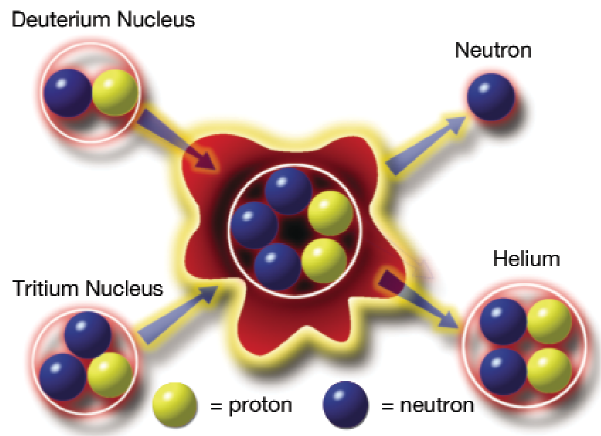
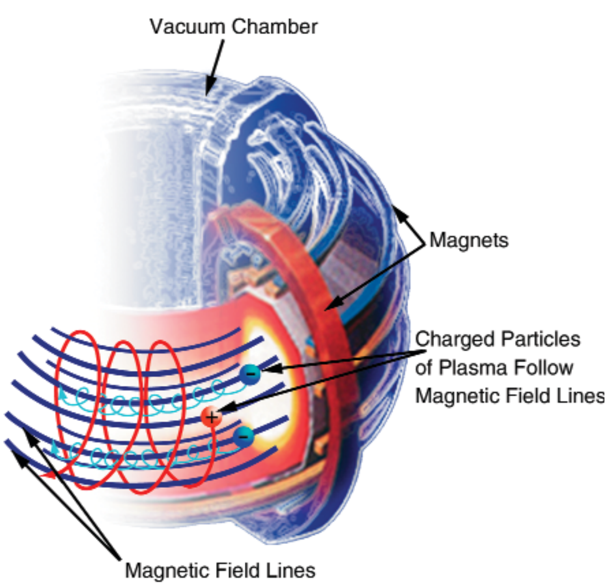
Fusion

Most energy experts agree that, as world electrical energy consumption continues to grow, fossil fuels (oil, coal and gas) will either become too scarce or too polluting to rely upon after the next few decades. If this is true, there exist only three alternative energy sources – solar and renewable fuels, fission and fusion. Even assuming the most optimistic predictions with regard to world population, energy conservation and fossil fuel supplies, we will need to create vast new energy supplies to power the future.



A fusion reaction takes place when two small atoms combine to form a larger one, releasing substantial energy. This fundamental process fuels the sun and the stars.

Fusion, the energy source of the sun and other stars, is a reaction process that can convert small quantities of matter into tremendous amounts of energy. Fusion occurs when nuclei of hydrogen, such as deuterium or tritium isotopes, are combined – fused together to form a single nucleus of helium. Since both nuclei have positive charges they tend to repel each other. Consequently, high particle energies are needed for them to hit each other and fuse. During the fusion process, some of the mass involved in the reaction is converted directly into large amounts of energy. For example, the amount of deuterium in one gallon of sea water would yield the energy equivalent of 300 gallons of gasoline.



In a tokamak, spiraling charged particles at temperatures of over one hundred million degrees Celsius — a temperature ten times hotter than the sun — follow magnetic field lines. They seldom hit the walls of this doughnut-shaped metal confinement device, whose surface is near room temperature.

To create a significant amount of electricity, a large number of nuclei needs to fuse. This collection of electrically-charged particles forms a plasma, which has unique properties, especially in its interaction with electric and magnetic fields. For a useful amount of fusion to occur a plasma must be hot and dense. Increasing heat speeds up the nuclei in the plasma, while increasing density adds more nuclei to a given space. These two factors increase the chance that two nuclei, both with positive charges that would naturally repel, can collide and fuse. Creating a practical device that will confine and control a plasma at temperatures and densities high enough to make nuclei fuse has been the primary challenge for fusion researchers.

In a star, the large stellar mass has sufficiently high gravitational forces to confine the fusion fuel (deuterium and tritium). This, together with the very high temperature of the stellar interior, provides the conditions required for fusion energy production. In one approach to fusion on earth, scientists and engineers use magnetic "bottles" called "tokamaks" to hold the fusion fuel.

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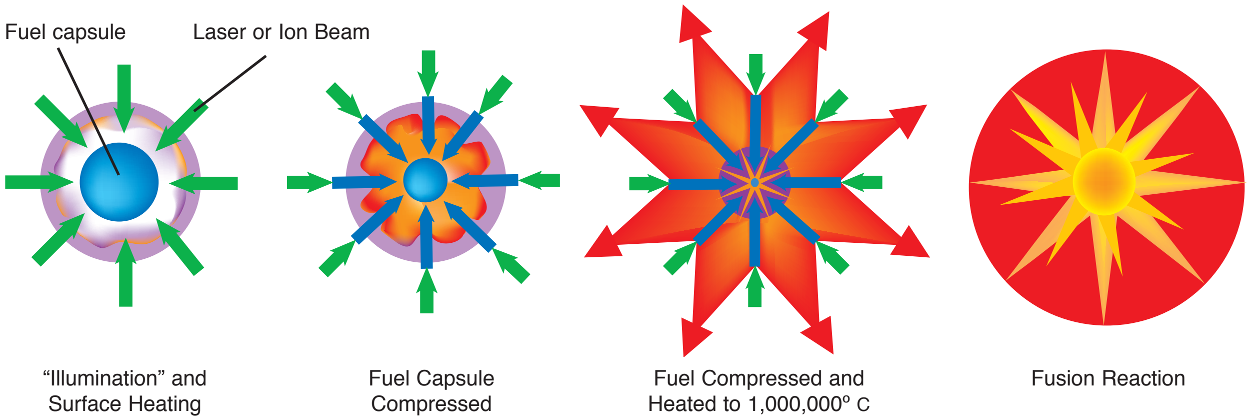
The tokamak, a great magnetic fusion innovation, was invented in the Soviet Union. It employs magnetic fields in a doughnut-shaped configuration to confine the plasma long enough to heat it. The heating is accomplished using radio waves, energetic particle beams, and the self-heating from the fusion process itself.

A second approach to fusion is through inertial confinement, which produces short-duration, extremely dense plasmas by compressing small pellets of fusion fuel. The pellet surface is heated rapidly by an intense pulse of x-rays, ion beams or laser beams, which blasts away the outer layers of the pellet. The resulting shock waves cause the pellet to implode, compressing the fuel pellet into a high-density plasma. The compressed pellet produces fusion energy until it disassembles, which takes only a billionth of a second.



In inertial confinement, high power laser beams lead to compression of the Deuterium-Tritium fuel pellet, thereby achieving thermonuclear burn.

Although fusion is a nuclear process, it differs from the fission process in that there is no radioactive by-product from the fusion reaction – only helium gas and neutrons. The neutrons from the fusion reaction do produce some radioactivity in the surrounding systems, but at a much lower level than in a fission reactor.

A fusion power station will be an inherently safe system with no potential for a Chernoblyl-type meltdown event. Any malfunction will rapidly eliminate the conditions necessary to sustain the fusion reaction; this will assure a complete and safe shutdown of the fusion process.

The challenge of fusion energy demands deep, creative scientific research. This research requires insights and conceptual innovations in a broad range of scientific disciplines, including fluid mechanics, astrophysics, kinetic theory, plasma physics, material science and nonlinear dynamics. It stimulates major advances in computer simulations. The resulting growth in scientific understanding has aided a wide variety of technical applications: computer chip manufacturing, high-power magnet design, and materials processing. Researchers continue to contribute to various applications and discover exciting technical challenges as they seek to make fusion a practical reality.

Suggested Reading:
T. Kenneth Fowler, *The Fusion Quest*, Johns Hopkins Press, 1997.
Hans Wilhelmsson, *Fusion: A Voyage Through the Plasma Universe*, IOP, 1999.
Yaffa & Shalom Eliezer, *The Fourth State of Matter*, Hilger, Bristol, 1989, (2nd edition, 2001).

Text: Adapted from *Fusion Energy Science*, Department of Energy; and *Fusion Science: Harnessing the Energy of the Stars*; General Atomics
Images: General Atomics