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Press Release

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Interviews with Dr. Bernard Bigot, Director-General of ITER are available.
Contact in the U.S: Marshall Hoffman, H&H, +1 703 533-3535, marshall@hoffmanpr.com
Contact in France: Sabina Griffith, ITER, +33 6 27 96 14 82, Sabina.Griffith@iter.org
Contact in the U.K: Juliet Heller, H&H, +44 (0) 1621 868083, +44 (0) 7946 616150(m), julietheller.co.uk
Video B-Roll: available at: to come

World's most complex machine is 50 percent completed

ITER is proving that fusion is the future source of clean, abundant, safe and economic energy

The International Thermonuclear Experimental Reactor (ITER), a project to prove that fusion power can be produced on a commercial scale and is sustainable, is now 50 percent built. Fusion is the same energy source from the Sun that gives the Earth its light and warmth.

ITER will use hydrogen fusion, controlled by superconducting magnets, to produce massive heat energy. In the commercial machines that will follow, this heat will drive turbines to produce electricity with these positive benefits:

- Fusion energy is carbon-free and environmentally sustainable, yet much more powerful than fossil fuels. A pineapple-sized amount of hydrogen offers as much fusion energy as 10,000 tons of coal.

- ITER uses two forms of hydrogen fuel: deuterium, which is easily extracted from seawater; and tritium, which is bred from lithium inside the fusion reactor. The supply of fusion fuel for industry and megacities is abundant, enough for millions of years.
- When the fusion reaction is disrupted, the chamber simply shuts down—safely and without external assistance. Tiny amounts of fuel are used, about 2-3 grams at a time; so there is no physical possibility of a meltdown accident.
- Building and operating a fusion power plant will be comparable to the cost of a plant fueled by fossil fuels or nuclear fission. But unlike today's nuclear plants, a fusion plant will not have the costs of high-level radioactive waste disposal. And unlike fossil fuel plants, fusion will not have the environmental cost of releasing CO_2 and other pollutants.

ITER is the most complex science project in human history. The hydrogen plasma will be heated to 150 million degrees Celsius, ten times hotter than the core of the Sun, to enable the fusion reaction. The process happens in a donut-shaped reactor, called a tokamak,[1] which is surrounded by giant magnets that confine and circulate the superheated, ionized plasma, away from the metal walls. The superconducting magnets must be cooled to minus 269°C, as cold as interstellar space.

The ITER facility is being built in Southern France by a scientific partnership of 35 countries. ITER's specialized components, roughly 10 million parts in total, are being manufactured in industrial facilities all over the world. They are subsequently shipped to the ITER worksite, where they must be assembled, piece-by-piece, into the final machine.

> The ITER magnet system will be the largest and most integrated superconducting magnet system ever built.
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> Ten thousand tons of superconducting magnets, manufactured from niobium-titanium or niobium-tin, will produce the magnetic fields that will initiate, confine, shape and control the ITER plasma.

Each of the seven ITER Members—the European Union, China, India, Japan, Korea, Russia, and the United States—is fabricating a significant portion of the machine. This adds to ITER's complexity.

In a message dispatched on December 1 to top-level officials in ITER member governments, the ITER project reported that it had completed 50 percent of the "total construction work scope through First Plasma." First Plasma, scheduled for December 2025, will be the first stage of operation for ITER as a functional machine.

"The stakes are very high for ITER," writes Bernard Bigot, Ph.D., Director-General of ITER. "When we prove that fusion is a viable energy source, it will eventually replace burning fossil fuels, which are non-renewable and non-sustainable.

"ITER's success has demanded extraordinary project management, systems engineering, and almost perfect integration of our work.

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[1] "Tokamak" is a word of Russian origin meaning a toroidal or donut-shaped magnetic chamber. Tokamaks have been built and operated for the past six decades. They are today's most advanced fusion device design.

"Our design has taken advantage of the best expertise of every member's scientific and industrial base. No country could do this alone. We are all learning from each other, for the world's mutual benefit."

The ITER 50 percent milestone is getting significant attention.

"We are fortunate that ITER and fusion has the support of many world leaders," says Director-General Bigot. "President Macron and U.S. President Donald Trump discussed ITER during their meeting this past July. One month earlier, President Xi Jinping of China hosted Russian President Vladimir Putin and other world leaders in a showcase featuring ITER at the World EXPO in Astana, Kazakhstan.

"We know that other leaders have been similarly involved behind the scenes. It is clear that each ITER member understands the value and importance of this project."

(For the full text of the "Statement on ITER Progress" sent to government leaders, which notes the recent achievements and contributions by each ITER member, see Annex 1.)

Why use this complex manufacturing arrangement?

More than 80 percent of the cost of ITER, about $22 billion or €18 billion, is contributed in the form of components manufactured by the partners. Many of these massive components of the ITER machine must be precisely fitted—for example, 17-meter-high magnets with less than a millimeter of tolerance. Each component must be ready on time to fit into the Master Schedule for machine assembly.

Members asked for this deal for three reasons. First, it means that most of the ITER costs paid by any member are actually paid to that member's companies; the funding stays in-country. Second, the companies working on ITER build new industrial expertise in major fields—such as electromagnetics, cryogenics, robotics, and materials science. Third, this new expertise leads to innovation and spin-offs in other fields.

For example, expertise gained working on ITER's superconducting magnets is now being used to map the human brain more precisely than ever before.

The European Union is paying 45 percent of the cost; China, India, Japan, Korea, Russia, and the United States each contribute 9 percent equally. All members share in ITER's technology; they receive equal access to the intellectual property and innovation that comes from building ITER.

When will commercial fusion plants be ready?

ITER scientists predict that fusion plants will start to come on line as soon as 2040. The exact timing, according to fusion experts, will depend on the level of public urgency and political will that translates to financial investment.

How much power will they provide?

The ITER tokamak will produce 500 megawatts of thermal power. This size is suitable for studying a "burning" or largely self-heating plasma, a state of matter that has never been produced in a controlled environment on Earth. In a burning plasma, most of the plasma heating comes from the fusion reaction itself. Studying the fusion science and technology at ITER's scale will enable optimization of the plants that follow.

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

How much would a fusion plant cost and how many will be needed?

The initial capital cost of a 2,000-megawatt fusion plant will be in the range of $10 billion. These capital costs will be offset by extremely low operating costs, negligible fuel costs, and infrequent component replacement costs over the 60-year-plus life of the plant. Capital costs will decrease with large-scale deployment of fusion plants.

At current electricity usage rates, a city the size of Washington, D.C. could be powered with three fusion plants, with zero carbon emissions.

(To see the number of fusion plants that would be needed to power other major cities with carbon-free electricity, see the table in Annex 2).

"If fusion power becomes universal, the use of electricity could be expanded greatly, to reduce the greenhouse gas emissions from transportation, buildings and industry," predicts Dr. Bigot. "Providing clean, abundant, safe, economic energy will be a miracle for our planet."

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Annex 1

Statement of ITER Progress

The ITER project has reached a significant milestone: the completion of 50 percent of the total construction work scope through First Plasma. This is no small achievement. It represents the collective contribution and commitment of ITER's seven members. So it is with a sense of pride in that collective accomplishment, as well as a sense of deep gratitude to each member government, that we announce this accomplishment.

"Total construction work scope," as used in our project performance metrics, is a start-to-finish term. It includes design, component manufacturing, building construction, shipping and delivery, assembly, and installation. First Plasma, scheduled for December 2025, will be the first stage of operation for ITER as a functional machine. It will be followed by a staged approach of additional assembly and operation in increasingly complex modes, culminating in Deuterium-Tritium Plasma in 2035.

Globally, these indicators show that the ITER project is progressing steadily on schedule, budget and scope. For the past two years, we have met every agreed project milestone. This has not happened easily. A project of this complexity is full of risks; and our schedule to First Plasma 2025 is set with no 'float' or contingency. Effective risk management is a daily discipline at ITER.

The stakes are very high for ITER. When we prove that fusion is a viable energy source, it will eventually replace burning fossil fuels, which are non-renewable and non-sustainable.

ITER's success has demanded extraordinary project management, systems engineering, and almost perfect integration of our work.

Our design has taken advantage of the best expertise of every member's scientific and industrial base. No country could do this alone. We are all learning from each other, for the world's mutual benefit.

Looking ahead, we will need the commitment and support of every member to maintain this performance. By choosing to build this machine in an integrated way, we have made our success interdependent. A shortfall in the commitment of any member, if it impacts the delivery of that member's components, will have a cascading effect in delays and costs to all other members.

Below I have listed some of the recent achievements and contributions of each ITER member. Each member has cause for pride in these accomplishments. With your continued support, we can succeed together.

By demonstrating the feasibility of fusion as a clean, safe, and nearly limitless source of energy, we can leave a strong legacy for future generations.

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Contributions of the ITER Members

More than 80 percent of the cost of ITER is contributed in the form of components manufactured by the partners. Each member has a Domestic Agency to oversee products designed and fabricated by its companies, universities, and laboratories. This list illustrates the value being contributed by each member for the mutual benefit of all.

[Photos and graphics in the links below are available in high resolution on request to ITERCommunication@iter.org.]

Europe

On-site construction:

As part of its 45.6 percent contribution to ITER, Europe is constructing all the buildings on the ITER worksite. Today, the European Domestic Agency (known as Fusion For Energy) has completed 42 percent of work on site.

Work is underway on the last two levels of the "bioshield"—the concrete-and-steel cylinder that will surround the ITER Tokamak. See the collection of construction photos here:

First cryopump:

ITER's six cryopumps will maintain an ultra-high vacuum in the 1400 cubic meter vacuum vessel where fusion takes place. The vacuum will trap particles on charcoal-coated panels and extract helium ash from the fusion reaction. Each cryopump will weigh 8 tons and stand 3.4 meters tall.

Two additional cryopumps will maintain a lighter vacuum in the cryostat, the 8,500 cubic meter refrigerated chamber that will house the entire tokamak.

The first cryopump was delivered to ITER on 22 August after intensive R&D involving 15 high-technology European companies. It took four years of fabrication by Germany's Research Instruments and the France's Alsyom to create the first cryopump.

After mechanical testing at ITER and cryogenic testing at Germany's Karlsruhe Institute of Technology, fabrication of the additional cryopumps will follow.

More details are provided here. See also the images here and here.

Cryogenic tanks:

The ITER cryoplant will be the largest single-platform cryogenics facility ever built. Nearly 25 tons of liquid helium—at minus 269°C—will circulate through a five-kilometer network of pipes, pumps and valves to cool the superconducting magnets, thermal shield, vacuum cryopumps and diagnostics.

As of October, all eleven tanks for helium and nitrogen storage have been delivered by Europe. The cryoplant piping system is being contributed by India.

More details on the cryoplant are provided here, with photos and graphics. More details on delivery of the last two tanks are here, with photos. Additional photos are available on request.

Negative ion beam source:

Three systems will be used to heat the hydrogen plasma to 150 million °C, the temperature needed for fusion. The "neutral beam" system will provide more than half the heating for the plasma by injecting two high-energy particle beams of 16.5 MW each (33 MW total) into the tokamak vacuum vessel.

The circumference of each particle beam is about 2.5 meters, greatly exceeding the size of previous beams, which had circumference of a dinner plate and a fraction of the power. The size of ITER requires thicker particle beams and faster individual particles in order to penetrate the plasma deeply enough to create fusion.

In addition, new negative ion source technology must be used, instead of the positive ion source technology used in past machines. Years of research have gone into the optimization of these ion sources (for more details, see here).

Last month, Europe successfully delivered the negative ion source to the Neutral Beam Test Facility in Padua, Italy. Here the critical components of the system will be tested in advance, before transfer and installation at ITER.

First toroidal field magnet core:

ITER will control the fusion reaction using magnetic confinement. Inside the metal torus or donut-shaped vacuum vessel of the ITER Tokamak will be a second, invisible cage created by magnetic fields. These powerful electromagnets will keep the heated plasma in circulation away from the walls.

Eighteen of these magnets, called toroidal field magnets, will be integrated into the vacuum vessel. These magnets are being manufactured both in Europe and Japan. The first of Europe's toroidal field magnet cores, called a "winding pack" and weighing 110 tons, was completed in May 2017 in La Spezia, Italy (see more about that, including photo here).

The magnet core has now been delivered to Italy's SIMIC, the company that will complete cold tests and insert the magnet core into its final case (see more about the Japanesemanufactured coil cases, including photo here). The completed magnet will then be delivered to the ITER site.

United States

Central solenoid:

In Poway, California, General Atomics is creating the ITER central solenoid, a pillar-like magnet standing 18 meters tall, sometimes called "the beating heart of ITER."

The central solenoid is made up of six individual coils, made from approximately 6,000 meters of niobium-tin (Nb3Sn) conductor made in Japan. The central solenoid will be among the most powerful electromagnets ever built, strong enough to lift an aircraft carrier.

Work is underway on the central solenoid support structure and central solenoid assembly platform. The first parts of the central solenoid assembly platform were delivered in October. The first central solenoid coil passed its heat treatment tests in May; for more see here.

U.S. completes electrical deliveries:

The U.S. has completed its contribution to ITER's steady state electrical network (SSEN), which will power the pumps and auxiliary loads of the ITER facility. The 35th and final shipment of equipment arrived at the ITER site in October. The global procurement was managed by Princeton Plasma Physics Laboratory; for more details, see here.

The U.S. is supplying 75 percent of SSEN components; Europe is supplying 25 percent.

Tokamak cooling water system:

The Tokamak cooling water system will absorb the heat produced by the ITER fusion reaction. More than 36 kilometers of nuclear-grade stainless steel piping for the system is being fabricated in Robinsville and Hernando, Mississippi. See the story here.

In October, the final design review was completed for the entire system—which means that more orders for high-tech equipment will soon be placed.

China

Magnet feeders:

ITER's magnet feeders will relay electrical power, cryogenic fluids and instrumentation cables from outside the machine in to the superconducting magnets, crossing the warm/cold barrier of the machine. These complex systems are equipped with independent cryostats and thermal shields and packed with a large number of advanced technology components such as the high-temperature superconductor **current leads**, cryogenic valves, **superconducting**

busbars, and high-voltage instrumentation hardware. They will be among the first components installed.

China is supplying all 31 feeders. The first feeder arrived in France in October; see the story with photos and video here.

Correction coils:

The correction coils are ITER's smallest magnets. Weighing no more than 4.5 tons each, they are delicate by ITER standards, much thinner and lighter than the massive toroidal field and poloidal field magnets. Yet their role is vital: to fine-tune the magnetic fields to offset any imperfections in the position and geometry of the main magnets.

China is producing these magnets. Eighteen superconducting correction coils will be distributed around the ITER Tokamak at three levels. Qualification activities are completed and production is underway on the first coils and cases. For details, see here and here.

Electrical conversion components

In addition to the steady state network that will supply electricity to buildings and auxiliary systems, ITER will operate a pulsed power electrical system (PPEN) to deliver power to the magnet coils and the heating and current drive systems during plasma pulses.

Earlier this year, China delivered the last of the PPEN voltage transformers (see more here) for the pulsed power electrical network (PPEN). In October, China delivered four 128-ton converter-transformers for the magnet power conversion system (see more here).

Russia

Poloidal field coil #1

Six ring-shaped poloidal field coil magnets will encircle the ITER machine to shape the plasma and contribute to its stability by "pinching" it away from the vacuum vessel walls.

Poloidal field coil #1 (PF1) is being built at the Srednenevsky Shipbuilding Plant in Saint Petersburg, Russia. Specialists from the Efremov Institute and other Russian experts are winding niobium-titanium superconductor material into flat "pancakes." The fifth of eight pancakes that will make up the PF1 magnet is now being wound.

The final PF1 magnet, which will weigh 300 tons, will be shipped to ITER and installed at the top of the machine. See more details here.

First completed port stub extension for vacuum vessel

The ITER vacuum vessel, where the fusion reaction occurs, will be encased in a second, much larger vessel, the cryostat. Each of the vacuum vessel's 44 openings will have custom-made "extensions" to create the junction to the cryostat. These 44 custom-made ports are being built in Russia.

While the extension pieces are small in relation to the vacuum vessel, they are still quite sizable. Port stub extension (PSE) #12, for example, weighs more than 17 tons, covers an opening of 4 meters x 2.5 meters, and is 3.4 meters in length. Last month Russia completed PSE #12 and shipped it to Korea, where it will be welded onto its vacuum vessel sector. See more details here.

Power supply and magnet protection system

Russia is responsible for a wide variety of electro-technical components that make up the switching networks, fast discharge units, DC busbars and instrumentation procurement package. Manufacturing is underway now on the busbars and switching network resistors; and the R&D program is concluding for the fast discharge unit components. See more details here.

Korea

Vacuum vessel fabrication

The ITER vacuum vessel, a donut-shaped stainless steel chamber heavier than the Eiffel Tower and more than 10 times larger than the next largest tokamak, is being built in nine pieces, like sections of an orange. Europe is building five sections, and Korea five.

Korea has completed the first segment of vacuum vessel sector #6 was just completed on time according to IC milestones. Sector #1 is nearly half complete, and sector #8 is well underway. For more details on vacuum vessel fabrication, see here.

Giant assembly tools to pre-assemble the vacuum vessel

The tools ITER will use to assemble the vacuum vessel sectors are truly colossal: six stories high with "wings" that spread 20 meters. Each tool weighs 800 tons. Each is strong enough to hold a 440-ton vacuum vessel sector and two 310-ton toroidal field magnets in its arms, bringing them together to make a unit.

Two of these "sector sub-assembly tools" (SSATs) will work side-by-side in the 60-meter-high ITER Assembly Hall. They will build the nine sectors of the vacuum vessel before their transfer to the Tokamak Pit, where they will be welded together to form the ITER vacuum chamber.

Korea delivered the first SSAT to ITER in batches over the summer. It is currently being erected in the Assembly Hall. A second, identical, tool is under fabrication in Korea. For more details, see here, here and here.

Thermal shield

Since ITER's superconducting magnets must be cooled to minus 269°C, they must be heavily protected from any heat source. The toroidal field magnets, which surround the vacuum chamber, require a special high-tech thermal shield: stainless steel electroplated in silver.

At SFA Engineering Corporation in Changwon, Korea, the fabrication of the ITER thermal shield is now underway. See more details here.

India

Cryostat assembly underway

The 3800-ton ITER cryostat will be the largest stainless steel vacuum chamber in the world. It will encasing the entire vacuum vessel and all the superconducting magnets, ensuring an ultra-cool, protective environment.

India is manufacturing the cryostat, but it is far too massive to be shipped as a whole. Steel segments have been precision-fabricated by Larsen & Toubro in India, and transported by sea to Marseille. About half the cryostat has been shipped so far. At the ITER worksite, the Indian Domestic Agency is supervising a team of German welders in the final fabrication of the first two sections—the base and lower cylinder.

The cryostat base, at 1,250 tons, will be the heaviest single load of machine assembly. It will also be the first major component installed. For more details on the fabrication, see here. For recent progress, see here.

Cryolines

More than five kilometers of "cryoline" piping will be used to deliver cryogenic cooling fluids—liquid helium and liquid nitrogen—to ITER components. These cryolines will travel along an elevated bridge from the cryoplant to the Tokamak Building. From there, the distributed cryoline network will cool the ITER magnets, thermal shield, and cryopumps.

The first batch of cryolines was shipped to ITER in June. For more details, see here.

Japan

Toroidal field coil magnets and cases

Japan has the responsibility for making 9 of ITER's 19 toroidal field (TF) coil magnets, as well as all of the cases for these magnets. These steel cases are being made in segments at Mitsubishi Heavy Industries in Futumi, Japan. They constitute the main structural element of the magnet system—not only encasing the winding packs that make up the core of the toroidal field magnets, but also anchoring the poloidal field coils, central solenoid and correction coils.

In September Japan shipped the first segment of the first case. See more details here. For more about the function of the cases, see here. For more about the completion of Japan's first TF magnet earlier this year, see here.

Superconductor for the central solenoid

The central solenoid, the gigantic pillar at the core of the ITER Tokamak, is being built in southern California. But the production of 43 kilometers (745 tons) of special niobium-tin (Nb3Sn) superconductor that will make up this magnet is the responsibility of Japan.

Japan recently completed a major milestone, shipping the last of this material to the U.S., where it will be wound into the modular coils that make up the central solenoid magnet. For more on the fabrication of the central solenoid, see here.

Deliveries to the Neutral Beam Test Facility

The "neutral beam" system will provide more than half the heating for the ITER plasma. Given the groundbreaking nature of this system, a full-scale Neutral Beam Test Facility (NBTF) has been constructed in Padua, Italy, with significant contributions from Japan.

In November, Japan completed its deliveries of power supply components to the NBTF.

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