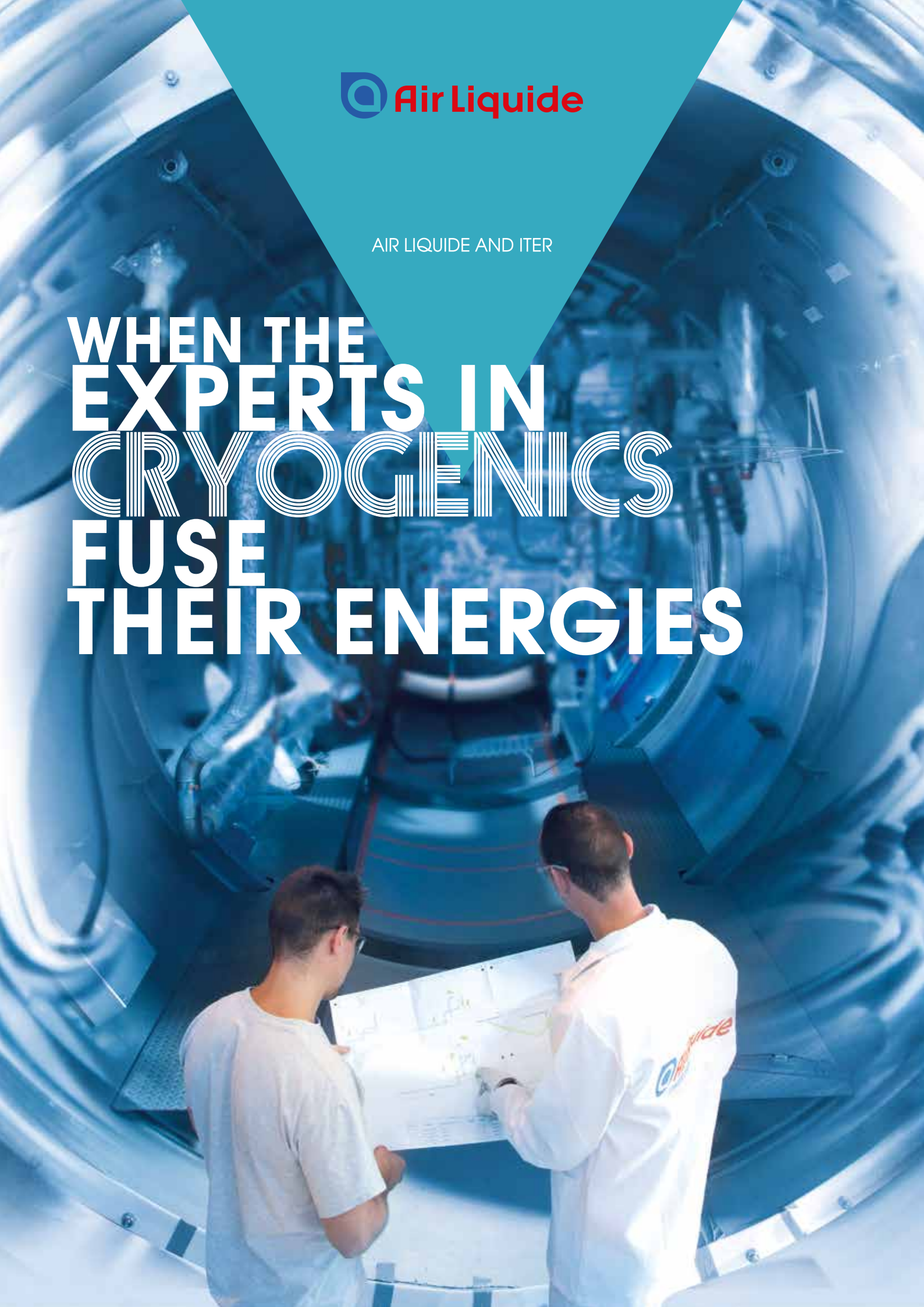
Air Liquide

AIR LIQUIDE AND ITER

WHEN THE EXPERTS IN CRYOGENICS FUSE THEIR ENERGIES



ITER, A UNIQUE PROJECT

Towards cleaner, safer, unlimited energy

Mastering fusion on Earth would pave in the way to unlimited energy resources. Controlled fusion is in fact one of the most promising paths to carbon-free energy. And this is precisely what the ITER[1] project seeks to do in order to demonstrate that fusion could become a source of carbon-free energy by around 2050. A source of energy that is manageable, safe, sustainable, and inexhaustible. This project was thus designed to address the challenge of global energy demand: twice as much energy by 2050, given population growth, but with greenhouse gas emissions reduced twofold in order to limit climate change.

The world's biggest tokamak

ITER is a research facility that was set up to demonstrate that a fusion reactor can produce ten times more energy than it consumes. To this end, the ITER organization is building an experimental reactor (or tokamak) in Cadarache, located in the South of France, which is exploring the parameters of fusion. This will be the world's largest tokamak: a toroidal magnetic confinement chamber measuring 840m^3. The bigger the reactor is the easier it is to reach more than 100 million degrees centigrade, the temperatures at which fusion reactions occur. This is a fantastic wager, one whose participants include China, South Korea, the United States, India, Japan, Russia, and the European Union.

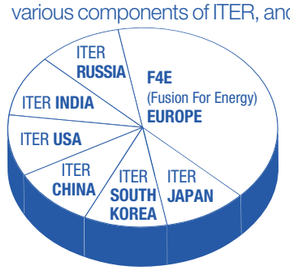
1 : International Thermonuclear Experimental Reactor

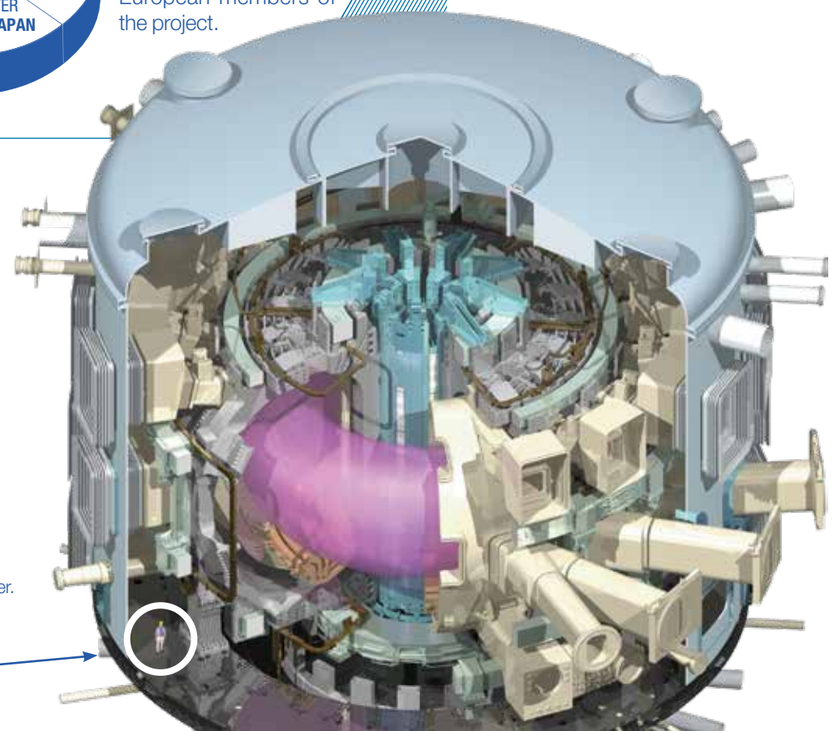
SEVEN INTERNATIONAL PARTNERS

The magnitude of the scientific, technical and organizational challenge, plus the considerable resources deployed in connection with ITER, has led the scientific community to combine their finances, their expertise, and their research. Seven countries have thus become partners on the ITER project, dividing up the tasks among themselves.

ITER Organization (IO) is an organization created from an international treaty that was concluded by and between the seven members of ITER on November 21, 2006 in Paris. It designed the ITER tokamak and will handle its installation and operation. Directed by a general deputy and four country representatives, the organization employs several hundred people from around thirty different countries.

Each of ITER's member nations also runs a national agency that is responsible for managing the timetables, budgets, the fabrication of various components of ITER, and compliance with the commitments made with respect to the project. As for Europe, it has its own agency – the F4E – which federates the work and commitments of the European members of the project.

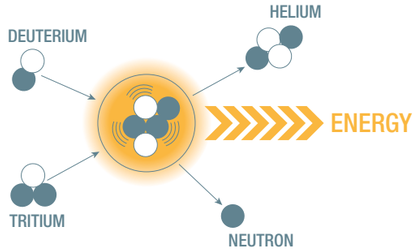




This exploded-view drawing of the ITER tokamak shows the plasma in ring form, inside the vacuum chamber. The silhouetted human figure on the left, at the foot of the machine, gives an idea of its size.

FUSION, A NATURAL REACTION IN THE SUN AND THE STARS

Fusion occurs naturally at the core of the sun and the stars. It can be defined as the assembly of light cores at temperatures that reach several million degrees to give birth to heavier cores. On the planet Earth, fusion occurs out of hydrogen isotopes – deuterium and tritium – which fuse to form a plasma. This reaction produces helium and frees neutrons and is accompanied by the liberation of a considerable amount of energy. Above all, this reaction generates little in the way of waste and rules out the risk of setting off a runaway nuclear chain reaction.



WHY CRYOGENICS?

840 M³
OF PLASMA VOLUME // OR STAR MATTER // INSIDE THE TOKAMAK

500 MW
OF ENERGY SHOULD EVENUTALLY BE PRODUCED BY ITER

10 TIMES
THE TEMPERATURE AT THE SUN'S CORE, OR 150 MILLION° C, WILL BE REACHED INSIDE THE TOKAMAK

Without cryogenics, energy needs would be colossal

Controlling the confinement of the fusion plasma in the tokamak is a complex operation. To carry it out, electromagnetic coils are used to create magnetic fields that are 50,000 times more intense than the earth's electromagnetic field! This intensity requires huge quantities of energy, unless the superconducting properties of certain materials is exploited, which offer no resistance to the electrical current… at an extremely low temperature.

ITER's magnets will therefore be fabricated using superconducting materials cooled by circulating supercritical helium at the temperature of 4.5K (-269°C). They will be installed in an immense cryostat*, with a thermal shield cooled using a helium flow at 80K (-193°C).

* A cryostat is a tank used for storage at cryogenic temperatures using a liquefied gas and vacuum insulation.

73 METERS,
THAT'S THE TOTAL HEIGHT OF THE TOKAMAK: EVEN HIGHER THAN THE ARC DE TRIOMPHE IN PARIS

80,000 KM
OF SUPERCONDUCTING FILS WILL BE NEEDED FOR THE MAGNETS OF THE TORE OF ITER

AIR LIQUIDE, THE CRYOGENICS EXPERT

"AIR LIQUIDE HAS EXPERTISE THAT IS UNIQUE IN THE WORLD WHEN IT COMES TO THE AREA OF EXTREME TEMPERATURES. ITER CHOSE OUR GROUP FOR ITS SAVOIR-FAIRE IN THE ROLLOUT OF LARGE CAPACITY GAS LIQUEFACTION AND REFRIGERATION SYSTEMS."

For ITER, we are supplying the largest centralized cryogenic cooling system ever built, which includes three helium cooling units, two nitrogen cooling units, and 1.6 kilometers of cryolines. Teams from Air Liquide Global Market & Technologies (GM&T) and from Air Liquide Engineering & Construction (E&C) will handle the jobs of design, fabrication and supervision of the installations.

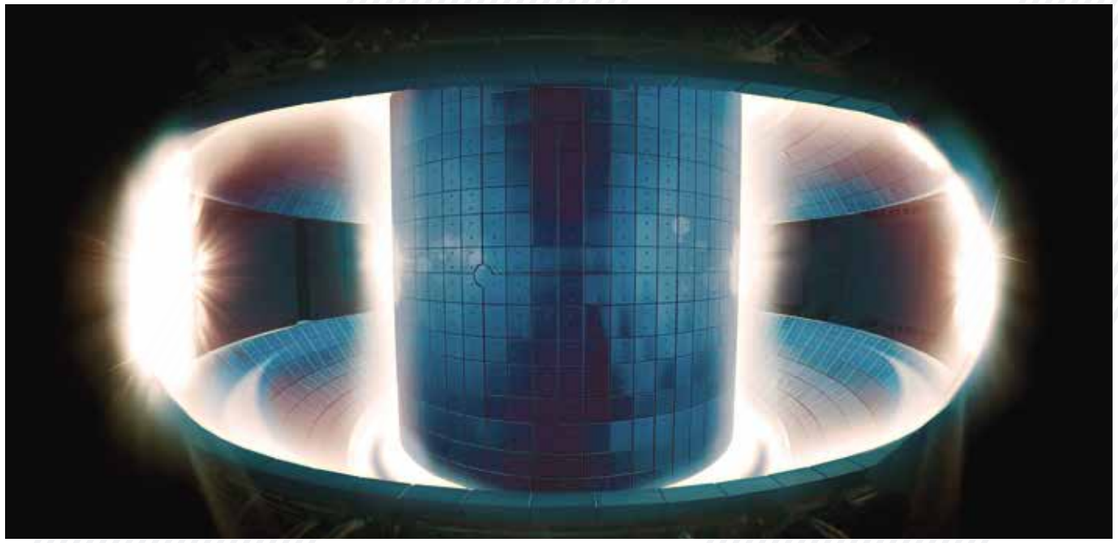
Suzanne Roy,
ITER Program
Vice-President
at Air Liquide

Unique expertise in cryogenics

Air Liquide has taken part in numerous largescale liquefaction and refrigeration projects. A few examples will suffice to demonstrate the expertise of its teams in the area of extremely low temperatures.

The Group has contributed to the cryogenic facilities at **CERN, the world's largest particle physics laboratory**, located between France and Switzerland. To maintain the 1700 superconducting magnets of the gigantic LHC particle accelerator at a temperature of 1.9K (-271°C), Air Liquide designed, fabricated, and tested groundbreaking helium cooling and distribution systems. This gigantic cryogenic equipment is spread over 27km. An extraordinary challenge for Air Liquide!

More recently, the Air Liquide teams at GM&T and E&C worked in close collaboration to design and build **the world's largest plant for the purification and liquefaction of helium** from natural gas, at the Ras Laffan site in Qatar. The turbines made for these facilities are the most powerful machines ever created to liquefy helium.



Equipping the biggest fusion projects

For 25 years, Air Liquide has been developing the specific savoir-faire required to supply customized cryogenic equipment for the world's largest nuclear fusion projects: Tore Supra in France, JET in Great Britain, SST-1 in India, KSTAR in South Korea and, as part of ITER, JT-60SA in Japan.

Tore Supra is one of the largest tokamaks in the world, operated in Cadarache, for which Air Liquide produced and commissioned a helium liquefaction and distribution system. This is where the first long-lasting plasmas were obtained in 2003.

For the **KSTAR** project in South Korea, Air Liquide built and installed the helium liquefaction and distribution system for use in cooling the reactor's superconducting magnets, at a temperature close to absolute zero, (-273°C).

The **JT-60SA** reactor was designed to optimize the method of generating plasma for the ITER and DEMO industrial reactor. It is the result of a fruitful collaboration between Europe and Japan in connection with an ITER side project. For this project, Air Liquide is supplying a turnkey cryogenic factory. The system for JT-60SA was installed in Naka, Japan, by teams from Air Liquide GM&T and Air Liquide Engineering Japan.

MORE THAN **200** EMPLOYEES INVOLVED

300,000 WORK HOURS ENSURED BY AIR LIQUIDE

21M / 4.2M / **405** TONS
THE TOTAL WEIGHT OF THE 3 COLD BOXES FROM THE HELIUM PRODUCTION UNIT

TEMPERATURES OF THE PROCESS FLUIDS DISTRIBUTED:
80 K / -193°C
4.5 K / -269°C

WORLDWIDE SUPPLIERS

INSTALLED ELECTRICAL POWER: AROUND **40 MW**

FROM **40** CM TO **1** M IN DIAMETER
FROM **2** TO **8** PROCESS PIPES
FOR THE 19 DIFFERENT CRYOGENIC LINES

1.6 KM OF CRYOGENIC LINES

CRYOGENIC PRODUCTION SYSTEM & DISTRIBUTION

The cryogenic production system

The cryogenic production system is composed of helium and nitrogen cooling units, large storage capacities for helium, nitrogen, and cryogenic lines mostly provided by Air Liquide. This unit can cool and distribute helium at different cryogenic temperatures (in particular 4.5K (-269°C) and 80K (-193°C), which is then used to cool certain Tokamak components.

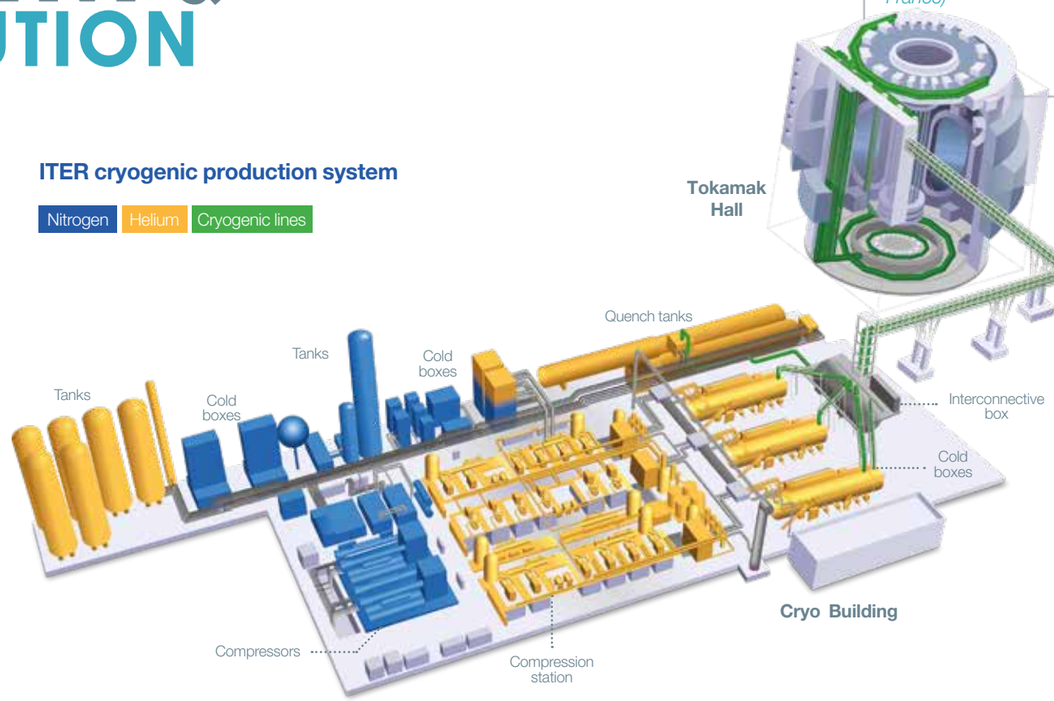
Helium units

// produced by Air Liquide / customer ITER Organization

The helium units are comprised of three refrigerators that are 21 meters long and 4m20 in diameter, and that weigh 135 tons each, with a cooling capacity ranging from 75kW to 4.5K (-269°C). This unit is completed by a helium compression and purification system.

ITER cryogenic production system

Nitrogen | Helium | Cryogenic lines



Cryo Building

Éric Dupasquier
Project Manager for ITER helium units at Air Liquide GM&T
(Sassenage, France)

AIR LIQUIDE HAS BEEN PREPARING FOR ITER SINCE 2006. THIS PROJECT HAS GUIDED OUR STRATEGIC CHOICES, TO BE EVER MORE COMPETITIVE AND EXPERT.

Our objective was to be" ready with a bid for each and every call for tender related to cryogenics for ITER, and we succeeded. ITER is a project of unrivaled magnitude, which offers us the opportunity to set up completely new project management methods, with a dedicated team and shops fitted out specifically for the fabrication of colossal cold boxes. In this sense, the project has been a learning experience. Our other projects just as ITER benefits from the expertise acquired in the course of earlier large capacity helium cooling and liquefaction projects, just as ITER benefits from the expertise acquired in the course of earlier large capacity helium cooling and liquefaction projects.

Anaïs Philippon
Project Manager for nitrogen production units and storage at Air Liquide E&C
(Champigny-sur-Marne, France)

AIR LIQUIDE E&C AND GM&T ARE WORKING TOGETHER ON THE ITER PROJECT. THE EXPERIENCE ACQUIRED IN CONNECTION WITH PREVIOUS PROJECTS, LIKE THE REFRIGERATION PLANTS IN QATAR AND AT CERN, IS FOUNDATIONAL: IT HELPED TO DEFINE THE CRYOGENIC PRODUCTION SYSTEM.

We are set up to execute complex projects and meet the technological challenges of an innovative system. Our specialists are mobilized to design a thermically efficient system that responds to multiple run scenarios of the demonstrator and optimizes the recovery of industrial gases (helium and nitrogen). Installing these units at Cadarche is also a challenge that we will be able to meet.

Nitrogen refrigerators and helium 80 K loops

// managed by Air Liquide / customer Fusion For Energy

The two nitrogen refrigerators and the two helium 80K cold boxes offer additional cooling to the 4,5K helium refrigerators. These perlite vertical cold boxes were designed by the E&C cryogenic teams.

Impressive storage capacity of nitrogen and hélium

// managed by Air Liquide / customer Fusion For Energy

Impressive storage capacity ensuring the optimized recovery of various fluids is provided by Air Liquide: helium in liquid and gas form, nitrogen inliquid and gas form. Two additional helium storage units can absorb large fluctuations in flow rates of helium in the tokamak's quench phases.

The cryogenic lines

// managed in majority by Air Liquide / customer ITER India

The cryogenic lines are designed to convey helium at different temperatures, close to absolute zero in some cases. They are fabricated using high tech processes and sophisticated design. Intended to link up the cryogenic plant to the tokamak, they represent in total a 1.6km network that will distribute the cold power needed to run various ITER equipment.

Cryodistribution

// The cryodistribution box is not provided by Air Liquide / managed by ITER India

Liquid helium is distributed by an interconnective box that serves as the interface between the cryogenic production unit and the tokamak. The cryolines complete this distribution system.

Vincent Billot
Project Manager for cryolines at Air Liquide GM&T
(Sassenage, France)

THE EXPERIENCE ACQUIRED THANKS TO THE 27 KM OF CRYOGENIC LINES PROVIDED FOR CERN'S LHC IS PRECIOUS, PARTICULARLY WITH RESPECT TO SUPER-INSULATION.

The ITER lines are 10 times shorter but they are more varied and technical: there are 19 different kinds of vacuum cryolines, conveying different supply temperatures, under up to 20 bars of pressure. Without the cryogenic lines, cold would never reach the magnets. For ITER, these lines are as vital as the system of veins in the human body: from the cryogenic production unit (the heart of the system), they carry cold liquid helium (fresh blood) to the tokamak (the brain), and then take heated helium back to the production unit, to close the loop.

VISION & OUTLOOK

In addition to fabricating equipment for the cryogenic plants and lines for ITER, Air Liquide offers its expertises and solutions in the area of cryogenics and vacuum, gas supply and gas engineering for ITER and its partners.

MORE ABOUT

www.airliquide.com/science/iter

www.advancedtech.airliquide.com

Another prospect: the DEMO design, which will pave the way for the industrial exploitation of fusion, is already a subject of discussion. ITER, the experimental reactor that will have demonstrated the feasibility of fusion as a source of energy, serves as a model for the DEMO construction. Already, each member of the ITER Organization has defined the broad outlines of what DEMO might be. With the experience and the expertise acquired in connection with ITER, Air Liquide is already prepared to take on this new challenge.

Air Liquide

www.airliquide.com

A world leader in gases, technologies and services for Industry and Health, Air Liquide is present in 78 countries with approximately 64,500 employees and serves more than 3.8 million customers and patients. Oxygen, nitrogen and hydrogen are essential small molecules for life, matter and energy. They embody Air Liquide's scientific territory and have been at the core of the company's activities since its creation in 1902.