The ITER Project:

opening the way to a new energy future

Bridge Forum Dialogue
Luxembourg
10 June 2021

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ITER Organization

The energy dilemma:

Fueling civilization without impacting the planet

- Electricity is the primary vector of social and economic development
- Inequality: 1.6 billion humans still not connected to the grid
- Global energy consumption: 50% growth since 1973
- Future: 60% more growth by 2030

The need: carbon-free energy on a massive scale!

ITER's goal: a long-term sustainable energy supply for the world

Requirement: decarbonization of energy production

- Current status: 80% of energy consumed is from fossil fuels
- 65% of electricity production

The task ahead: an "energy transition"

Sustainable clean energy sources: must come from well-known physical phenomena

Renewables: a partial solution

- Limitation: intermittent and low power density not suited to concentrated demands of industry, mega-cities

Nuclear fission: offers clear advantages

- Limitation: national policies, safety concerns, waste

Fusion: a promising solution

Advantages of Hydrogen Fusion

- Massive, predictable baseload power complementary to renewables
- Safe, environmentally responsible
- Virtually unlimited fuel for hundreds of millions of years, globally distributed
- No greenhouse gas emissions
- No long-lasting high-activity radioactive waste

Fusion in the Universe

Powers the sun and stars

Source of all heat and life on Earth

Physics of hydrogen fusion:

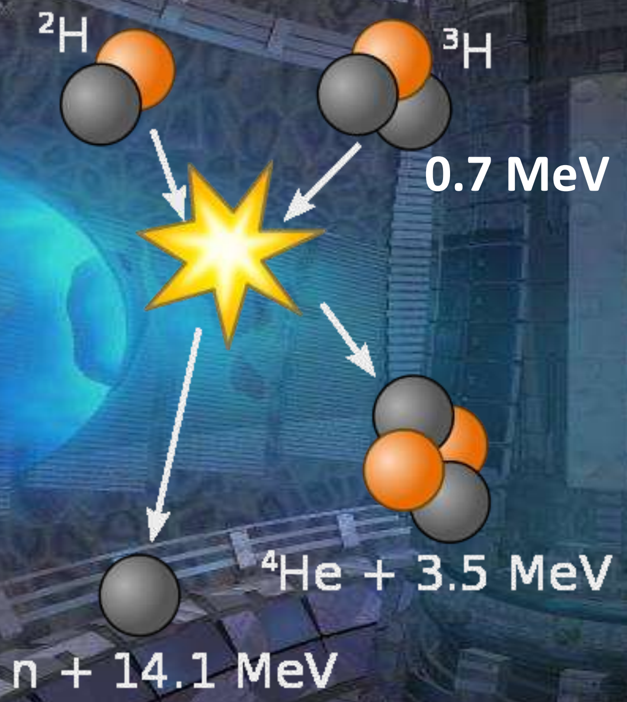
- Two light atomic nuclei combine, form a heavier nucleus, and release energy
- Limitation: challenging to re-create on Earth

$$\Delta E=\Delta mc^2$$

A tiny loss of mass
A huge liberation of energy

Fusion on Earth

1 gram of fusion fuels = 8 tons of oil



A plasma of Deuterium + Tritium (hydrogen) is heated to around 150 million °C.

- **Shaped and confined by strong magnetic fields**
- **Helium nuclei sustain "burning plasma"**
- **Neutrons transfer their energy to the walls as heat**
- **In a fusion power plant, a steam turbine transforms the heat into electricity**

"Tokamak": Russian acronym for "Toroidal Chamber, Magnetic Coils"

The ITER narrative:
from paper project to steel-and-concrete reality

November 1985, Geneva Summit
Reagan & Gorbachev announce project *“for the benefit of all mankind”…*

November 2006
ITER Agreement signed at the Élysée Palace.

August 2010
Construction works begin in earnest.

Today
Project is nearly 75% complete.

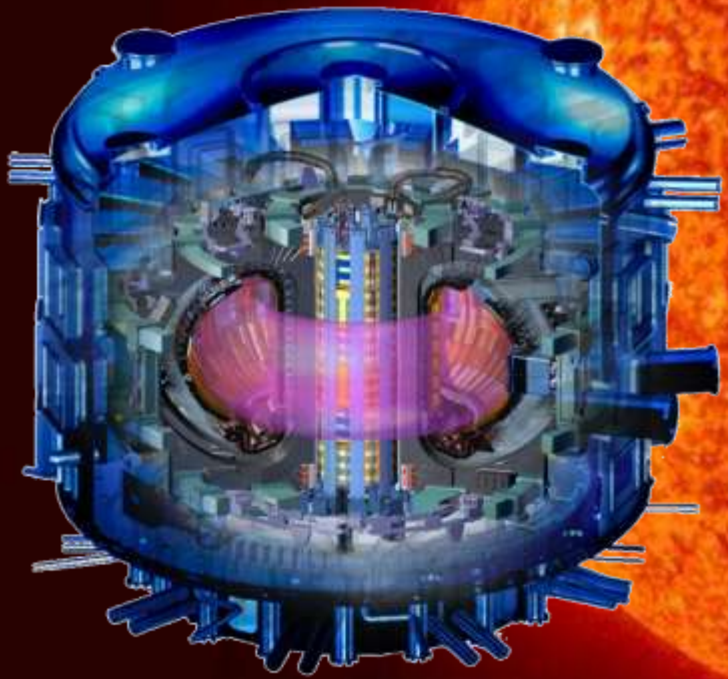
A global challenge; a global response

A multinational scientific collaboration without equivalent in history

United in a common cause: to transform our energy legacy

China EU India Japan Korea Russia USA

The ITER mission

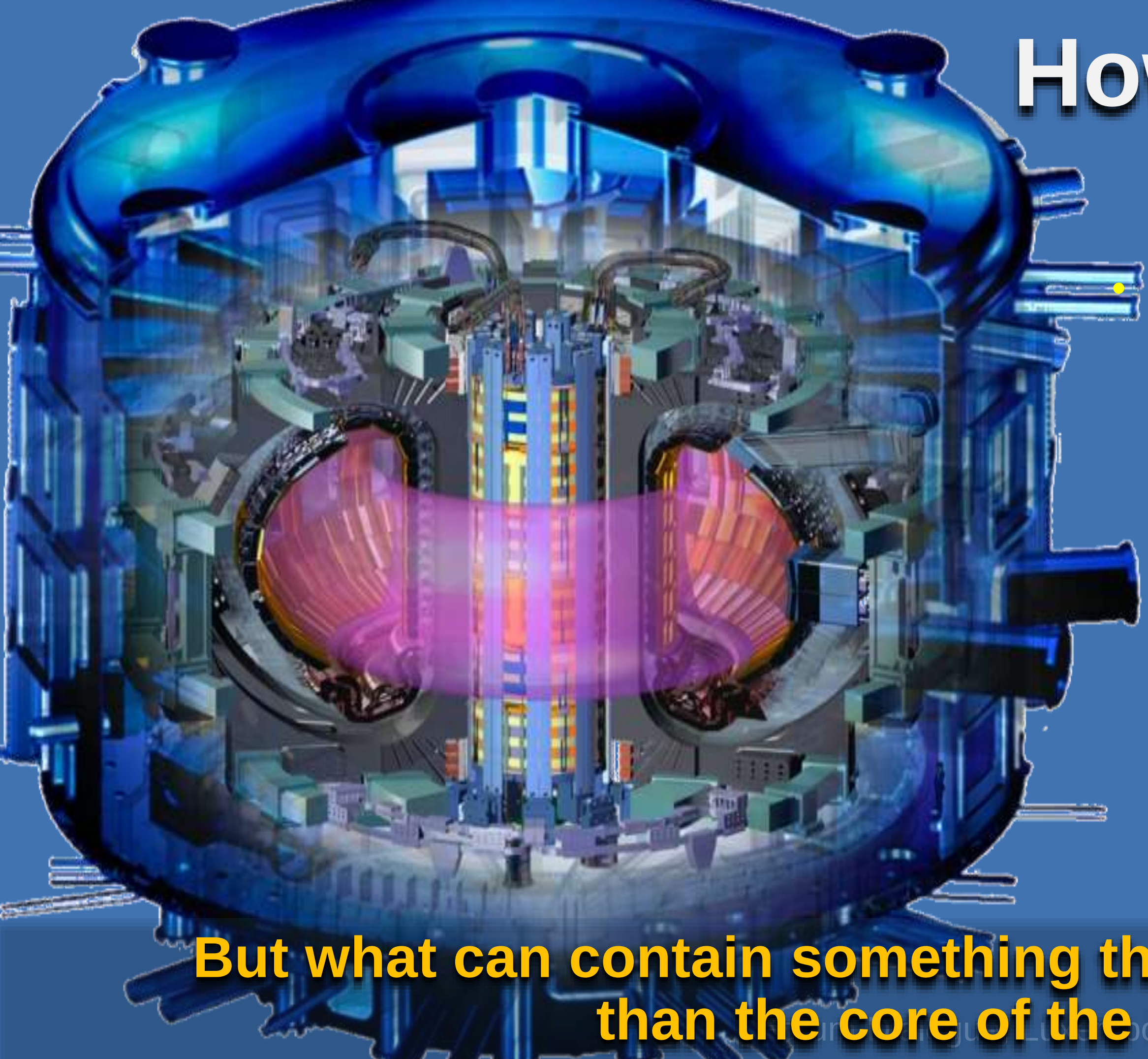


To demonstrate the scientific and technological feasibility of fusion power for peaceful purposes at industrial scale

To produce a burning (self-heating) plasma

To achieve $Q \geq 10$ (thermal output of 500 MW from 50 MW of heating input)

How does it work?



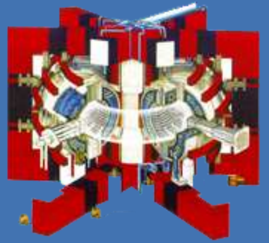
- Run a strong electrical current in the DT gas, to create a plasma.
- Continue heating with electromagnetic waves.
- Inject high-energy neutral particles.
- By combining these heating techniques, the temperature needed for fusion is achieved.

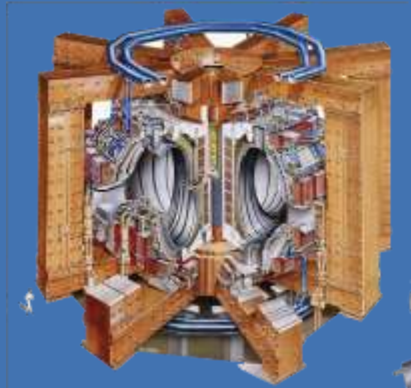
But what can contain something that is 10 times hotter than the core of the Sun?

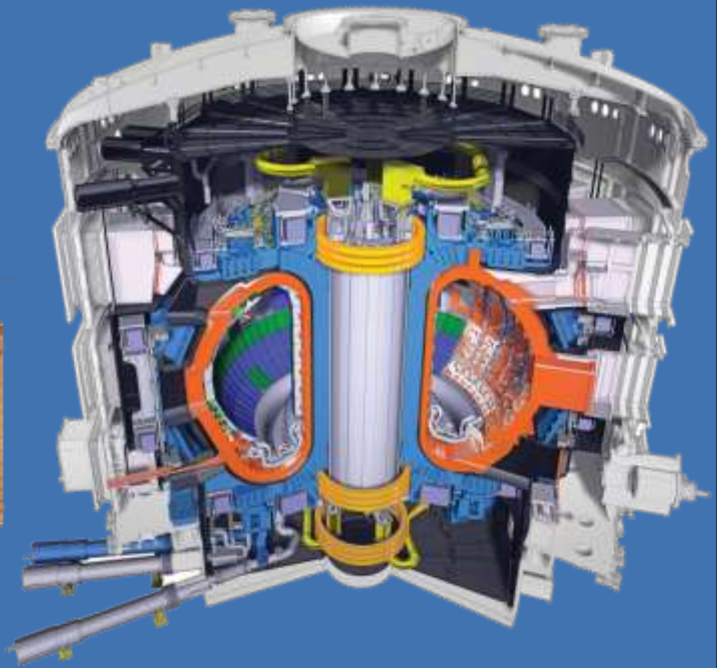
Size matters

Ratio of output thermal power over input heating power (Q) depends on:

- **Magnetic field strength**
- **Plasma density**
- **Plasma volume**

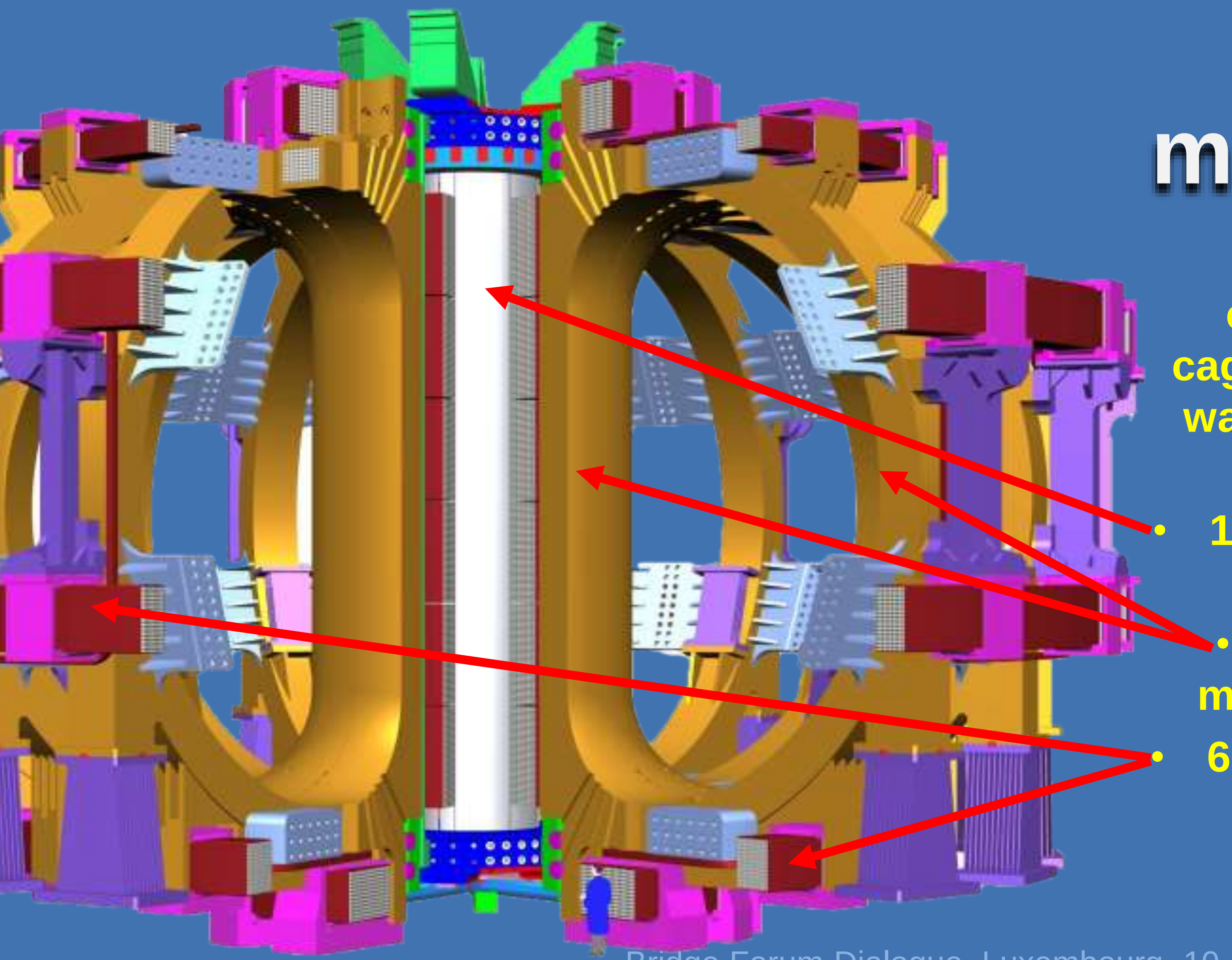






	Tore Supra (CEA-Euratom)	JET (Europe)	ITER (35 countries)
V_{plasma}	25 m^3	80 m^3	830 m^3
P_{fusion}	~0	~16 MW	~500 MW
$P_{heating}$	~15 MW	~23 MW	~50 MW
T_{plasma}	~400 s	~30 s	>400 s
I_{plasma}	~1.7 MA	~5-7 MA	~15 MA

A large magnetic cage



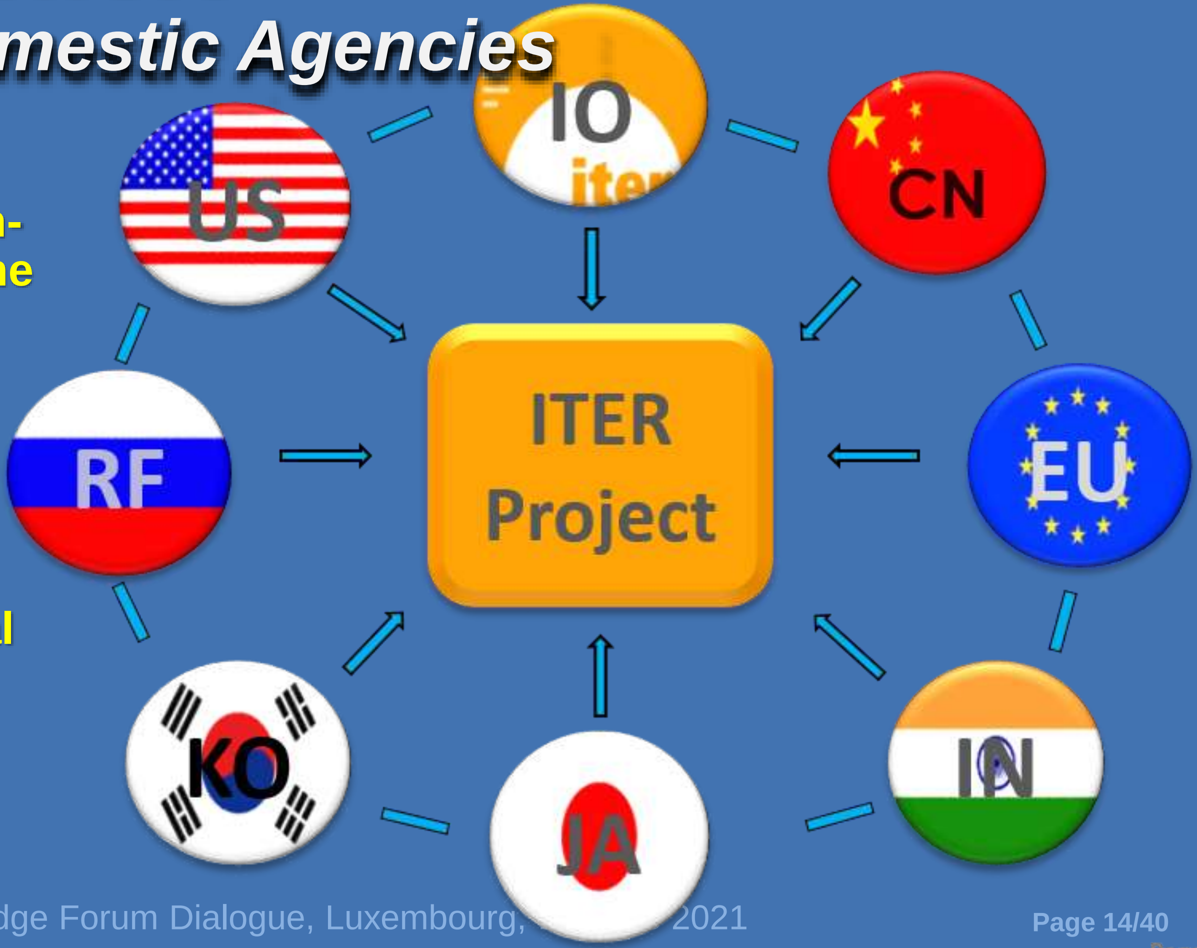
Superconducting magnets create an invisible magnetic cage inside the vacuum vessel walls to shape and control the plasma.

- **1 central solenoid, 13 metres high, 1,000 tonnes**
- **18 Toroidal Field Coils, 17 metres high, 360 tonnes each**
- **6 Poloidal Field Coils, 8 to 24 metres in diametre, 200-400 tonnes each**

An integrated effort

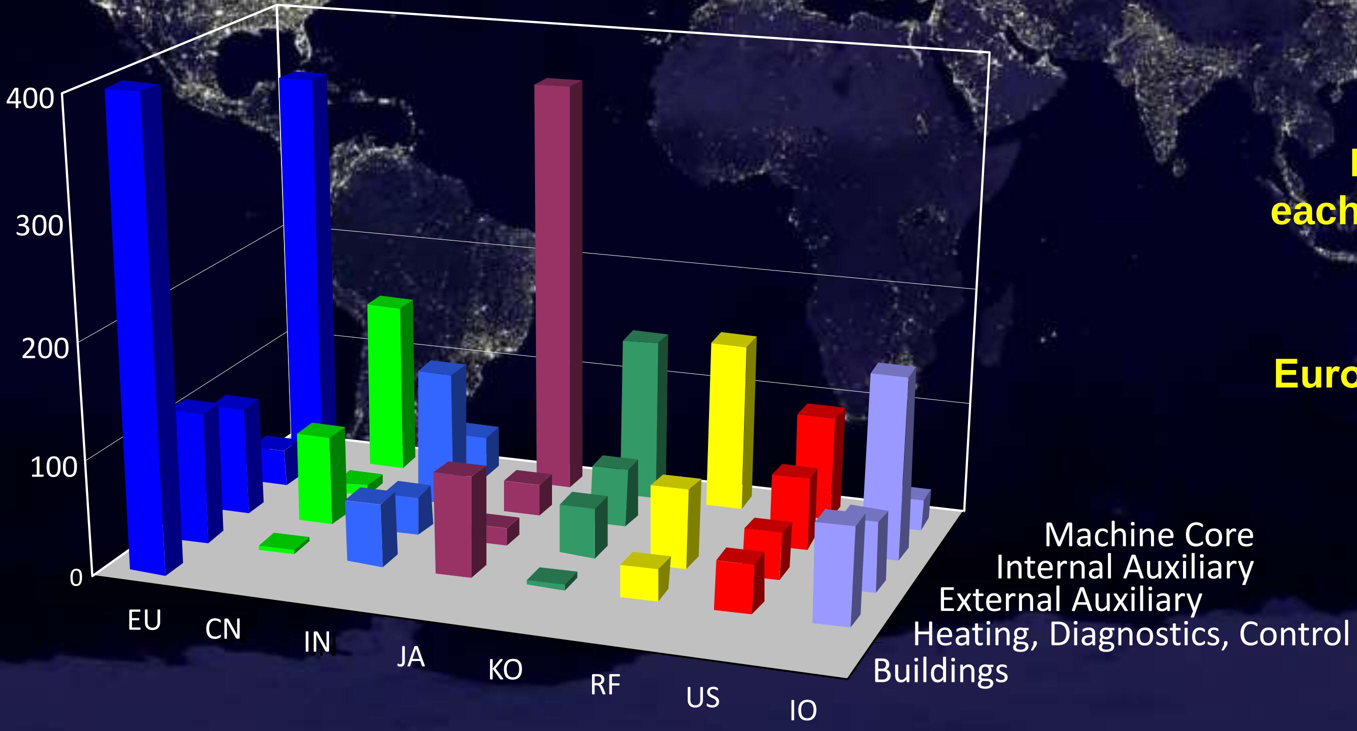
Central team & 7 Domestic Agencies

- **Members provide cash and in-kind contributions (90%) to the ITER Project. Domestic Agencies manage their industry suppliers.**
- **The ITER Organization manages project integration.**
- **Members share all intellectual Property generated by the project.**



A unique formula:

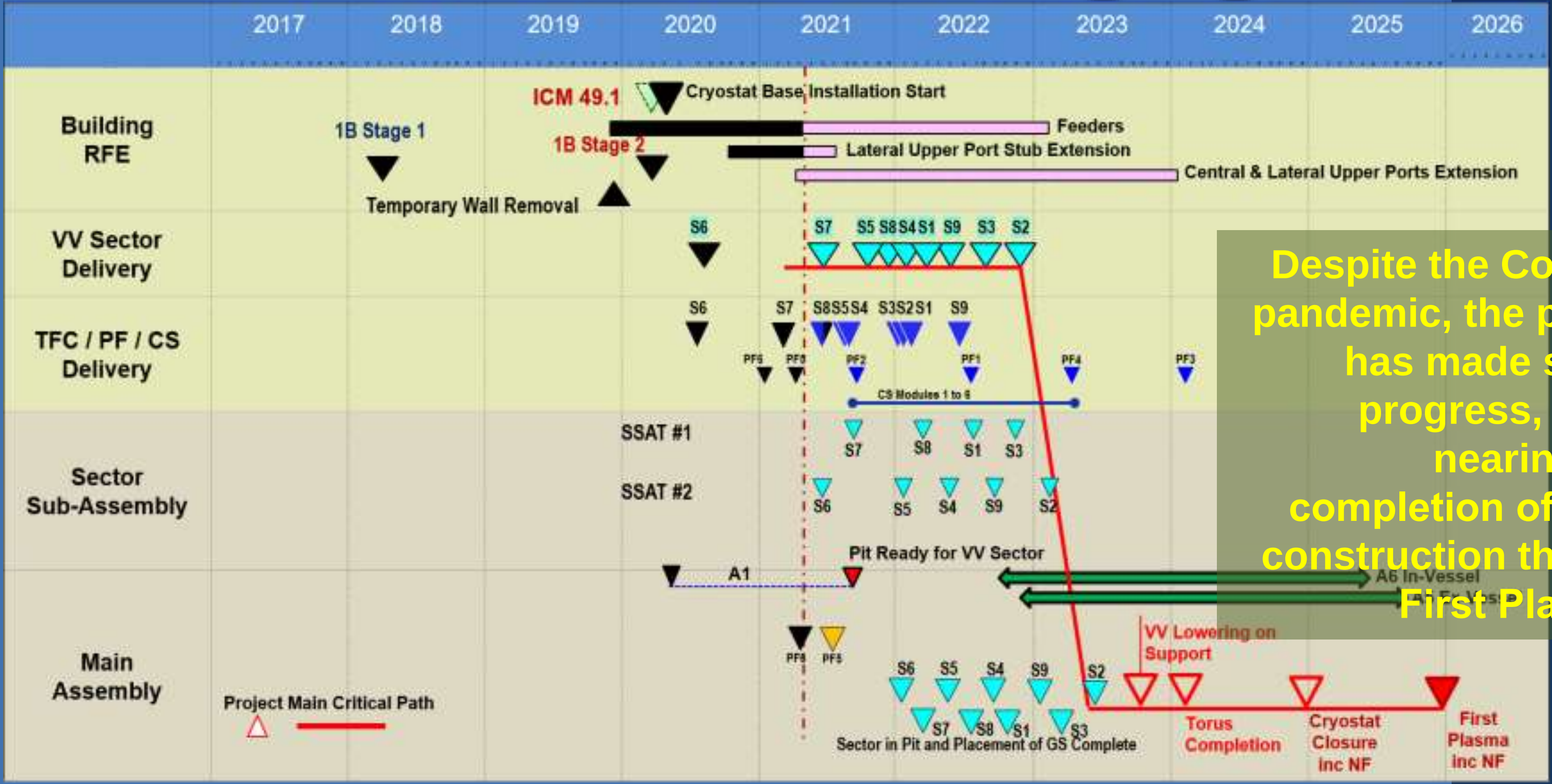
ITER is being built through the in-kind contributions of the seven Members of the ITER Organization.



China, India, Japan, Korea, Russia and the United States each have responsibility for ~ 9% of procurement packages.

Europe's share, as Host Member, is ~ 45% (construction and manufacturing).

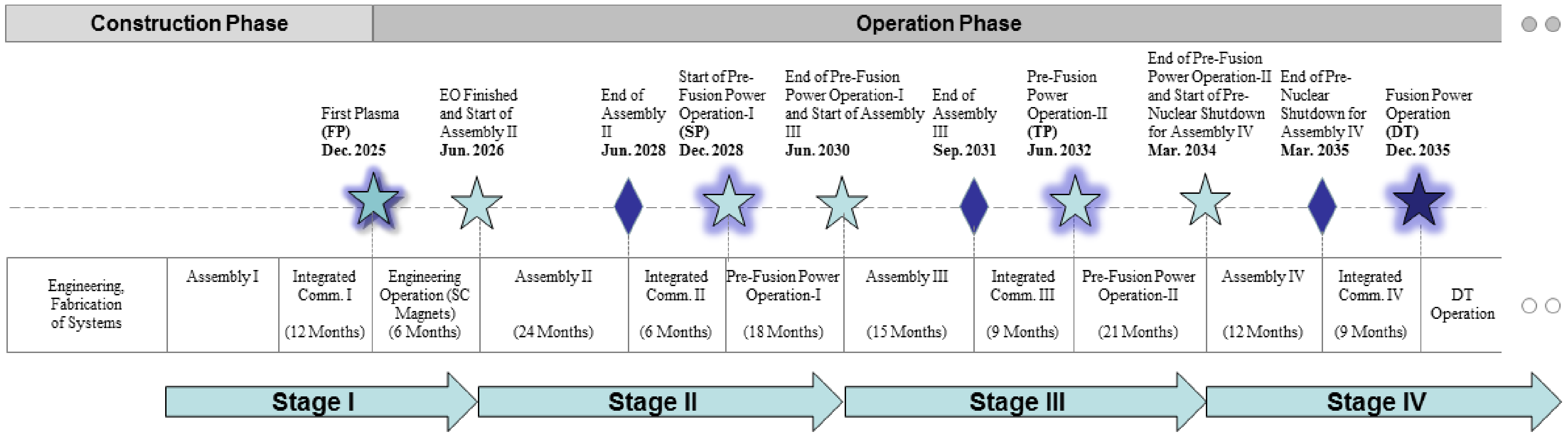
A challenging schedule



Despite the Covid-19 pandemic, the project has made steady progress, and is nearing 75% completion of "total construction through First Plasma."

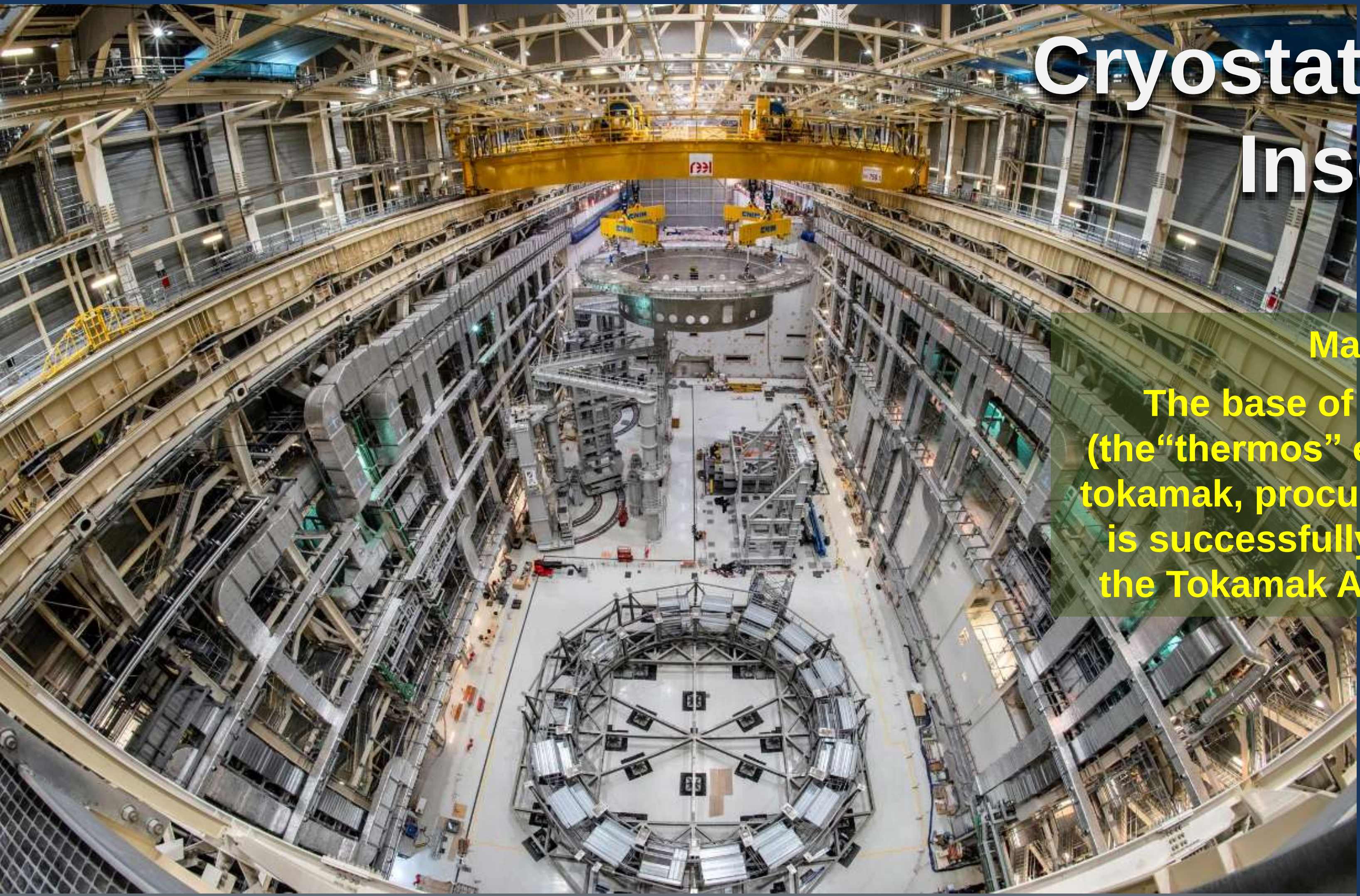
A staged approach to DT plasma

- ✓ Extensive IO/DA interactions to finalize post-Covid baseline schedule
- ✓ Use of 4-stage approach through Deuterium-Tritium (2035) consistent with Members' financial and technical constraints



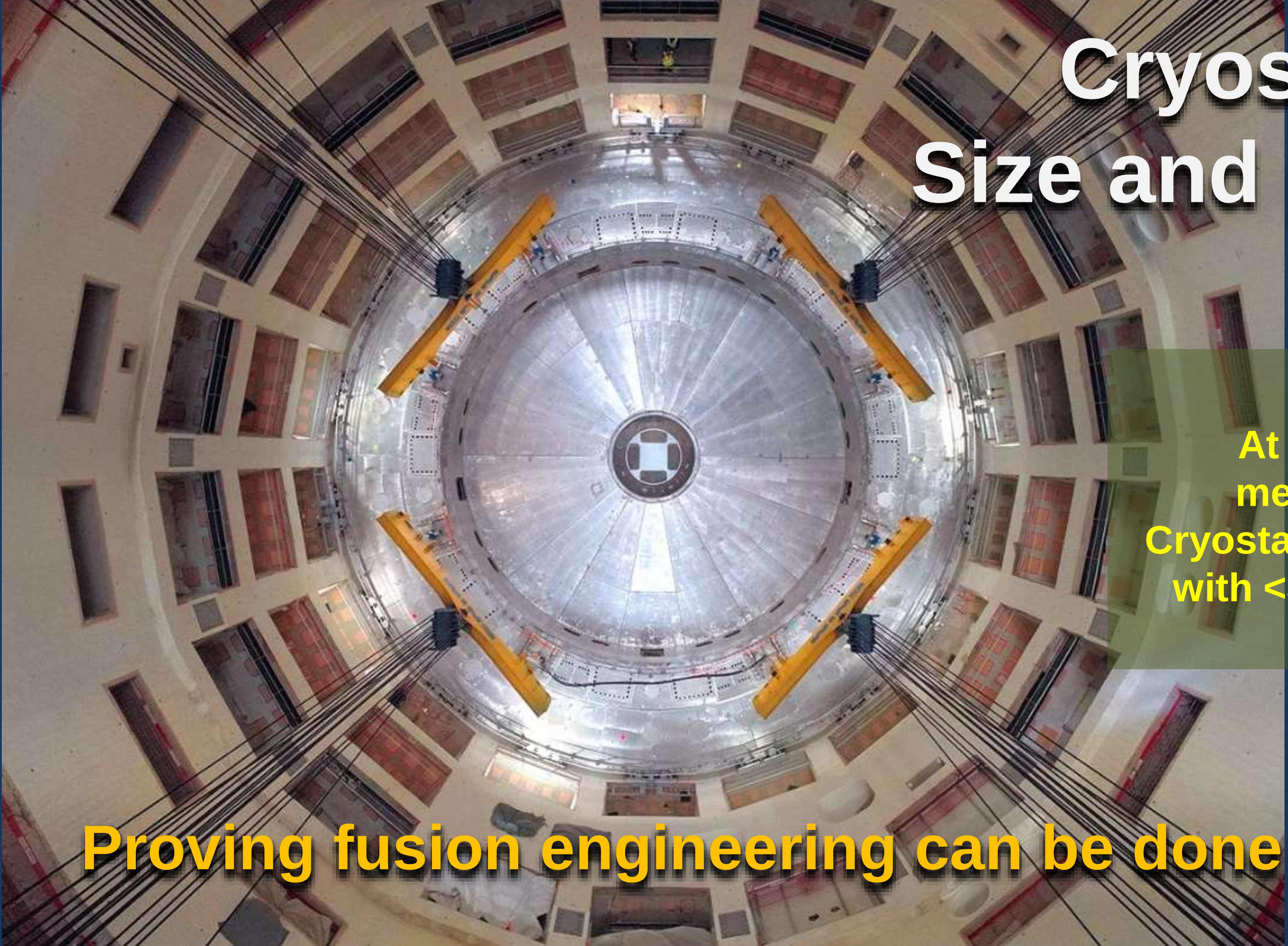
Project progress: making the dream a reality

Cryostat Base Insertion



May 26-27 2020

The base of the Cryostat (the“thermos” encasing the tokamak, procured by India) is successfully installed in the Tokamak Assembly Pit.



Cryostat Base: Size and precision

Top-Down View

At 1,250 tonnes and 30 metres in diameter, the Cryostat Base is positioned with <3mm tolerance at all metrology points.

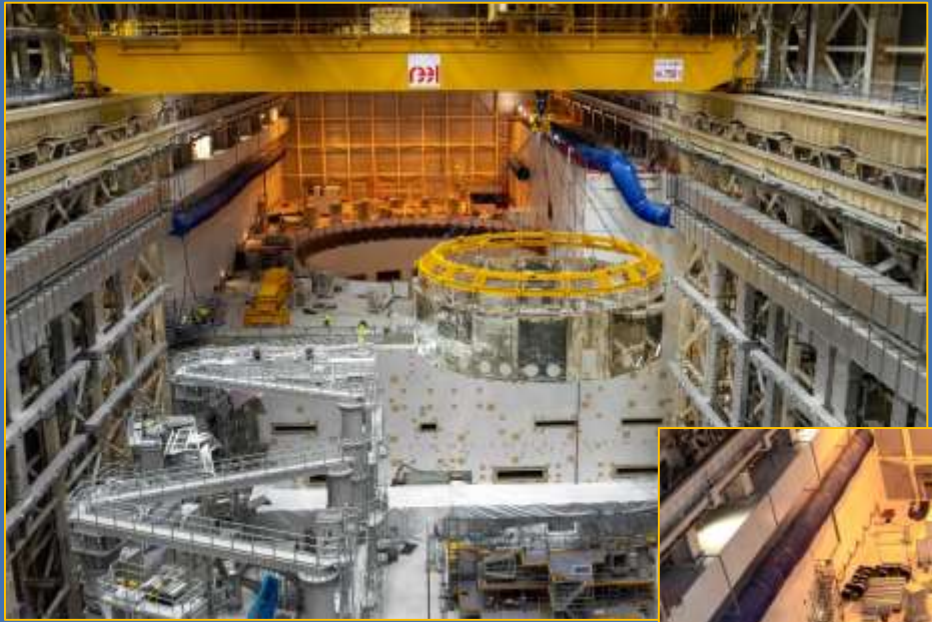
Proving fusion engineering can be done at full-scale.

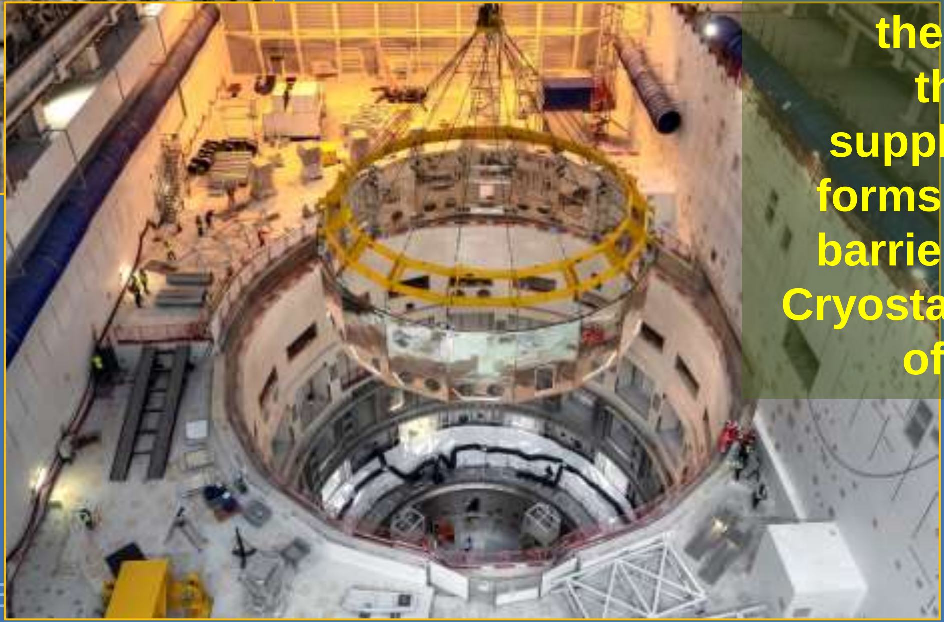
Cryostat Lower Cylinder insertion

31 August 2020

At 10 metres high and 30 metres diameter (the size of Stonehenge), it is a perfect fit with the Cryostat Base.

Thermal Shield Insertion





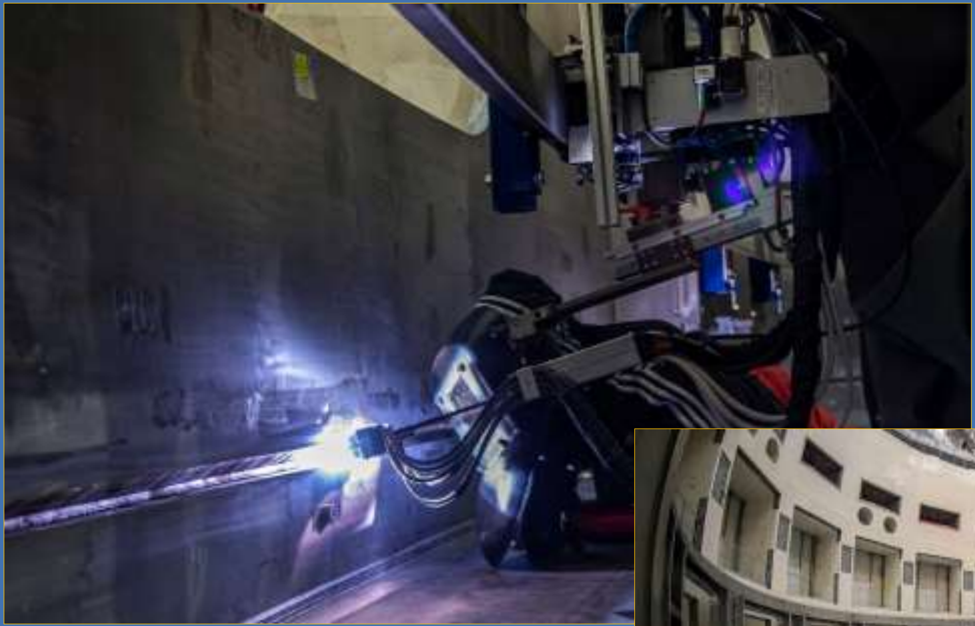
14 January 2021

Massive but delicate, the silver-coated thermal shield, supplied by Korea, forms an insulation barrier between the Cryostat and the rest of the machine.

ITER Innovation:

Korea is using the insights learned from manufacturing the thermal shield to improve shipping containers for liquefied natural gas.

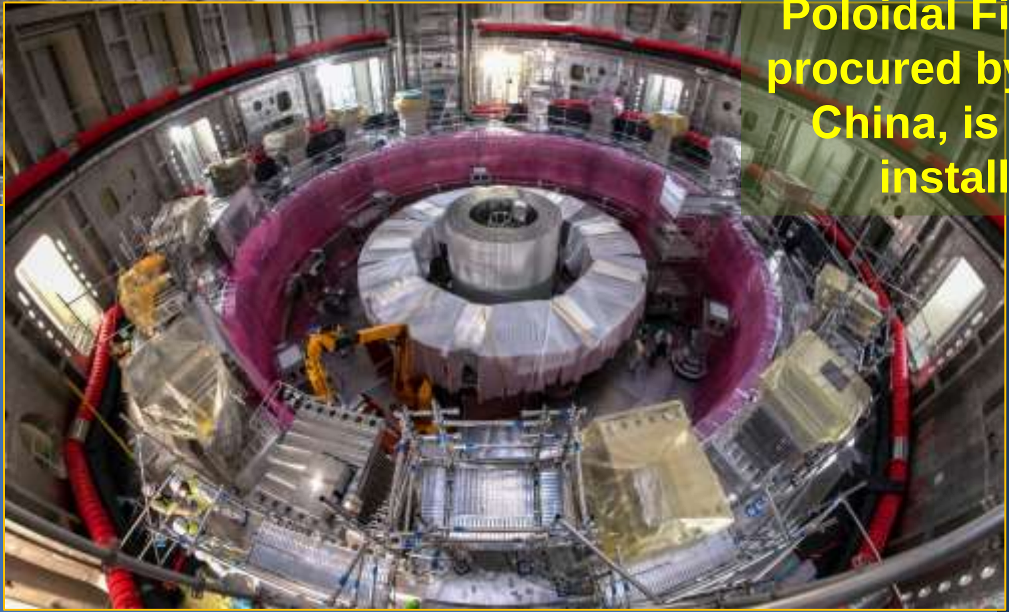
Preparing to install ITER’s magnets



Early 2021

Welding of Lower Cylinder to Base is completed; magnet supports are installed in the “cathedral” of the Tokamak Pit.

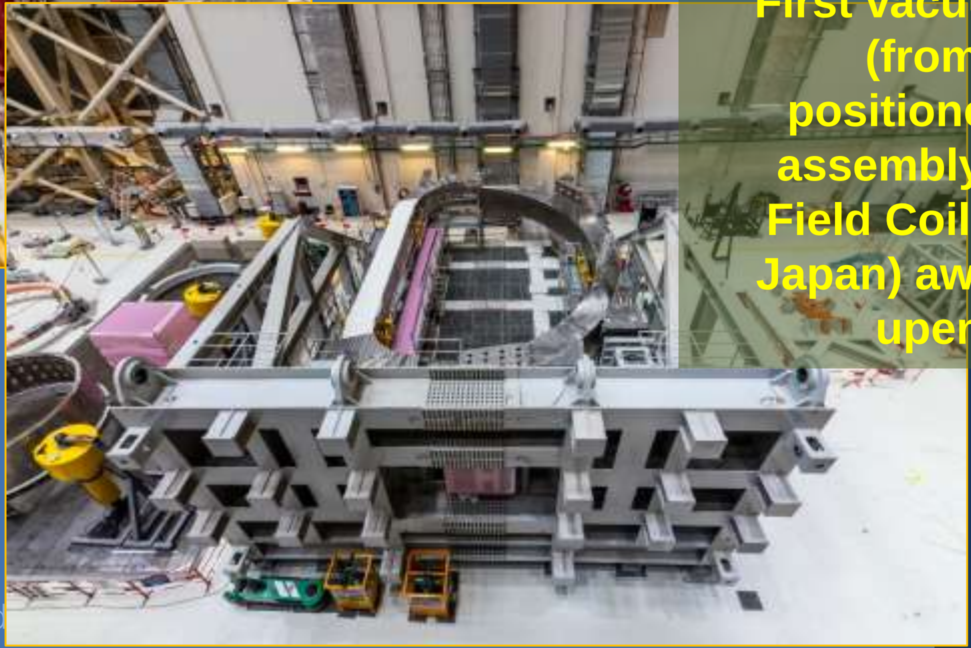
First Magnet Installed



April 2021

Poloidal Field Coil #6, procured by Europe in China, is ITER's first installed magnet.

First Sector Subassembly



May-June 2021

First vacuum vessel (from Korea) is positioned for pre-assembly; Toroidal Field Coil #12 (from Japan) awaits in the upending tool.

Cryogenics plant and system

Cryoplant and cryoline installation:

Nearly 25 tonnes of liquid helium will circulate to cool ITER's magnets to -269°C, making them superconducting.

R&D is ongoing to scale up "high-temperature" super-conducting magnets. If successful, this could eliminate the need for cryogenics systems in future tokamaks.

Electrical networks

January 2019:

400kv steady state network connected to French grid

June 2021:

Reactive power compensation (about 1 hectare of specialized equipment) nears finalization.

Magnet Power Converstion

Electrical components from China, India, Korea and Russia are being progressively installed inside the Magnet Power Conversion Buildings, exterior bays and Tokamak Building.

Global supply chain:

The ITER project is creating a worldwide network of companies with experience in meeting the demanding requirements of fusion engineering.

Heat rejection system

ITER's cooling water systems will be capable of removing ~1.2 gigawatts of heat.

The Road to ITER

June-July 2020

Poloidal Field Coil #6, made in China, and Toroidal Field Coil #13, made in Japan, are two of many components to arrive safely at ITER.

By sea and land:

The complex logistics designed to deliver massive, high-precision components from three continents has proven reliable, even during the pandemic.

Manufacturing: onsite fabrication

Upper left: PF6 completes cold testing onsite.

Bottom right: PF5, finalized, is briefly positioned inside one of the “pancakes” for PF4, showing the size contrast.

Too big to ship:

Due to their size, at 17m & 24m in diameter, four of ITER’s six Poloidal Field magnets are being manufactured onsite.

Manufacturing: onsite fabrication

Upper left: pieces of the Cryostat Lid as they arrived at ITER.

Bottom right: ongoing assembly and welding of the Cryostat Lid.

Collaboration at work:

Forged in Hazira, pieces of the Cryostat Lid are welded together by German experts under Indian supervision & French nuclear regulation on an international site.

Manufacturing: ongoing globally

As ITER's largest contributor, Europe is supplying 10 of 19 toroidal field coils (4 delivered so far, upper left); and 5 of 9 vacuum vessel sectors (67 to 89% complete, bottom right).

Manufacturing: ongoing globally

Upper left: Poloidal Field Coil #1 nears completion in Russia.

Bottom right: Japan has completed 4 toroidal field coils, with 5 others in fabrication.

Manufacturing: ongoing globally

Upper left: India has manufactured many components of the cooling water systems.

Bottom right: Korea has 3 more vacuum vessel sectors in fabrication, with completion rates from 86 to 99%.

Manufacturing: ongoing globally

Upper left: China is delivering >1,600 tonnes of equipment for the magnet feeder systems.

Bottom right: The United States has completed the first two of seven modules for the Central Solenoid.

Other fusion projects:

Publicly and privately funded complementary efforts

Joint European Torus (JET)
United Kingdom

Wendelstein-7X
Max Planck Institute for Plasma Physics, Germany

SPARC
MIT spin-off, United States

Tokamak Energy
United Kingdom

The way forward

...

- ITER will be followed by DEMO, a pilot fusion power plant.
- Some ITER Members are pursuing their own pilot plants.
- Private industry is beginning to invest in fusion energy initiatives.
- Fusion Power Plant may be connected to the grid in Europe by 2060.

We need to prove that fusion energy is a viable option!

ITER site: the right choice for the first fully controlled sustained plasma

Both as a scientific experiment and as a global collaboration, ITER is the First-of-a-Kind with still many challenges ahead. But the potential benefit is so large!

ITER: only current project scaled to produce a "burning plasma"

Thank you for your attention!

For an extended tour of the ITER worksite, please visit:

https://www.iter.org/news/videos/571