2.5 NUCLEAR FUSION

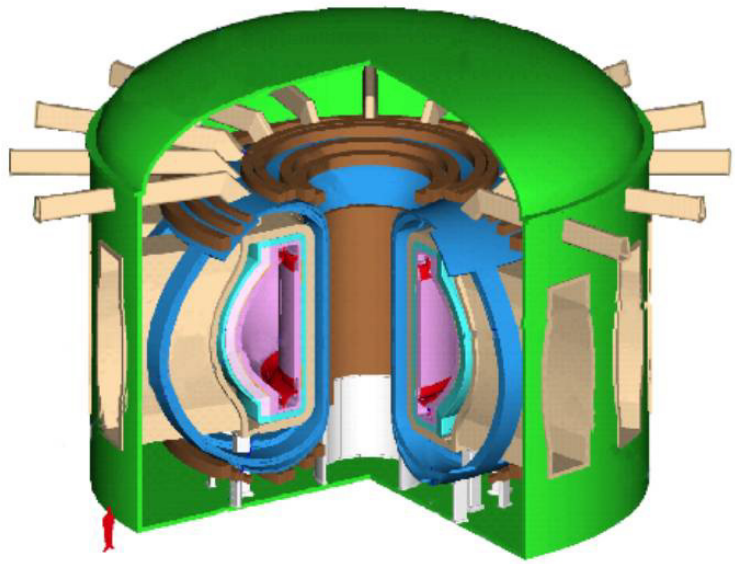
2.5.1 FUSION POWER

Technology Description

Magnetic fields or particle inertia are used to confine a hot plasma to produce fusion energy from deuterium/tritium fuel. Deuterium is abundantly available from water, and tritium can be produced from lithium within the fusion plant. The energy of the fusion reactions could be used to generate electricity and/or hydrogen at central power plants with no greenhouse gas emissions. Due to anticipated low fuel costs, electricity produced from fusion at off-peak hours could also be used to generate hydrogen at off-site fueling stations.

System Concepts

- Strong magnetic fields produced by, in some cases, superconducting coils confine plasmas with temperatures of several hundred million degrees Celsius. Twenty percent of the heat from the fusion reactions remains in the fuel to sustain its high temperatures; the rest is carried out by neutrons and is absorbed in a surrounding blanket that serves both as a heat source to produce power and as a medium for producing the tritium.
- Compressed fuel pellets ignite and burn, producing repetitive pulses of heat and neutrons in a reaction chamber. For some approaches, flowing molten salt walls in the chamber can serve as blankets.



Pictured above is the fusion-specific portion of a 1,000 MWe power plant, the result of a conceptual design study done to explore the scientific and technological issues associated with the possible reactor embodiments of fusion.

Representative Technologies

- Large, high-current-density superconducting magnets; deuterium ion beams (energies of 100–1000 keV); millimeter-wave high-power microwaves; high-power, radio-frequency sources and launchers; and particle fueling apparatus for magnetic fusion.
- Heavy ion beam accelerators, diode-pumped solid-state lasers or krypton-fluoride gas lasers, target fabrication technologies, and advanced chamber technologies are required for inertial fusion.
- Structural materials with low-activation properties will be required to fulfill the ultimate potential of fusion devices. Tritium generation and heat-recovery systems are other common nuclear system technologies required for both magnetic and inertial fusion.

Technology Status/Applications

- Moderate-sized magnetic confinement fusion experiments, with plasmas at temperatures needed for power plants, have produced more than 10 MW of fusion power, and more than 20 MJ per pulse.
- A facility is being designed through an international project, which will support scientific experiments and engineering tests for magnetic fusion burning plasma that is near commercial power plant scale (500 MW of fusion power, 500-2500 sec pulse length).
- The physics of subignited targets has been advanced with glass lasers, and underground test results have resolved certain feasibility questions of high gain for power plants.
- The target physics of ignition and high gain, using glass lasers, are objectives of the National Ignition Facility, now under construction.
- Dramatic advances have been made in the understanding and control of magnetically confined plasmas, allowing improved designs of confinement systems and increased confidence in extrapolations to power plant scale.

Current Research, Development, and Demonstration

RD&D Goals

- Accelerate the advance of scientific understanding of fusion plasmas.
- Determine the approaches and configurations for both magnetic and inertial fusion that will take the best advantage of the newest scientific insights.
- Establish the technological basis for an efficient, low-cost ion beam using an induction accelerator; develop high-average-power, durable and cost-effective solid-state and gas laser systems; and demonstrate useful gain from compression and burn of National Ignition Facility targets.
- Qualify low-activation materials that meet structural and compatibility criteria.

RD&D Challenges

- Develop magnetic geometries optimal for heat containment that at the same time (1) minimize technical complexity, (2) maximize fusion power density for good economics, and (3) operate in a continuous mode.
- Understand target requirements for high gain; reduce the development cost of candidate drivers; and develop long-life chambers and low-cost pellet targets.
- Develop low-activation materials that also meet structural and compatibility criteria.

RD&D Activities

- Coordinated worldwide magnetic fusion experimental and theoretical efforts center on configuration improvements. Fusion technology and materials development is also being pursued internationally.
- The United States has joined Europe, Japan, Canada, China, and Russia to develop plans for construction of a magnetic fusion-burning plasma science and engineering test facility (called ITER), which is to be capable of operation for 500–2,500 sec with fusion power level of 500 MW.
- Inertial fusion efforts are concentrated on driver, chamber, and pellet manufacturing technologies.
- The National Ignition Facility project, funded by the National Nuclear Security Administration, will provide information on high-gain, single-shot pellet burn experiments for inertial fusion energy.

Recent Progress

- More than 10 MW of fusion power was produced in magnetically confined plasma for about 1 second, using deuterium-tritium fuel.
- Improved understanding of plasma stability and turbulence has led to improved plasma performance in existing facilities and improved configuration designs for the future.
- Results from underground tests in the United States have resolved fundamental questions of feasibility of high gain for efficient fusion power plants.
- Results from the NOVA laser at Lawrence Livermore National Laboratory have confirmed the validity of computer models used to predict ignition and gain in the National Ignition Facility.
- Vanadium alloys show promise as a low-activation structural material in magnetic fusion devices, and liquid walls for inertial fusion chambers promise to avoid life-limiting radiation damage.

Commercialization and Deployment Activities

- Large central-station, electrical-generating plants could be commercialized late in the second quarter of the 21st century; the timescale depends on a sustained international effort and success in that R&D.
- Fusion power plants would replace aging and polluting power generators and fill a potential multibillion-dollar market sector.
- Many technologies developed for fusion are used in the commercial sector. Prominent are plasma processing for etching semiconductor chips, hardening of metals, thin-film deposition, and plasma spraying and lighting applications. Other applications from this research include medical imaging, heat-removal technologies, destruction of toxic waste, X-ray lithography and microscopy, micro-impulse radar, precision laser cutting, large-scale production of precision optics, and high-power microwave and accelerator technologies.
- Emphasize fusion science, concept improvement and alternative approaches, and development of materials.
- Recognize increasing importance of international cooperation as a means of building major facilities.

Market Context

- Large potential market in the United States and throughout the world.