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Launch of ITER's assembly phase is made possible by the arrival of components from all over the world in recent months (video: https://bit.ly/2BtoA9m) . It demonstrates the willingness of the 35 partner countries of the ITER international research project to join together in an enduring way in their common fight against climate change. Credit: ITER

French President Emmanuel Macron and leaders from the European Union, China, India, Japan, Korea, Russia, and the United States have declared the start of a new energy era today with the official start of the assembly of the world's largest fusion device at ITER in Southern France.

The ITER machine, the world's largest science project, is being assembled to replicate the fusion power of the sun. The launch of the ITER assembly phase is made possible by the arrival of components from all over the world in recent months. It demonstrates the willingness of the 35 partner countries of the ITER international research project to join together in an enduring way in their common fight against climate change.

"I heartily congratulate the ITER Project," says Shinzo Abe, Prime Minister of Japan. "I believe disruptive innovation will play a key role in addressing global issues including climate change and realizing a sustainable carbon-free society."

Fusion provides clean, reliable energy without carbon emissions. Fusion is safe, with minute amounts of fuel and no physical possibility of a runaway accident with meltdown. The fuel for fusion is found in seawater and lithium. It is abundant enough to supply humanity for millions of years. A pineapple-sized amount of this fuel is the equivalent of 10,000 tons of coal.

The cost of building and operating a fusion plant is expected to be similar to the cost of a nuclear fission plant, but without the large costs and long-term legacy of waste disposal. When ITER is finished, it is expected that it will demonstrate that fusion power can be generated sustainably on a commercial scale.

The Promise

It is because of the remarkable promise of fusion that the ITER project was born: The 35 partner countries are the EU (plus the United Kingdom and Switzerland), China, India, Japan, Korea, Russia, and the United States. These nations, representing more than 50% of the world population and more than 80% of the global gross domestic product, have pooled their vast expertise and resources to build the first industrial-scale research fusion device.

France is the host country. The European Union with the United Kingdom and Switzerland is the host member, funding 45% of the cost of ITER. Each of the other members, U.S. China, Japan, Russia, India and Korea funds 9%.

About 90% of ITER Member contributions are made in-kind, adding international complexity to an already multifaceted machine, called a Tokamak, for "magnetic Torus." When finished, the Tokamak will be made up of more than 1 million components.

Since the 1950s, when the concept of a Tokamak—magnetic confinement fusion—was first developed in the Soviet Union, fusion energy research has been an area of broad international collaboration.

In recent months, in preparation for the machine assembly, gigantic first-of-a-kind components have begun to arrive in France, in many cases weighing several hundred tons each. The parts are the culmination of more than five years of fabrication in factories, universities and national laboratories all over the world.

The Tokamak components must meet very strict specifications. They must arrive in France on time, according to an intricate schedule. "Constructing the machine piece by piece will be like assembling a three-dimensional puzzle on an intricate timeline," says Dr. Bigot. "Every aspect of project management, systems engineering, risk management, and logistics of the machine assembly must perform together with the precision of a Swiss watch. We have a complicated script to follow over the next few years."

At end of this period, in December 2025, ITER scientists and engineers will launch "First Plasma," the initial event demonstrating machine functionality.

How much power will the ITER Tokamak provide?

The plant at ITER will produce about 500 megawatts of thermal power. If operated continuously and connected to the electric grid, that would translate to about 200 megawatts of electric power, enough for about 200,000 homes.

A commercial fusion plant will be designed with a slightly larger plasma chamber, for 10 to 15 times more electrical power. A 2,000 megawatt fusion power plant, for example, would supply electricity for 2 million homes.

Would fusion make a difference in the amount of CO_2 going into the atmosphere?

Fusion power plants are carbon-free; they release no CO_2. But the benefit of fusion for the fight against climate change depends on how quickly these fusion plants are installed. More than 70% of carbon emissions come from energy use, and more than 80% of energy consumption comes from fossil fuels.

"If fusion power becomes universal in complement to renewable energies, the use of electricity could be expanded greatly to reduce the greenhouse gas emissions from transportation, buildings and industry," says Dr. Bigot. "Enabling the exclusive use of clean energy will be a miracle for our planet."

Fusion: how it works

1. A few grams of deuterium and tritium (hydrogen) gas are injected into a huge, donut-shaped chamber, called a Tokamak.
2. The hydrogen is heated until it becomes a cloud-like ionized plasma.
3. The ionized plasma is shaped and controlled by 10,000 tons of superconducting magnets.
4. Fusion occurs when the plasma reaches 150 million degrees Celsius—10 times hotter than the core of the sun.
5. In the fusion reaction, a tiny amount of mass is converted to a huge amount of energy.
6. The ultra-high-energy neutrons from fusion escape the magnetic cage and transmit energy as heat.
7. Water circulating in the walls of the Tokamak absorbs the escaped heat and makes steam. In a commercial plant, a steam turbine will generate electricity.
8. Hundreds of Tokamaks have been built; but ITER will be the first to achieve a "burning" or self-heating plasma.

The Start of Assembly

Cryostat

Manufactured by India, the Cryostat is the "thermos" that surrounds the Tokamak Vacuum Vessel and superconducting magnets which confine the super hot plasma. It is 30 meters high and 30 meters in diameter. It is the largest stainless steel vacuum chamber ever built. It has four main pieces: the base, lower cylinder, upper cylinder, and top lid. The lower cylinder is roughly the same dimensions as Stonehenge.

The Cryosat base section weighs 1,250 tons. It is the heaviest ITER component. It was the first major piece to be inserted into the Tokamak Pit in May. It was settled into position with an accuracy of under 3 millimeters.

ITER's magnets

ITER uses three closely integrated types of magnets to contain, control, shape, and pulse the 150 million degrees Celsius plasma. In order to be superconducting, the magnets are cooled internally with -269 degrees Celsius liquid helium, the temperature of interstellar space.

Toroidal Field (TF) Coils

Manufactured by Japan and Europe with components coming from China, Korea and Russia, more than 40 companies are involved in the manufacture of the 18 toroidal field (TF) coils. The function of the TF coils is to confine the ionized plasma particles. Each magnet is the height of a four-story building and weighs 360 tons. The first two TF coils arrived at the ITER site in April from Japan and Italy.

Poloidal Field (PF) coils

Manufactured by China, Europe and Russia, these magnets are ring-shaped and will be situated outside the TF coil system. The PF coils shape the plasma and hold it away from the walls. There are six PF coils ranging in diameter from 10 to 24 meters and weighing up to 400 tons. The first PF coil arrived at ITER in May from China. The second, made by Europe, was manufactured onsite.

Central Solenoid (CS)

Manufactured by the United States, this is the most powerful of ITER's magnets. It is sometimes called the "beating heart" of ITER because it will initiate a powerful current in the plasma in long pulses.

The central solenoid is being fabricated in six modules. When combined, it will be 13 meters tall, or 18 meters with the support structure, and will weigh 1,000 tons. It will have the magnetic power to lift an aircraft carrier.

The independently operating CS coil packs will create massive electromagnetic forces that pull in different directions. The support structures will have to withstand forces equal to twice the thrust of a space shuttle lift-off. The first CS module will arrive at ITER in Fall 2020.

Vacuum Vessel

Manufactured by Korea (four sectors) and Europe (five) sectors, with the protruding port stubs supplied by Russia, the vacuum vessel is a hermetically sealed, donut-shaped stainless steel chamber. Inside, the plasma particles spiral around continuously without touching the walls. Forty-four ports in the vacuum vessel provide access for remote handling operations, diagnostics, heating and vacuum systems.

The blanket modules lining the inner surfaces of the vessel will provide shielding from the high-energy neutrons produced by the fusion reactions. The volume of the plasma contained in the center of the ITER vacuum vessel (840 m^3) is 10 times larger than any previous tokamak.

The first vacuum vessel sector arrived in France on July 21, enabling the start of machine assembly. Buildings and civil works across the ITER worksite, constructed by Europe, are about 75% complete. Here are three examples:

- The Tokamak Building and Assembly Hall have been completed, joined by a 170-meter overhead crane rail supporting two 750-ton cranes that will transport and position components.
- The cryogenics facility, the largest centralized cryoplant in the world, is 60% completed. It provides the liquid helium for the extremely low temperatures for the superconducting magnets to work. The

equipment comes from China, India, Sweden, Czech Republic, Finland, Italy, Japan, and France. The cryolines are primarily from India.
- The magnet conversion buildings supplying power at precisely the right voltage and amperage to ITER's magnets are using specially designed equipment from China, India, Korea and Russia.

Assembling ITER, integrating the components delivered from around the world, is the responsibility of the central ITER Organization. This includes the assembly of the Tokamak itself as well as parallel installation of support systems such as radio frequency heating, fuel cycle, cryogenics, cooling water, vacuum, control, and high voltage electrical systems.

Principal assembly activities will take place in the Tokamak Building, where the ITER device will be installed in a partially embedded concrete bioshield. For the assembly phase, this building will operate as a clean area, and be maintained at a constant temperature to avoid the slightest distortion in the largest components.

More than 150 specialized tools, some weighing up to 800 tons, will be used to assemble, support, and position the Tokamak components. The circular Tokamak will be pre-assembled in nine sub-assemblies in the adjacent Assembly Hall. Each 40-degree section will integrate a vacuum vessel sector, a protective silver-coated thermal shield and two toroidal field coils.

The size and weight of major Tokamak components, the tiny tolerances, the diversity of manufacturers and the tight schedule combine to make ITER an enormous engineering and logistics challenge. Assembling the ITER machine will take 4.5 years.

Provided by ITER