key to the DIII-D at Program

Present (Actuator, Sensor) Planned

- Integrated control: 
  - Validated models
  - Expanded PCS

- Current profile control: 
  - ECCD/FWCD, MSE

- Optimized RWM control: 
  - I-Coil
  - Expanded magnetics

- Disruption detection, correction, mitigation: 
  - MHD regulation — PCS
  - Expanded magnetics

- Equilibrium: 
  - PF coils, RTEFIT

- RWM: 
  - C-Coil, n=1 magnetics

- Plasma beta: 
  - $P_{aux}$, RTEFIT

- NTM: 
  - ECCD, Magnetics

- Disruption: 
  - Gas jet, magnetics, bolometers

- Density: 
  - Cryopumps, CO$_2$ interferometers

- $T_e$: 
  - ECH, ECE
Variations of the Toroidal Plasma Configuration Address Key Fusion Issues

Spherical Torus offers high fusion power density at low magnetic field.

Compact Stellarator design optimizes plasma stability and steady-state properties.

Goal: Combine with ITER results for better fusion energy.
NSTX is Delivering Above Expectations and Ahead of Schedule

FY 00 FY 01

Record $\beta_t = 34\%$ reached

FY 02 Research Goal $\beta_t = 25\%$ reached

Plasma pressure / Magnetic Pressure %

FY 00

1Q 2Q 3Q 4Q

NBI

NBI Installation

Ohmic

FY 01

1Q 2Q 3Q 4Q

FY 02

1Q 2Q 3Q 4Q
The U.S. is Planning Two Compact Stellarator

Different configuration and design approaches are used

NCSX

Q PS
High Performance Facilities Support ITER and Look Beyond to Fusion Energy
Nanoscience and New Designs are Advancing Fusion Materials and Technologies

Molecular Dynamics calculation of atomic displacements due to neutron impact.

Simplified blanket designs allow high electrical efficiency and low radioactivity.

Goal: Convert fusion power to electricity with high efficiency and minimum radioactivity.
U.S. MFE Program Leaders have Developed an Optimized Plan to Put Fusion on the Grid

- Integrated Development
- Component Testing
- Materials Testing

Fig. 1, Magnetic Fusion Energy Facilities Operation Timeline

Being reviewed by FESAC
## Burning Plasma Decision Process

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 2002</td>
<td>Fusion Community Workshop to assess options for a Burning Plasma Experiment</td>
</tr>
<tr>
<td>September 2002</td>
<td>FESAC Recommendations for a Burning Plasma Program Strategy</td>
</tr>
<tr>
<td>December 2002</td>
<td>NRC Letter Report on Strategy</td>
</tr>
</tbody>
</table>
Fusion Energy Sciences Budget

FY 2003 Congressional

$257.3 M

* Housekeeping includes SBIR/STTR, GPE/GPP, TSTA cleanup, D-Site caretaking at PPPL, HBCU, Education, Outreach, ORNL Move, and Reserves