Provide energy from fusion

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What is fusion?

Fusion is the energy source for the sun. To be sure, producing power from fusion here on Earth is much more challenging than in the sun. There, enormous heat and gravitational pressure compress the nuclei of certain atoms into heavier nuclei, releasing energy. The single proton nuclei of two hydrogen isotopes, for example, are fused together to create the heavier nucleus of helium and a neutron. In that conversion, a tiny amount of mass is lost, transformed into energy as quantified by Einstein's famous equation, $E=mc^2$.

Earthbound reactors cannot achieve the high pressures of the sun's interior (such pressures have been achieved on Earth only in thermonuclear weapons, which use the radiation from a fission explosion to compress the fuel). But temperatures much higher than the sun's can be created to compensate for the lesser pressure, especially if heavier forms of hydrogen, known as deuterium (with one proton and one neutron) and tritium (one proton plus two neutrons) are fused.

Deuterium is a relatively uncommon form of hydrogen, but water -- each molecule comprising two atoms of hydrogen and one atom of oxygen -- is abundant enough to make deuterium supplies essentially unlimited. Oceans could meet the world's current energy needs for literally billions of years.

Tritium, on the other hand, is radioactive and is extremely scarce in nature. That's where lithium comes in. Simple nuclear reactions can convert lithium into the tritium needed to fuse with deuterium. Lithium is more abundant than lead or tin in the Earth's crust, and even more lithium is available from seawater. A 1,000 megawatt fusion-powered generating station would require only a few metric tons of lithium per year. As the oceans contain trillions of metric tons of lithium, supply would not be a problem for millions of years.

Can you control a fusion reaction?

Human-engineered fusion has already been demonstrated on a small scale. The challenges facing the engineering community are to find ways to scale up the fusion process to commercial proportions, in an efficient, economical, and environmentally benign way.

A major demonstration of fusion's potential will soon be built in southern France. Called ITER (International Thermonuclear Experimental Reactor), the test facility is a joint research project of the United States, the European Union, Japan, Russia, China, South Korea, and India. Designed to reach a power level of 500 megawatts, ITER will be the first fusion experiment to produce long pulse of energy release on a significant scale.

While other approaches to fusion are being studied, the most advanced involves using magnetic forces to hold the fusion ingredients together. ITER will use this magnetic confinement method in a device known as a tokamak, where the fuels are injected into and confined in a vacuum chamber and heated to temperatures exceeding 100 million degrees. Under those conditions the fusion fuels become a gas-like form of electrically charge matter known as a plasma. (Its electric charge is what allows confinement by magnetic forces.) ITER will test the ability of magnetic confinement to hold the plasma in place at high-enough temperatures and density for a long-enough time for the fusion reaction to take place.

Construction of ITER is scheduled to start by 2009, with plasma to be first produced in 2016, and generation of 500 megawatts of thermal energy by 2025. (It will not convert this heat to electricity, however.) Among ITER's prime purposes will be identifying strategies for addressing various technical and safety issues that engineers will have to overcome to make fusion viable as a large-scale energy provider.

What are the barriers to making fusion reactors work?

For one thing, materials will be needed that can withstand the assaults from products of the fusion reaction. Deuterium-fusion reactions produce helium, which can provide some of the energy to keep the plasma heated. But the main source of energy to be extracted from the reaction comes from neutrons, which are also produced in the fusion reaction. The fast-flying neutrons will pummel through the reactor chamber wall into a blanket of material surrounding the reactor, depositing their energy as heat that can then be used to produce power. (In advanced reactor designs, the neutrons would also be used to initiate reactions converting lithium to tritium.)

Not only will the neutrons deposit energy in the blanket material, but their impact will convert atoms in the wall and blanket into radioactive forms. Materials will be needed that can extract heat effectively while surviving the neutron-induced structural weakening for extended periods of time.

Methods also will be needed for confining the radioactivity induced by neutrons as well as preventing releases of the radioactive tritium fuel. In addition, interaction of the plasma with reactor materials will produce radioactive dust that needs to be removed.

Building full-scale fusion-generating facilities will require engineering advances to meet all of these challenges, including better superconducting magnets and advanced vacuum systems. The European Union and Japan are designing the International Fusion Materials Irradiation Facility, where possible materials for fusion plant purposes will be developed and tested. Robotic methods for maintenance and repair will also have to be developed.

While these engineering challenges are considerable, fusion provides many advantages beyond the prospect of its almost limitless supply of fuel.

Will fusion energy be safe?

From a safety standpoint, it poses no risk of a runaway nuclear reaction — it is so difficult to get the fusion reaction going in the first place that it can be quickly stopped by eliminating the injection of fuel. And after engineers learn how to control the first generation of fusion plasmas, from deuterium and tritium fuels, advanced second- or third-generation fuels could reduce radioactivity by orders of magnitude.

Ultimately, of course, fusion's success as an energy provider will depend on whether the challenges to building generating plants and operating them safely and reliably can be met in a way that makes the cost of fusion electricity economically competitive. The good news is that the first round of challenges are clearly defined, and motivations for meeting them are strong, as fusion fuels offer the irresistible combination of abundant supply with minimum environmental consequences.

References

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