2.5 FUSION

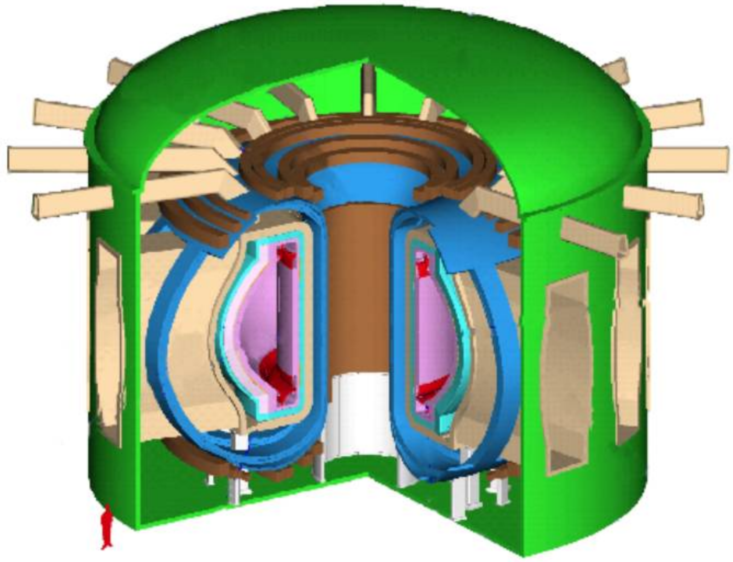
2.5.1 FUSION ENERGY

Technology Description

Fusion can be achieved using either magnetic forces to confine the hot plasma fuel or intense laser/particle beams, which rapidly compress a pellet of fuel. Both methods use 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 superconducting coils confine plasmas with temperatures of several hundred million degrees Celsius. Approximately 20% 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. Like its magnetic counterpart, inertial fusion uses a blanket, which surrounds the fusion chamber to produce power and breed tritium.



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); plasma-facing components: millimeter-wave high-power microwaves; high-power, radio-frequency sources and launchers; and tritium fueling apparatus are required for magnetic fusion.
- Heavy ion beam accelerators; diode-pumped solid-state lasers, krypton-fluoride gas lasers, or fast Z-pinches; and target design and fabrication 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 all fusion concepts.

Technology Status/Applications

- Moderate-sized magnetic confinement fusion experiments, with plasmas at temperatures needed for power plants, have produced more than 16 MW of fusion power, and more than 22 MJ per pulse.
- A facility has been designed through an international project called ITER; which, if built, 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 target physics of ignition and high gain, using glass lasers, are objectives of the National Ignition Facility, now under construction.
- Candidate high-efficiency, high-repetition gas and solid-state laser driver technologies for inertial fusion energy have been developed and demonstrated in a National Nuclear Security Administration (NNSA)-funded program.

- Dramatic advances have been made in the diagnosis, understanding, computer simulation, 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 that will take the best advantage of the newest scientific insights.
- Qualify low-activation materials that meet structural and compatibility criteria.

RD&D Challenges

- Create a self-sustaining burning plasma.
- 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 understanding plasma behavior in toroidal magnetic fields. Fusion technology and materials development is also being pursued internationally.
- The United States has joined Europe, Japan, South Korea, China, and Russia to negotiate an agreement for construction of ITER, a magnetic fusion-burning plasma science and engineering test facility, which is to be capable of operation for 500–2,500 sec with a fusion power level of 500 MW.
- 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.
- Ferritic steels show promise as a low-activation structural material for use in fusion devices.
- The potential improvement in the efficiency in the heating of an inertial fusion pellet by the use of a second laser pulse at the petawatt level in a scenario called Fast Ignition has been demonstrated experimentally.

Commercialization and Deployment Activities

- Large central-station, electrical-generating plants based on fusion could be commercialized late in the second quarter of the 21^{st} century; the timescale depends on a sustained international effort and success in that R&D.
- These fusion power plants would replace aging and polluting power generators and fill a potential multibillion-dollar per year market sector; they could also be used to produce hydrogen.
- Fusion also may find use in transmutation of fissile waste products.
- 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.