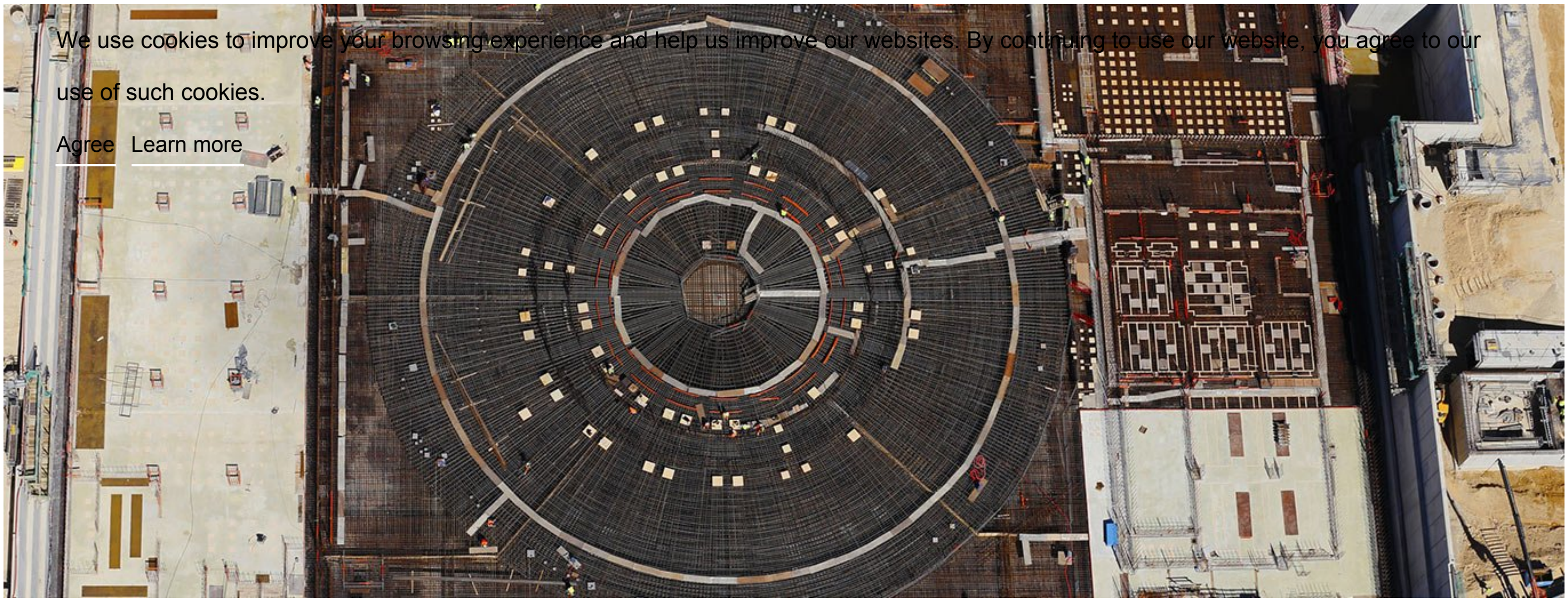
Air Liquide
creative oxygen



ITER

Contributing to the energy of the future

Now under construction at Saint-Paul-Lez-Durance (France), ITER is designed to demonstrate the technological and scientific feasibility of fusion as a large-scale and carbon-free source of energy. Construction work on the reactor began in 2014. The cryogenic plant designed by Air Liquide is a key component, since it provides the cooling essential to the system.

Thermonuclear fusion: an energy source of the future

The goal of ITER and its experimental international fusion reactor (Tokamak) is to meet the energy needs of future generations by exploiting an energy source as powerful as the core of the sun. This project takes on the scientific and technical challenge of demonstrating that a fusion power plant could potentially generate 10 times more energy than it consumes.

Recreating fusion reactions requires atoms to be heated to temperatures in excess of 150 million°C. These extreme temperatures intensify atomic motion to the point where the electrons detach from the nucleus, collide and fuse together, releasing an exceptionally high level of kinetic energy.

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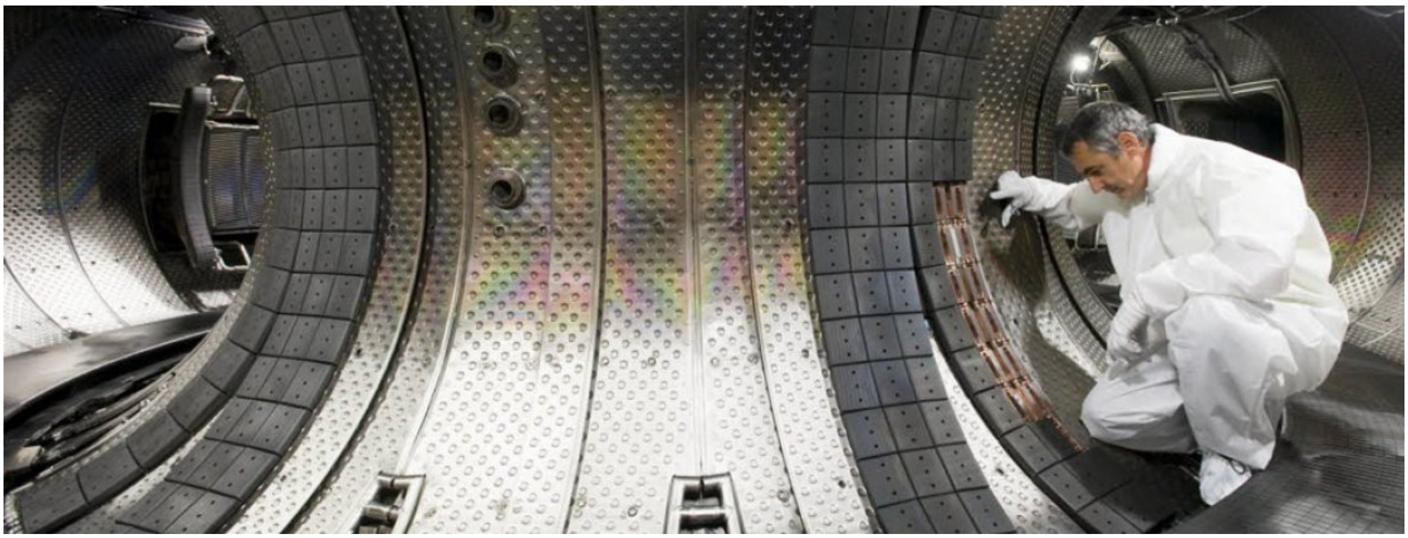
Recovered in the form of heat, this energy will then be used to generate electricity. Extremely powerful magnetic fields are needed to confine the fusion reactions inside the reactor vessel (the Tokamak), stabilize them and control their effects.



FOCUS ON

Tokamaks and nuclear fusion

Air Liquide partners the world's largest Tokamak projects, including KSTAR in South Korea and JT-60SA in Japan.

The first Tokamak (the word is a Russian acronym for 'Toroidal Chamber with Magnetic Coils') was developed in the 1950s by Russian physicists Andreï Sakharov and Igor Tamm.

The Tokamak is a toroidal (hollow ring-shaped) metal confinement chamber designed to contain the plasma–produced by heating atoms to extremely high temperatures–required to trigger nuclear fusion reactions. More than 200 Tokamaks have been built worldwide, and the most significant examples currently operational are Tore Supra in France, Jet in the UK and KSTAR in South Korea. These three will be joined by the JT-60SA project currently under construction in Japan.

Working towards the world's largest helium refrigeration unit

Creating the very powerful electromagnetic fields required to confine the nuclear fusion reaction demands the use of **superconducting magnets** that work only at extremely low temperatures close to absolute zero (-273° Celsius). At such temperatures, the electrical resistance of the magnets falls to a negligible level, enabling them to carry very high densities of electrical current.

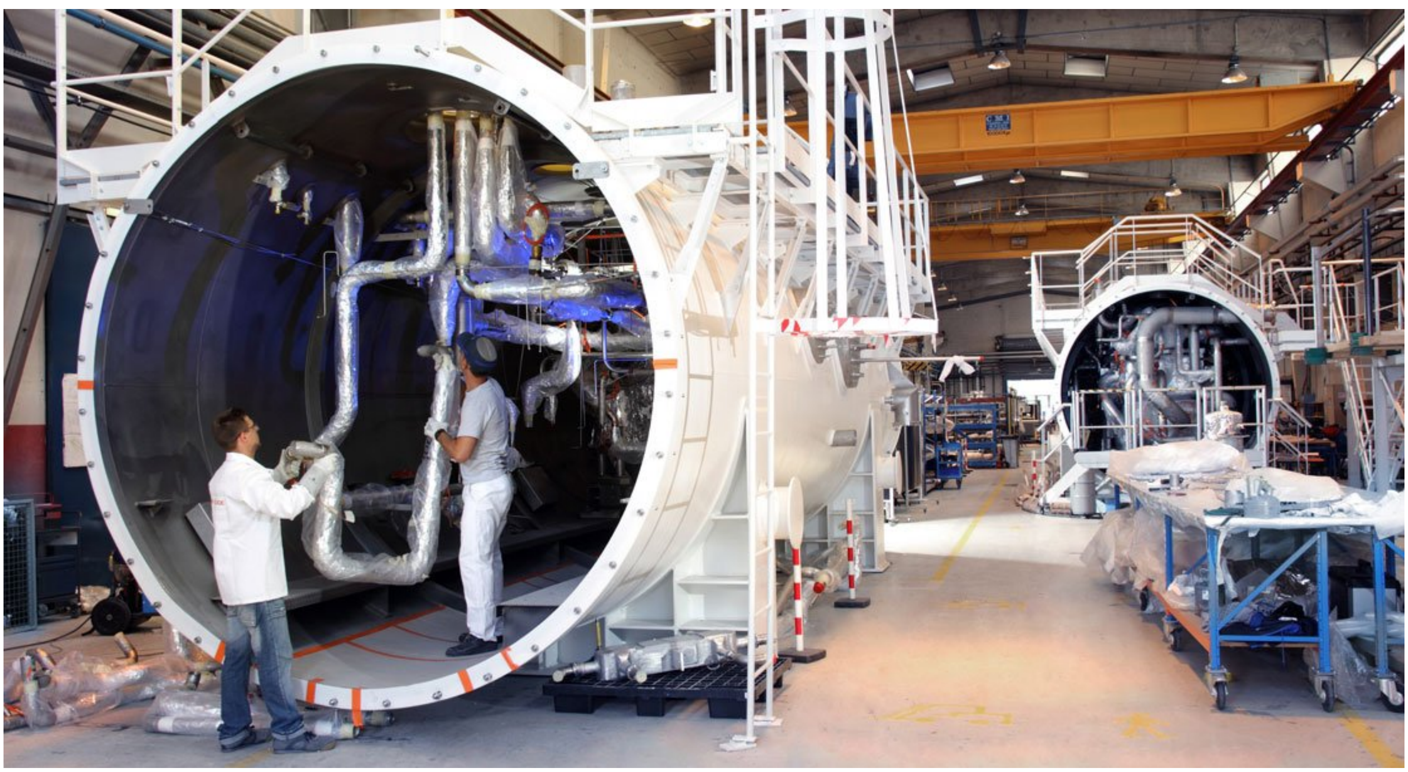
The ITER magnetic system composed of enormous field coils and 10,000 metric tons of magnets will be cooled using cryogenic systems supplied by Air Liquide.

Within the 5,400 m² cryoplant building, more than 3,000 m² are reserved for the helium plant. It includes several compressor stations and three refrigerators, each measuring 21 meters in length, 4,2 meters in diameter and weighing 135 metric tons. The three helium units will provide a total average cooling capacity of 75 kW at 4.5 K (-269 °C), making a maximum liquefaction rate of 12,300 liters per hour.

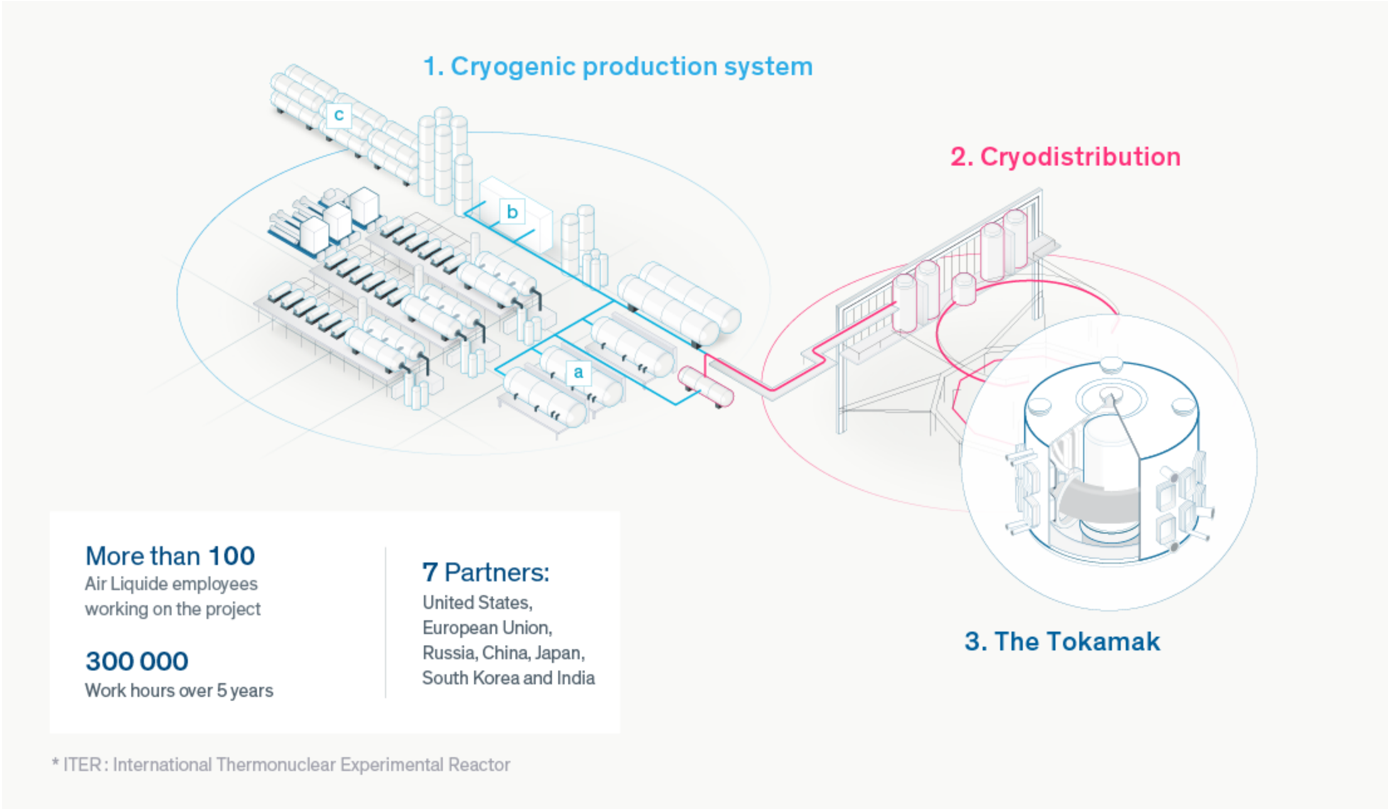
The largest ever designed centralized helium cryogenic plant

Air Liquide also provides nitrogen refrigeration units. The whole, including the helium plant, will form the largest ever designed centralized helium cryogenic plant.

ITER is a major project for Air Liquide, and joins other similar research programs to which we contribute worldwide. The expertise gained from projects like these further strengthen the Group's expertise in helium liquefaction.



The ITER Tokamak will rely on the largest cryogenic plant infrastructure ever built.



1. Cryogenic production system

The system consists of helium (a) and nitrogen (b) refrigeration units and extensive storage capacity for helium and nitrogen, provided by Air Liquide.

a. Helium units

They are comprised of three refrigerators, each measuring 20 meters in length and weighing 120 metric tons. Their combined refrigeration capacity is 75 kW at -269 °C. Liquid helium is then distributed over two kilometers of cryogenic transfer lines leading to the Tokamak in order to cool the magnets, vacuum pumps, and some of the diagnostic systems.

b. & c. Nitrogen units and storage capacity

Two nitrogen refrigerators will precool various components, including the helium refrigeration group, to -269 °C, and the helium loops to -193°C. Storage space for gas and liquid helium and nitrogen will make it possible to optimize fluid recovery during the Tokamak's different phases of operation.

2. Cryodistribution

Air Liquide may also bring its expertise to the complex distribution system that links the Tokamak to the plant by supplying cryogenic transfer lines and cryogenic valve boxes.

3. The Tokamak

At the heart of ITER, fuel consisting of hydrogen isotopes is heated to more than 150 million degrees Celsius. At this extreme temperature, electrons are separated from the nuclei and the gas turns into plasma, a hot, charged gas. Then the hydrogen nuclei fuse to generate energy. This reaction is made possible by magnetically confining the plasma in a ring-shaped vacuum chamber called the Tokamak: the intense magnetic field is created by superconductor magnets cooled with liquid helium.