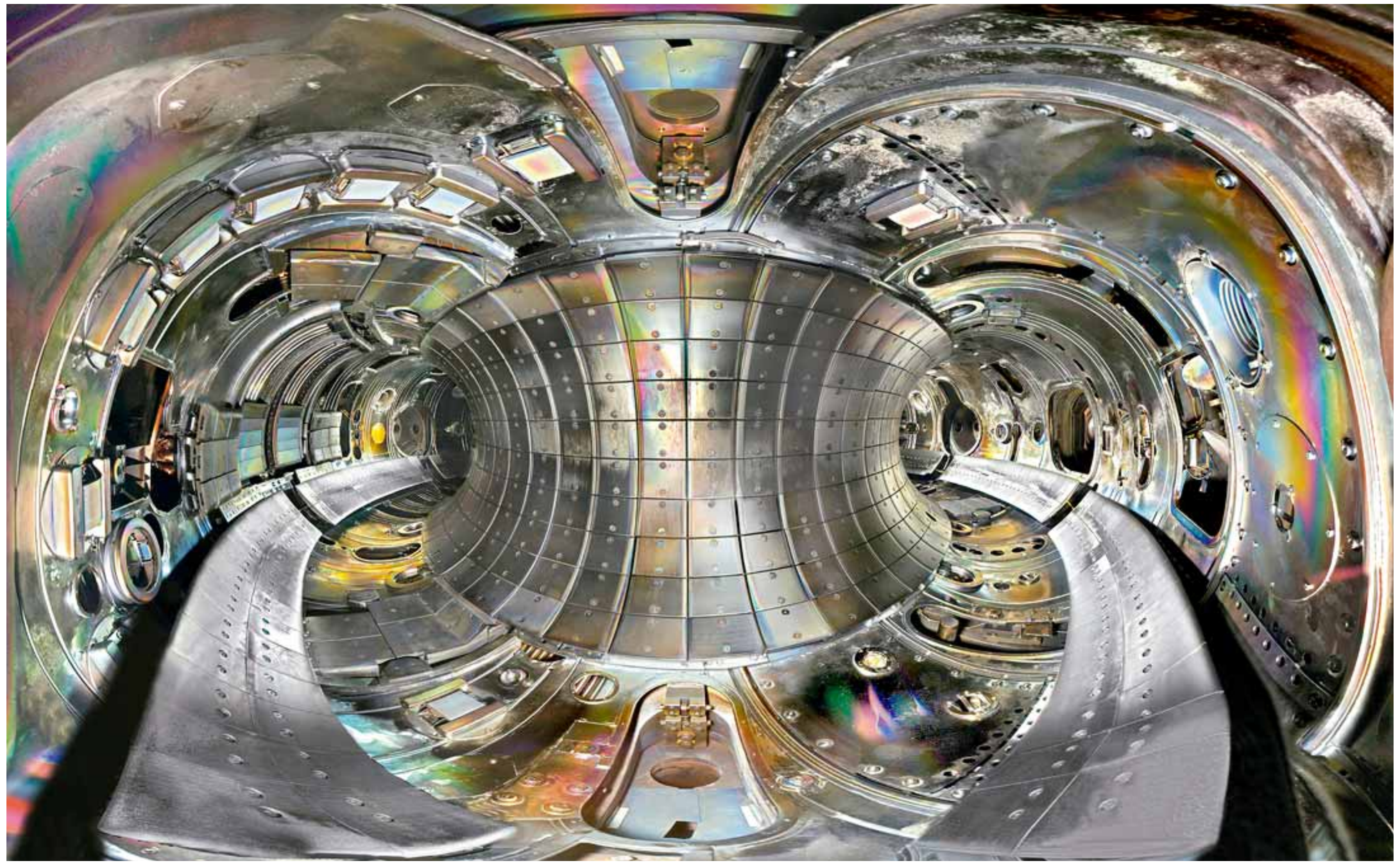

Researchers are experimenting with a fusion reactor known as a tokamak to revolutionize energy generation. The resulting knowledge has already yielded improved materials for turbine blades.

Here Comes the Sun

By 2030, researchers expect to build a fusion reactor demonstration plant that produces more energy than it consumes. If successful, fusion power will provide a nearly inexhaustible and CO_2-free source of energy. Related developments in materials research are driving improvements in many Siemens technologies.

Nuclear fusion is pure solar energy. Deep within a star, the atomic nuclei of light elements fuse, generating vast amounts of energy in the process. For a long time now, scientists have wanted to use such fusion power here on earth, because it promises to provide us with a virtually inexhaustible source of clean energy. The raw materials (water and lithium) for fusion power are available in practically unlimited amounts. Fusion energy does not emit CO_2 into the atmosphere and — unlike nuclear fission plants, which split heavy atomic nuclei — fusion does not produce highly radioactive waste that remains hazardous for thousands of years. The interior walls of a fusion reactor become only slightly radioactive after being bombarded by fast particles. After about 100 years, the radiation level declines to such an extent that all of the material can either be recycled or disposed of.

All fusion power plant concepts are based on fusing the hydrogen isotopes deuterium and tritium. The tritium, a rare substance, is produced by bombarding widely available lithium with fast neutrons that are created during the fusion reactions. Deuterium is produced from water. The plan is not without its problems, however. Because atomic nuclei have a positive charge and repel one another, they have to collide with one another very quickly for fusion to take place.

The difficulty is to heat a gas to a temperature of more than 100 million degrees Celsius and to keep the resulting hot plasma compacted long enough. Whereas researchers in the 1970s were still optimistic about the prospects of fusion power, they eventually realized that the plasma is extremely unstable and reacts negatively to even minimal disruptions. According to Prof. Günther Hasinger, Director of the Max Planck Institute for Plasma Physics (IPP) in Garching near Munich, Germany, this problem has now been overcome. "Plasma physics has come a long way in the past few decades through bigger experiments, for one thing, but also because supercomputers can simulate plasma processes," he says. "I think most of the difficulties have been solved and the focus is now on creating optimal reactor designs and operating scenarios."

The goal is to have two large-scale facilities generate more energy than is fed into them (see box). If the reactors are a success, these experiments will lead to the construction of commercial power plants by 2050. Is this too late to help reduce global CO_2 emissions? Hasinger doesn't think so. "The transformation of our energy generation systems will be one of the biggest tasks of the century," he says. "All the scenarios for the development of energy consumption, the availability of fossil fuels, and the necessary reduction of harmful greenhouse gas emissions show that far greater efforts will be required in the second half of the century than in the period up to 2050. If we manage to exploit fusion power by mid-century, it will come at just the right time to make a big difference."

Hot Synergies. Because fusion power involves technologies from a broad spectrum of fields, industrial companies are monitoring associated research efforts with great interest. One of these efforts is the search for suitable materials for the fusion reactor wall. Although a magnetic field keeps the hot plasma at a safe distance, the "cooler" outer areas of the plasma are channeled toward the reactor floor in order to clean it. Researchers estimate that certain plasma states could cause the temperature of the wall interior to rise to over 2,000 degrees Celsius, which few substances are capable of withstanding. In addition, the huge amount of heat generated by the deceleration of neutrons from a fusion reaction must not impair the mechanical stability of the reactor shell.

Siemens' Energy Sector is looking for heat-resistant materials for its turbine blades, which are covered with ceramic insulation material that allows them to operate reliably even at 1,300 degrees Celsius. Although such blades are far from reaching their melting point at that temperature, their rapid rotation causes centrifugal forces to affect them as heat levels rise. Over time, these forces can cause blades to actually stretch.

On the other hand, because the efficiency of a gas and steam turbine power plant increases by about one percentage point for every 100 degree Celsius rise in temperature, engineers are constantly investigating technologies that make higher temperatures possible, explains Dr. Stefan Lampenscherf, who researches heat-resistant materials at Siemens Corporate Technology (CT). Such an increase in efficiency would enable a 400 megawatt power plant to save one million euros in fuel costs per year. The tungsten alloys that are being developed for fusion reactors could, for example, allow the turbines to work reliably at up to 1,800 degrees Celsius.

CT is working with IPP and the Technical University of Munich to identify such dual-use technologies and analyze their cost-effectiveness. Dr. Thomas Hamacher from IPP is also interested in this research. "We have to design fusion power plants in such a way that they fit into as many different energy scenarios as possible," he says. "Due to the increasing importance of renewable energies, they will have to be very flexible, which means that many components will be subject to cyclical changes in thermal load. We now have to take a closer look at the technological and financial costs this will entail."

Siemens is also interested in work being done with superconducting magnets for fusion reactors. When such magnets are cooled to very low temperatures, they consume almost no electricity and can generate very powerful magnetic fields. Siemens Healthcare therefore uses them in many of its magnetic resonance tomographs to improve image resolution. Medical technology could benefit from research in high-temperature superconductors, which consume much less energy for cooling than conventional superconductors, and from techniques for the precise management of magnetic fields.

Prof. Hubertus von Dewitz from CT has great expectations regarding fusion research. "Take the Apollo space project," he says. "Putting a man on the moon took us a big step forward. Through massive investments in microelectronics, for example, space travel created the basis for today's communications technology. The development of fusion energy is a far bigger task than the moon flight. It should be energetically promoted, if only to achieve such technological leaps." German Chancellor Angela Merkel also believes it's worthwhile to invest in nuclear fusion and is seeking to foster international collaboration. Merkel, who is a physicist herself, visited the IPP site in Greifswald in early February to learn about the current state of research. ■ *Christine Rüth*

What's the Status of Fusion Research?

The National Ignition Facility in Livermore, California, the world's largest laser, was dedicated in 2009. Since then, measurements, including calibration and laser focusing, have been conducted. This summer (2010), the facility will begin experiments. For a few billionths of a second, the laser will generate a flash of 500 terawatts — over 100 times the output of all power plants worldwide — concentrated on a BB-sized droplet of hydrogen fuel. The flash will compress the droplet to such an extent that it will create a plasma in which a fusion reaction will occur. Researchers hope that in about two years they will achieve their first fusion reaction in which more energy is generated than is pumped in by lasers. However, to operate a fusion power plant they will have to develop lasers that flash five to ten times per second instead of once every few hours, as is currently the case.
Meanwhile, the International Thermonuclear Experimental Reactor (ITER) is being built in Cadarache in southern France. The facility, which is scheduled to enter service in 2018, is based on the most advanced type of fusion reactor, which is known as a tokamak. The plasma generated in this ring-shaped reactor is enveloped by powerful magnetic fields. The plasma is heated up by the electricity induced by a magnetic field, as well as by powerful microwave systems and high-energy particles. In the late 1990s the European JET tokamak used this technology to regain over 60 percent of the energy expended. It is hoped that ITER will be the first fusion reactor to generate more energy than it consumes — with a target of ten times the energy input, or around 500 megawatts. By 2026 this complex experiment will have progressed so far that researchers will be able to test their theory. This will be followed around 2030 by the construction of the first demonstration power plant.