ITER
The Hydrogen fusion option

Michiel Korthals Altes – Project management
ITER Organization

Michiel KORTHALS ALTES
Project director

MSc Engineering (Energetics), Ecole centrale Paris
MBA, ESCP Europe, 2005

ALSTOM POWER, 1992-2007
Gas, Coal, hydro

ESSENT/ RWE, 2007 - 2015
Gas, Coal, Wind, biomass, Nuclear (HNP)

MURRAY & ROBERTS, 2015-2017
Coal

STADSVERWARMING PURMEREND, 2017-2019
Biomass

ITER, 2020 - now
Fusion

Hydrogen fusion in the Universe

- **1920-1930:**
  - **Perrin, Eddington, Rutherford, Bethe … discover that hydrogen fusion powers the Sun and stars.**
  - **In a fusion reaction, two light atomic nuclei combine, form a heavier nucleus and release energy.**
- **1950s:**
  - **First research activities for a peaceful use of hydrogen fusion**

The Big Challenge: to reproduce a similar reaction in a fusion machine (Tokamak*).

$$\Delta E = \Delta m c^2$$

A tiny loss of mass

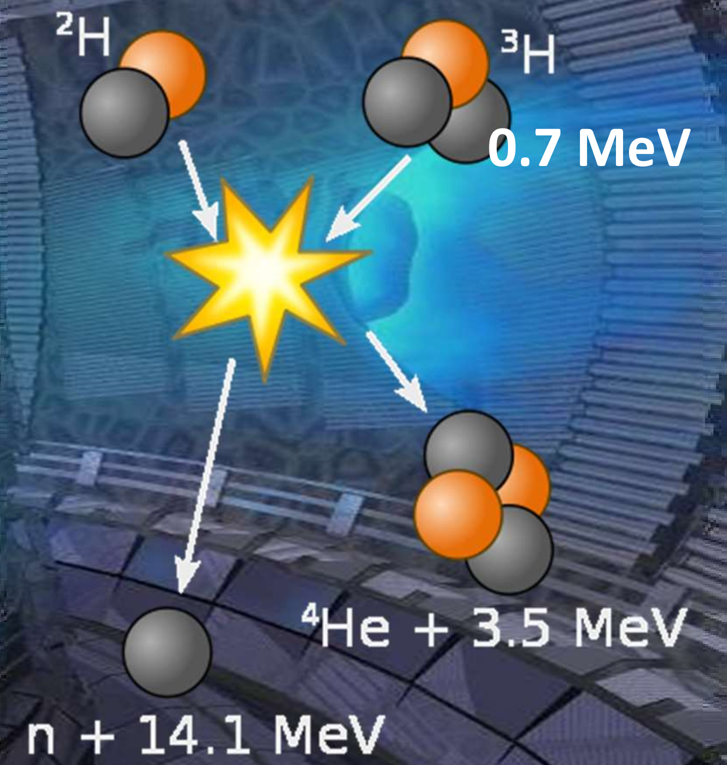
A huge liberation of energy

** Tokamak: a Russian acronym for « Toroidal Chamber, Magnetic Coils ».*

Hydrogen fusion on Earth

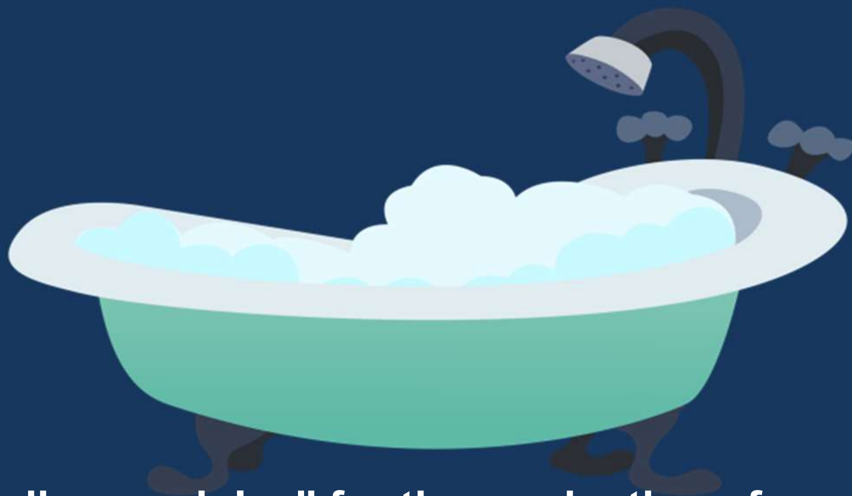
- A plasma of Deuterium + Tritium (hydrogen isotopes) is heated to more than 150 million °C.
- The hot plasma is shaped and confined by strong magnetic fields.
- Helium nuclei sustain burning plasma.
- Neutrons transfer their energy to the Blanket.
- In a fusion power plant, conventional steam generator, turbine and alternator will transform the heat into electricity.

1 gram of fusion fuels = 8 tons of oil



The fusion fuels

+



ITER will experiment lithium-based “tritium-breeding modules” for the production of tritium inside the machine

Lithium* contained in the battery of a single laptop computer and deuterium from half a bathtub of water can provide 200,000 kwh of electricity.

That's enough to cover the electricity needs of one person in Western Europe for 30 years.

** Neutrons impacting Lithium generate Tritium*

Why Fusion?

- Massive, predictable baseload power complementary to renewable energies
- Intrinsically safe
- Nearly unlimited supply of fuel for millions of years
- No greenhouse gases emission; no impact on climate
- Environmentally responsible
- No long-lasting high-activity radioactive waste

◀ A plasma in the EU Tokamak JET

«For the benefit of all mankind…»

1950s to 1970s :

- progress in the understanding of plasma physics and experiments in fusion devices leads to the realization that a very large machine is needed to demonstrate that significant energy gain is feasible.

November 1985:

- Geneva Summit Reagan-Gorbatchev: decision to launch an international collaboration in fusion "for the benefit of all mankind".

ITER

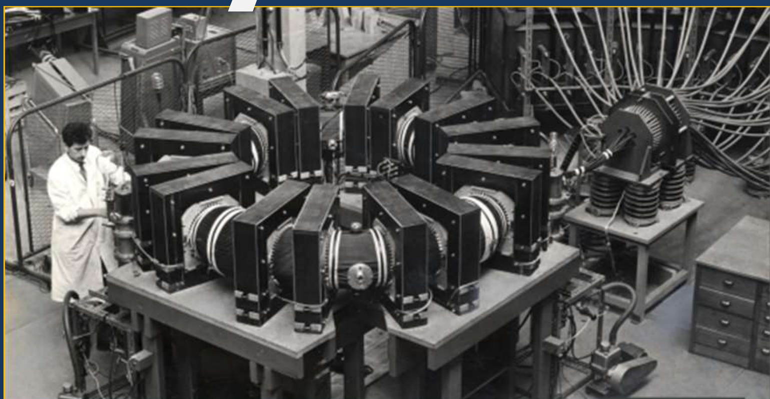
Global challenge, global response

- **28 June 2005: The ITER Members unanimously agreed to build ITER on the site proposed by Europe**
- **21 November 2006: The ITER Agreement is signed at the Élysée Palace, in Paris.**

The seven ITER Members represent more than 50% of the world's population and about 85% of the global GDP

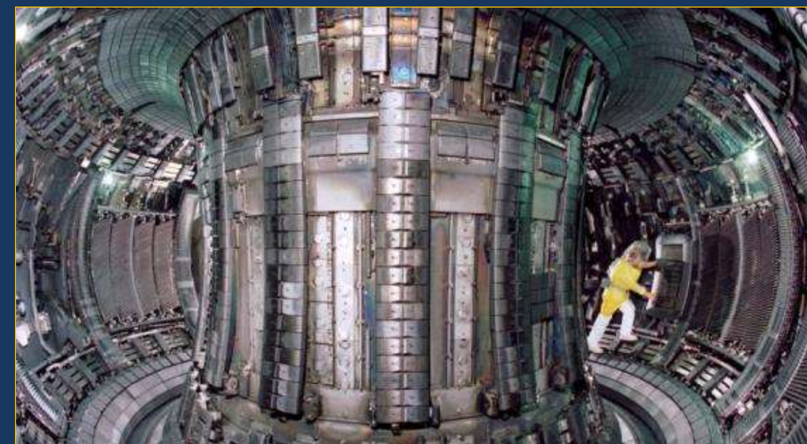
China EU India Japan Korea Russia USA

65 years of constant progress



TA-2000,
France, 1957

JET, Euratom,
1984 to present

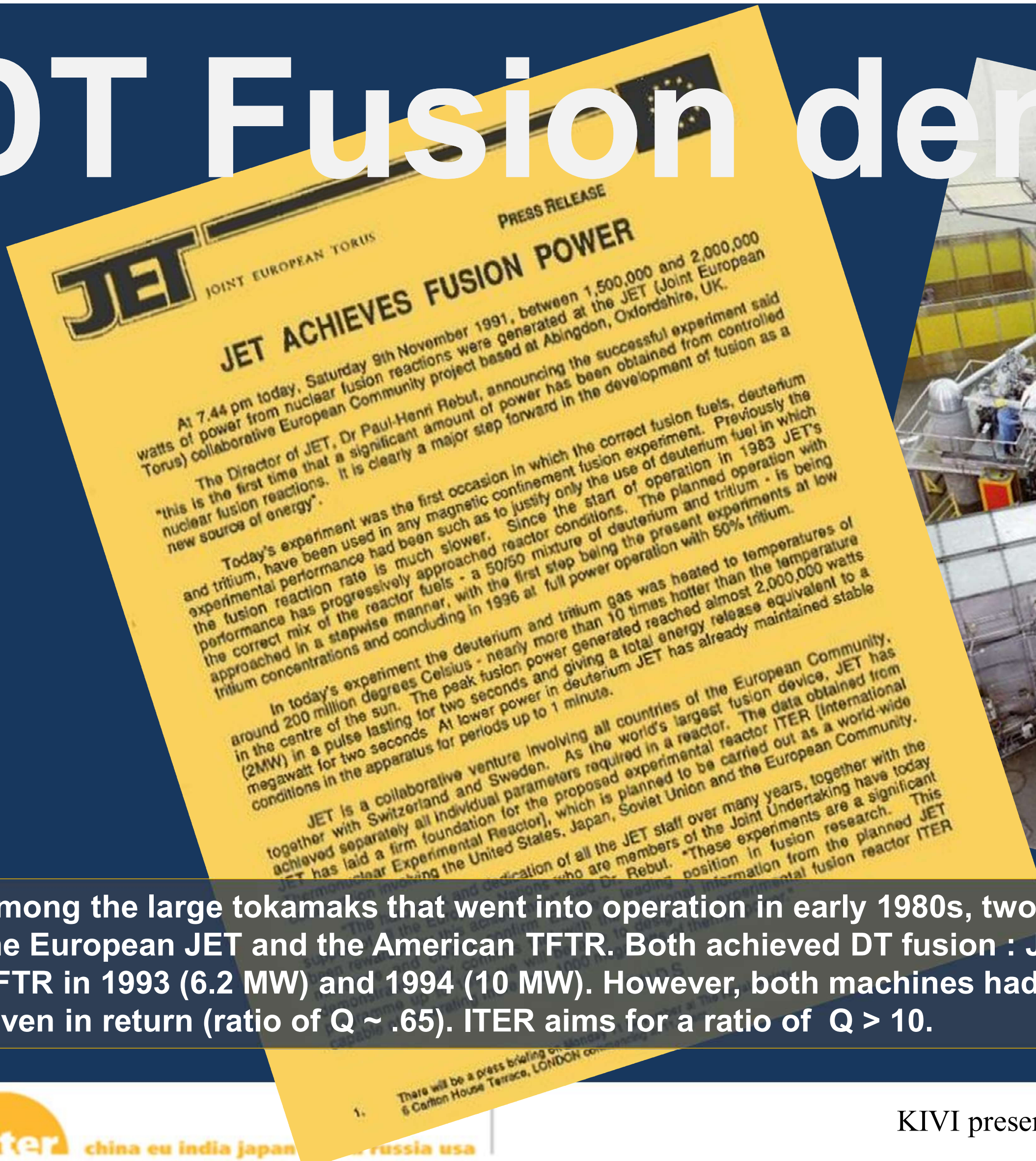


SST-1, India
1st plasma 2015

WEST, CEA-
Euratom, 1988,
now a testbed
for ITER

ADITYA, India
1989 to present

DT Fusion demonstrated!


JET JOINT EUROPEAN TORUS

PRESS RELEASE

JET ACHIEVES FUSION POWER

At 7.44 pm today, Saturday 9th November 1991, between 1,500,000 and 2,000,000 watts of power from nuclear fusion reactions were generated at the JET (Joint European Torus) collaborative European Community project based at Abingdon, Oxfordshire, UK.

The Director of JET, Dr Paul-Henri Rebut, announcing the successful experiment said "this is the first time that a significant amount of power has been obtained from controlled nuclear fusion reactions. It is clearly a major step forward in the development of fusion as a new source of energy".

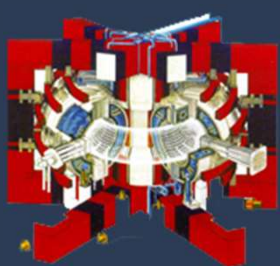
Today's experiment was the first occasion in which the correct fusion fuels, deuterium and tritium, have been used in any magnetic confinement fusion experiment. Previously the experimental performance had been such as to justify only the use of deuterium fuel in which the fusion reaction rate is much slower. Since the start of operation in 1983 JET's performance has progressively approached reactor conditions. The planned operation with the correct mix of the reactor fuels - a 50/50 mixture of deuterium and tritium - is being approached in a stepwise manner, with the first step being the present experiments at low tritium concentrations and concluding in 1996 at full power operation with 50% tritium.

In today's experiment the deuterium and tritium gas was heated to temperatures of around 200 million degrees Celsius - nearly more than 10 times hotter than the temperature in the centre of the sun. The peak fusion power generated reached almost 2,000,000 watts (2MW) in a pulse lasting for two seconds and giving a total energy release equivalent to a megawatt for two seconds. At lower power in deuterium JET has already maintained stable conditions in the apparatus for periods up to 1 minute.

JET is a collaborative venture involving all countries of the European Community, together with Switzerland and Sweden. As the world's largest fusion device, JET has achieved separately all individual parameters required in a reactor. The data obtained from JET has laid a firm foundation for the proposed experimental reactor ITER (International Thermonuclear Experimental Reactor), which is planned to be carried out as a world-wide collaboration involving the United States, Japan, Soviet Union and the European Community.

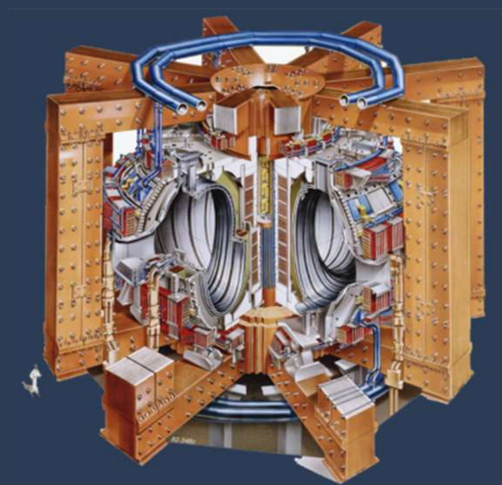
Among the large tokamaks that went into operation in early 1980s, two were designed to perform Deuterium-Tritium operations: the European JET and the American TFTR. Both achieved DT fusion : JET in 1991 (2 MW of fusion power) and 1997 (16 MW); TFTR in 1993 (6.2 MW) and 1994 (10 MW). However, both machines had required more energy to « light the fire » than the fire had given in return (ratio of Q ~ .65). ITER aims for a ratio of Q > 10.

Size matters!



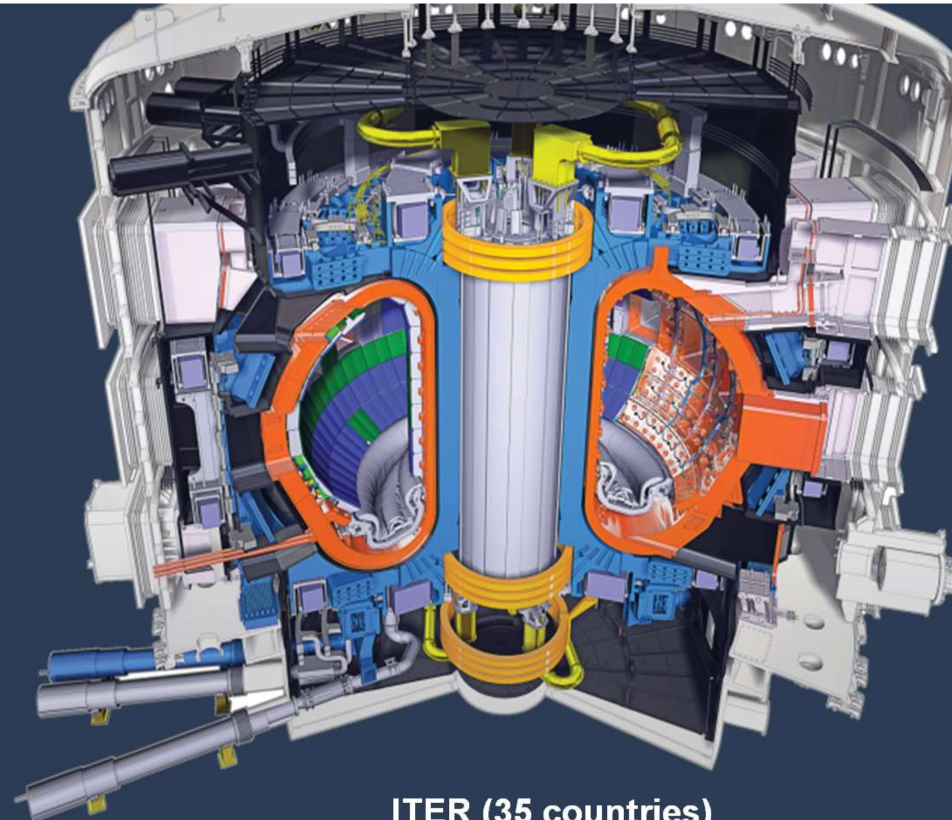
Tore Supra (CEA-Euratom)

V_{plasma} 25 m^3
P_{fusion} ~0
$P_{heating}$ ~15 MW
T_{plasma} ~400 s
I_{plasma} ~ 1.7 MA



JET (Europe)

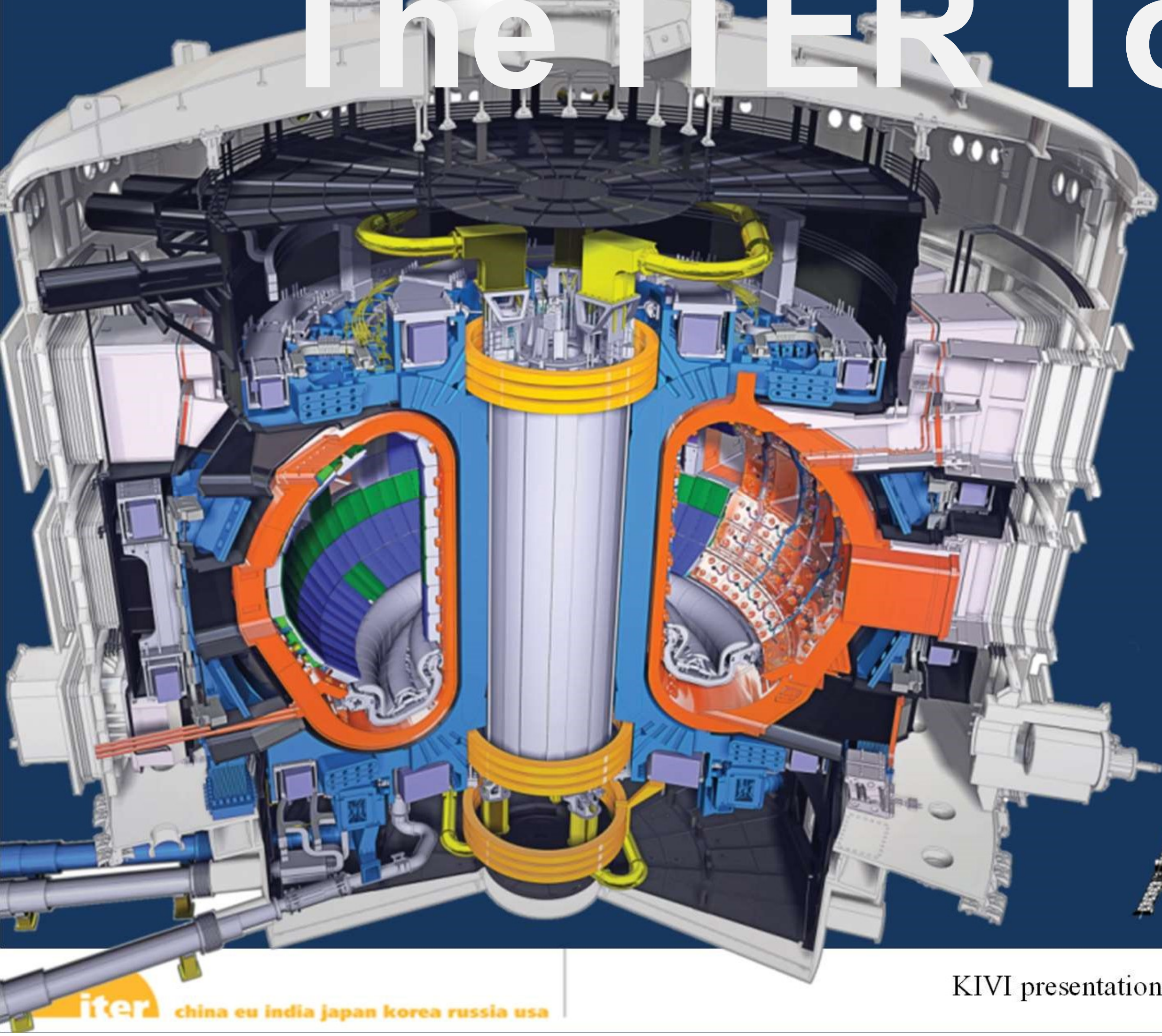
V_{plasma} 80 m^3
P_{fusion} ~16 MW
$P_{heating}$ ~23 MW
T_{plasma} ~30 s
I_{plasma} ~ 5-7 MA



ITER (35 countries)

V_{plasma} 830 m^3
P_{fusion} ~500 MW
$P_{heating}$ ~ 50 MW
T_{plasma} > 400 s
I_{plasma} ~ 15 MA

The ITER Tokamak

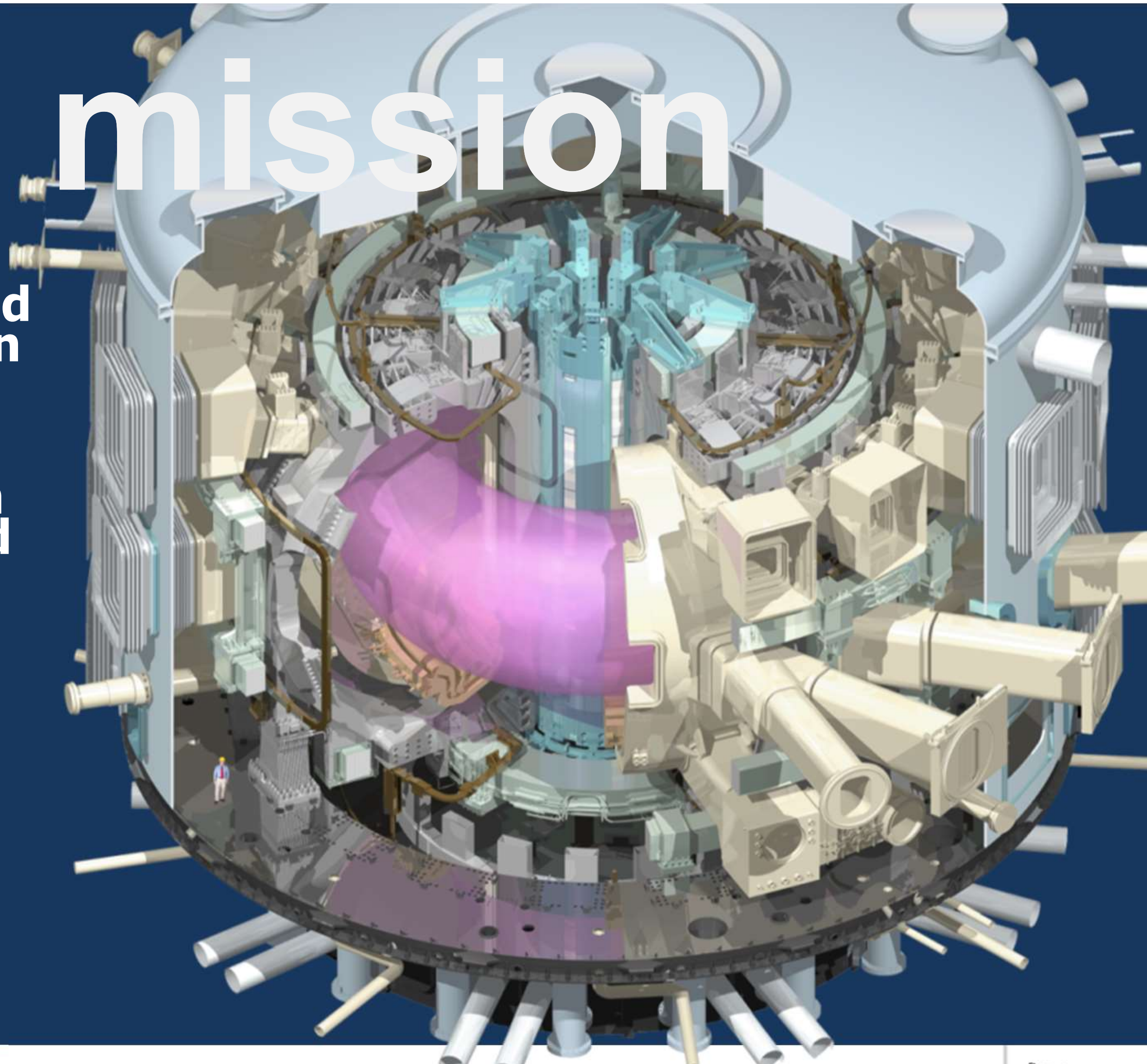


Vacuum Vessel: ~ 8 000 t.
TF Coils: ~ 18 x 360 t.
Central solenoid: ~ 1 000 t.
Etc.
Total ~ 23 000 t.

R=6.2 m, a=2.0 m,
I_p=15 MA, B_T=5.3 T,
23,000 tonnes

3,5 times the weight of the Eiffel Tower!

ITER mission



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

ITER is the only magnetic fusion device under construction aimed to produce a burning plasma.

Input (heating power): 50 MW

Output (fusion power): 500 MW

How does it work?

Run a strong electrical current in the DT gas.
You have created a plasma.

Continue heating by way of electromagnetic waves.

Inject high-energy neutral particles.

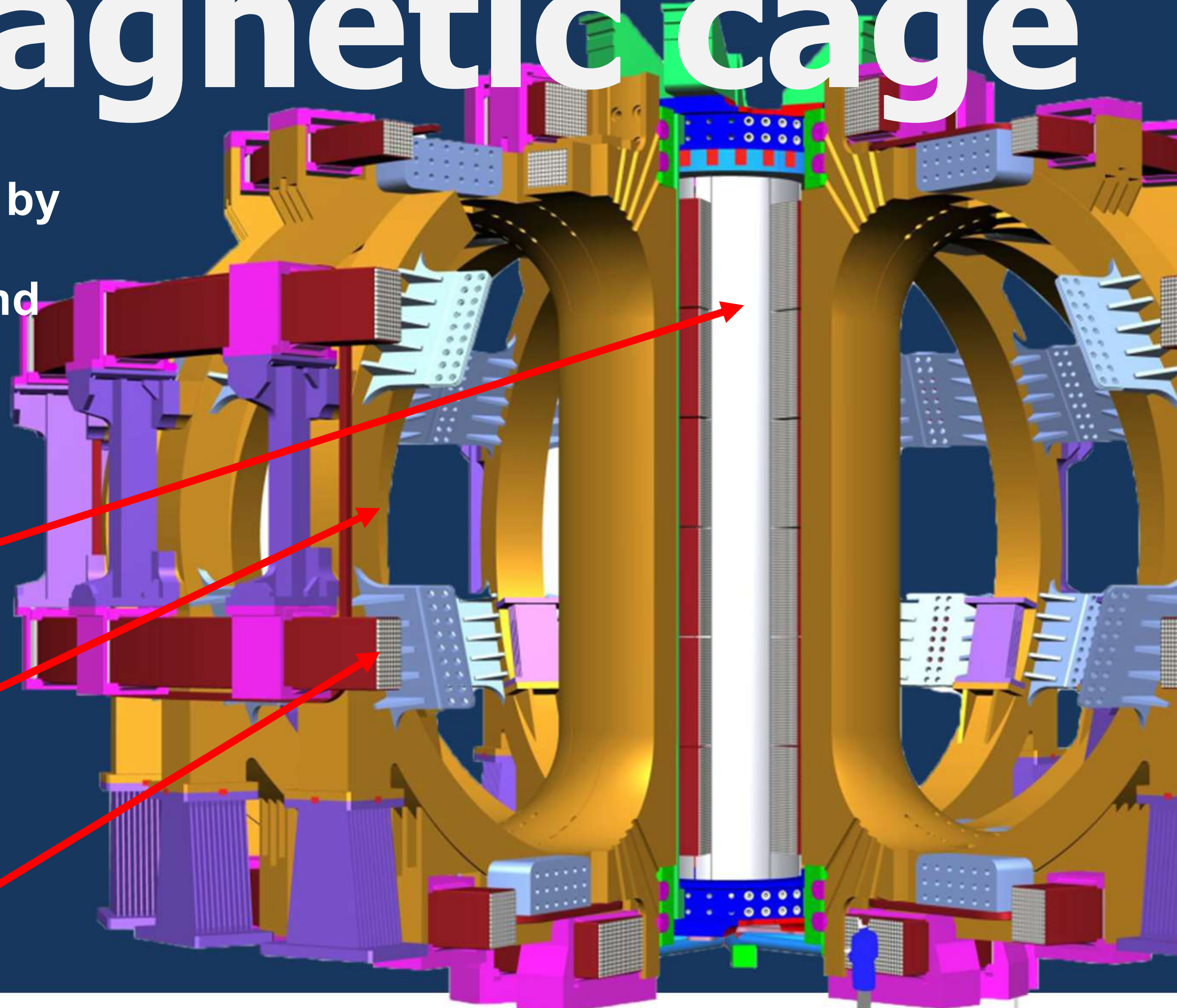
By combining these different heating techniques, you reach the requested temperature for fusion reactions to occur.

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

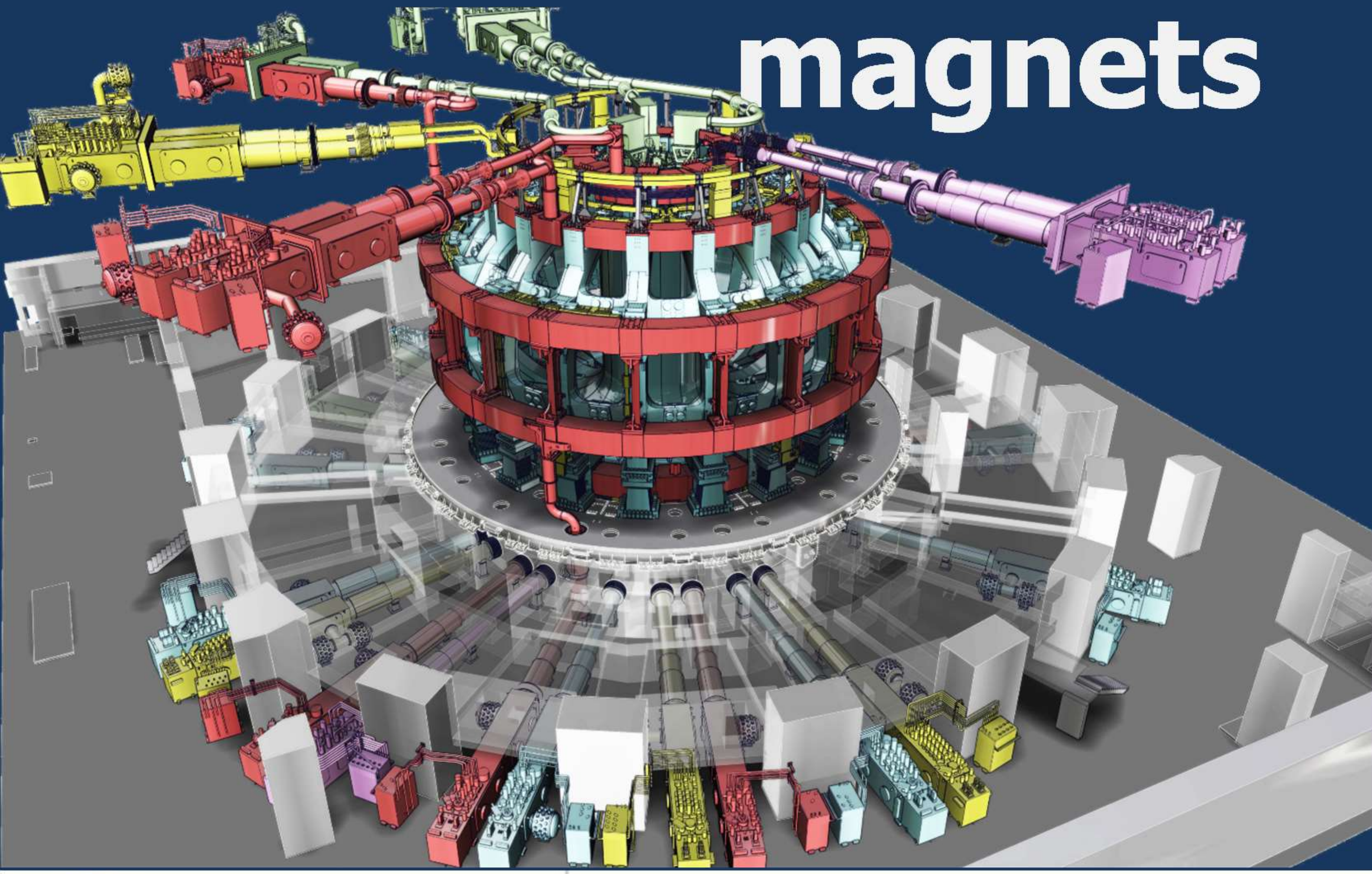
A large magnetic cage

An intense magnetic field, generated by powerful superconducting magnets shape and confine the hot plasma, and keep it away from the vacuum vessel wall.

- 1 central solenoid, 13 m high, 1,000 tons, powerful enough to lift an aircraft-carrier out of the water
- 18 Toroidal Field Coils, 17-metre high, 360 tons each.
- 6 Poloidal Field Coils, 8 to 24 m. in diametre, 200 to 400 tons.



10,000 tons of superconducting magnets

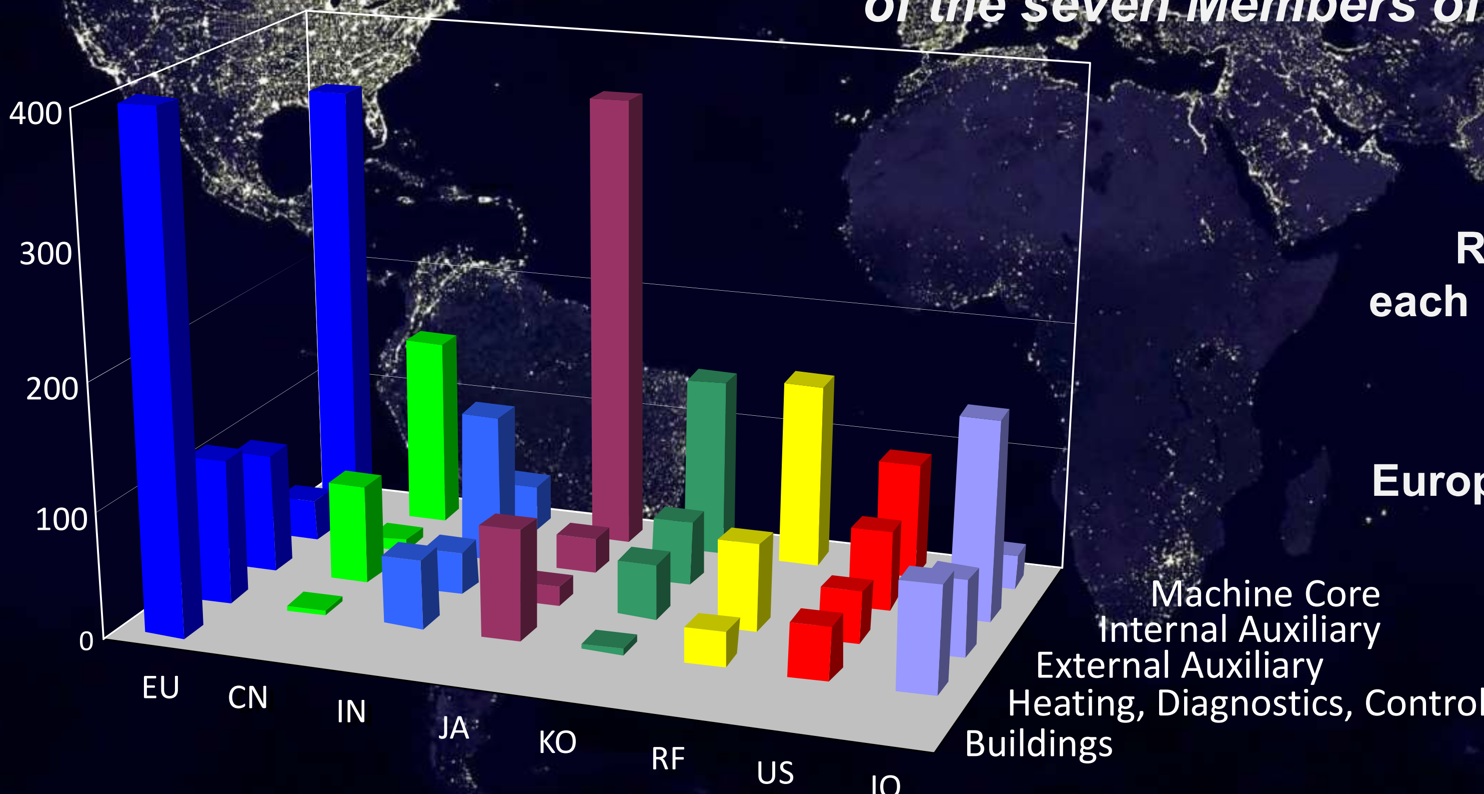


Manufactured from niobium-tin (Nb_3Sn) or niobium-titanium (Nb-Ti), the magnets become superconducting when cooled with supercritical helium in the range of 4 K (– 269 °C).

10,000 tons of magnets, with a combined stored magnetic energy of 51 Gigajoules (GJ), produce the magnetic fields that initiates, confines, shapes and controls the ITER plasma.

A unique formula

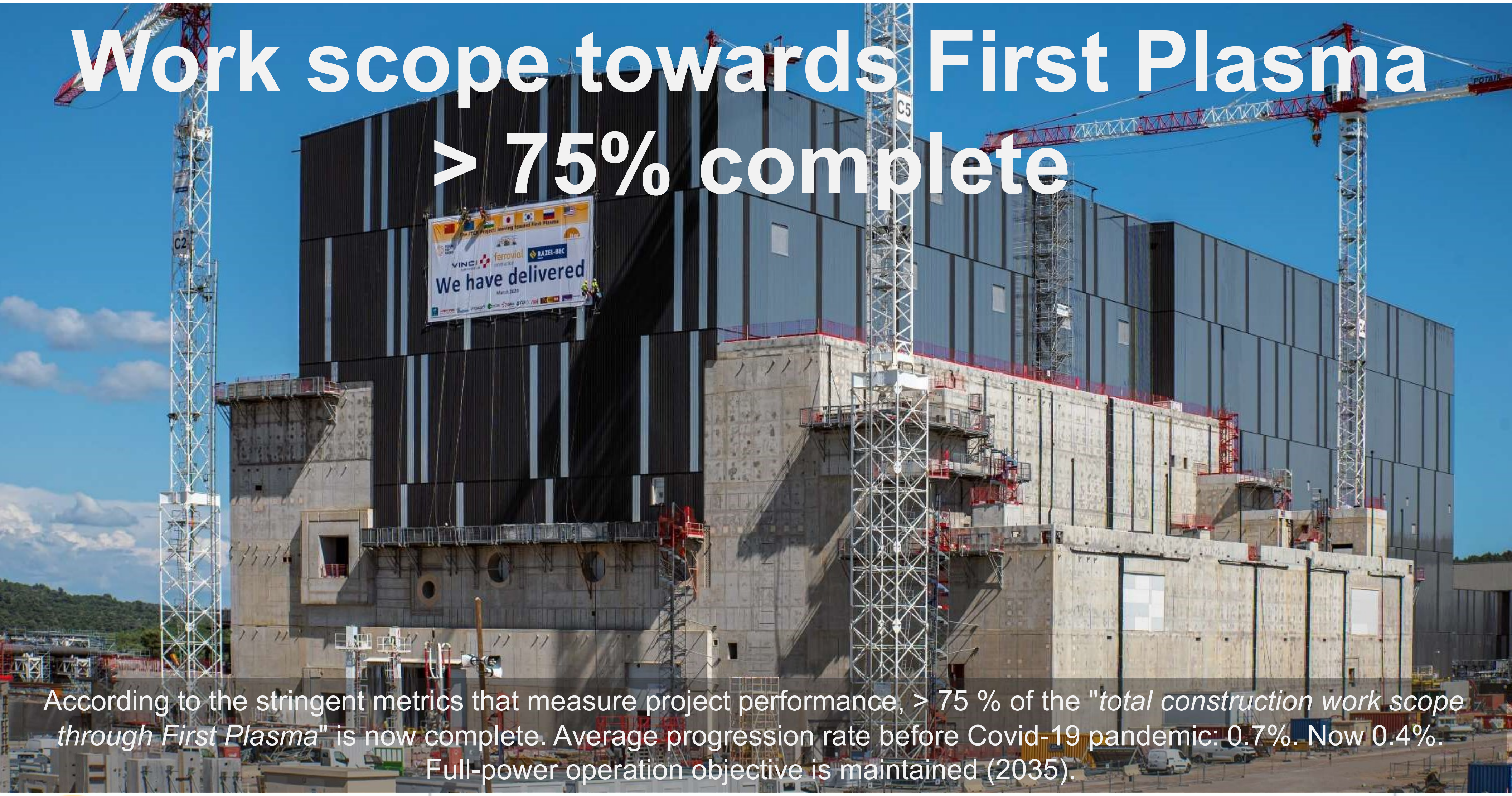
ITER is being built through the in-kind contributions of the seven Members of the ITER Organization.



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

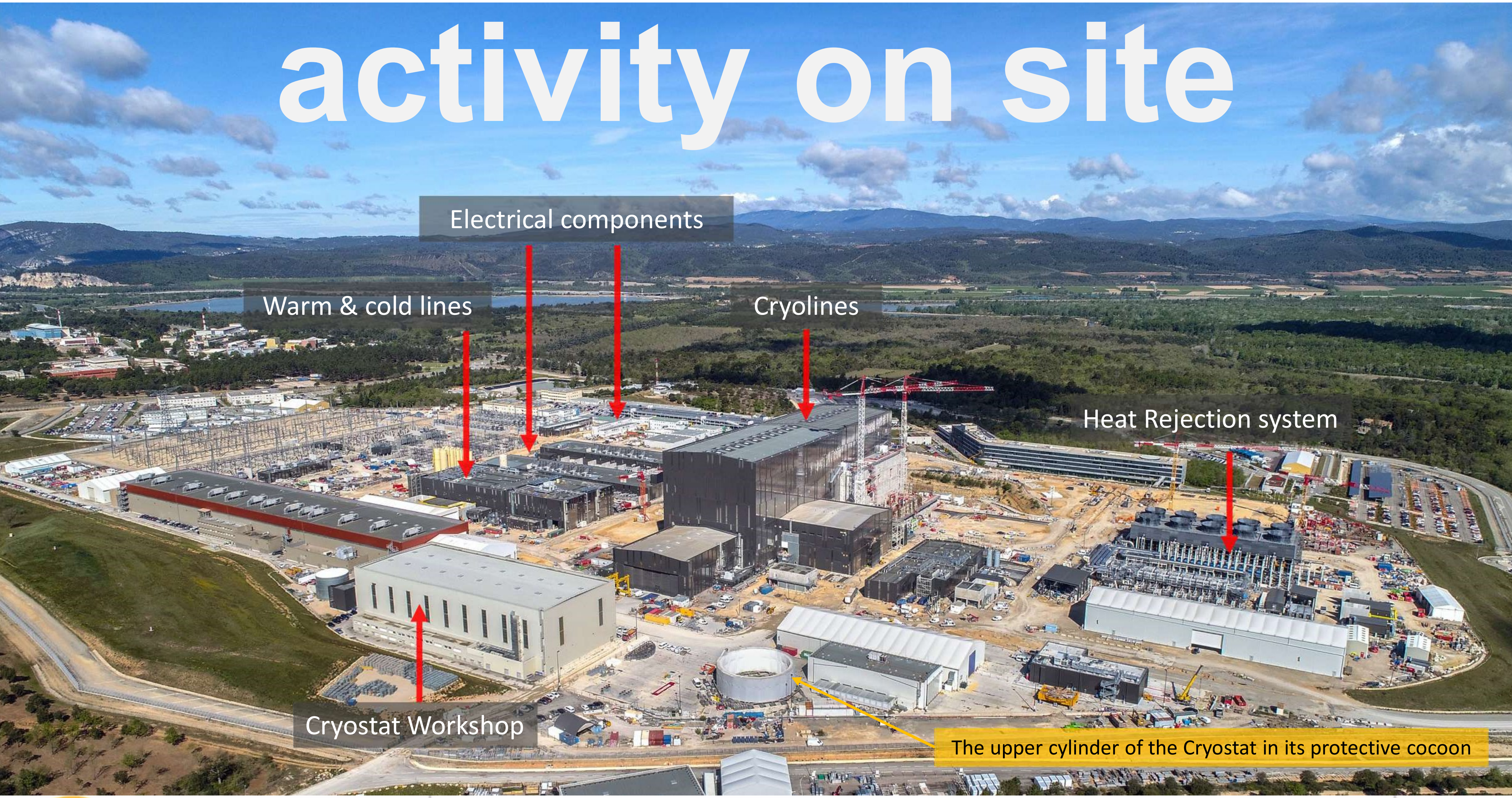
Europe's share, as Host Member, is ~ 45% (construction and manufacturing).

Work scope towards First Plasma
> 75% complete



According to the stringent metrics that measure project performance, > 75 % of the "*total construction work scope through First Plasma*" is now complete. Average progression rate before Covid-19 pandemic: 0.7%. Now 0.4%. Full-power operation objective is maintained (2035).

Worksite progress

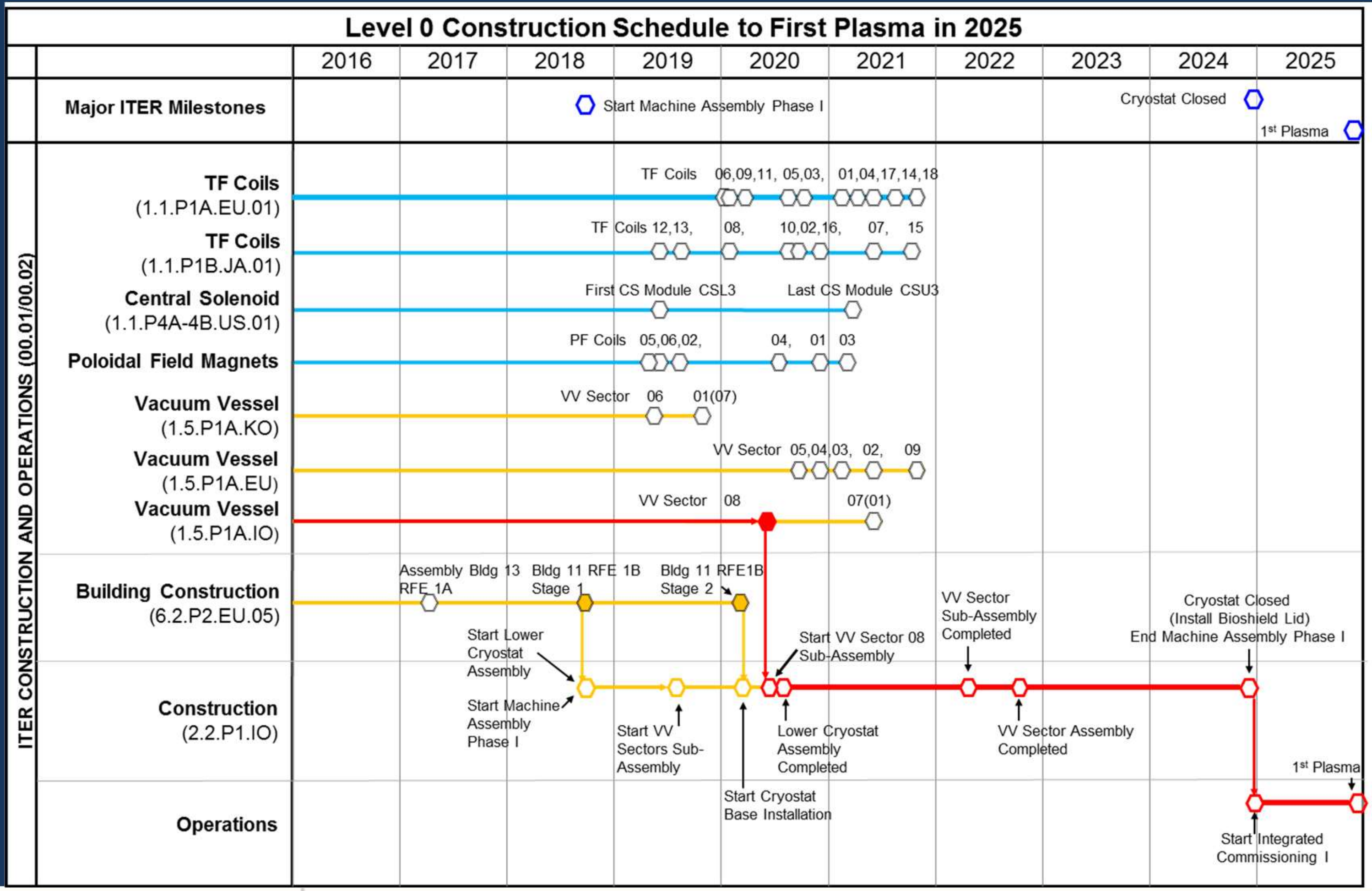

activity on site
Electrical components
Warm & cold lines
Cryolines
Heat Rejection system
Cryostat Workshop
The upper cylinder of the Cryostat in its protective cocoon

Seven years of steady progress

2014 –2021

More than 80% of the installation's civil works is now completed.

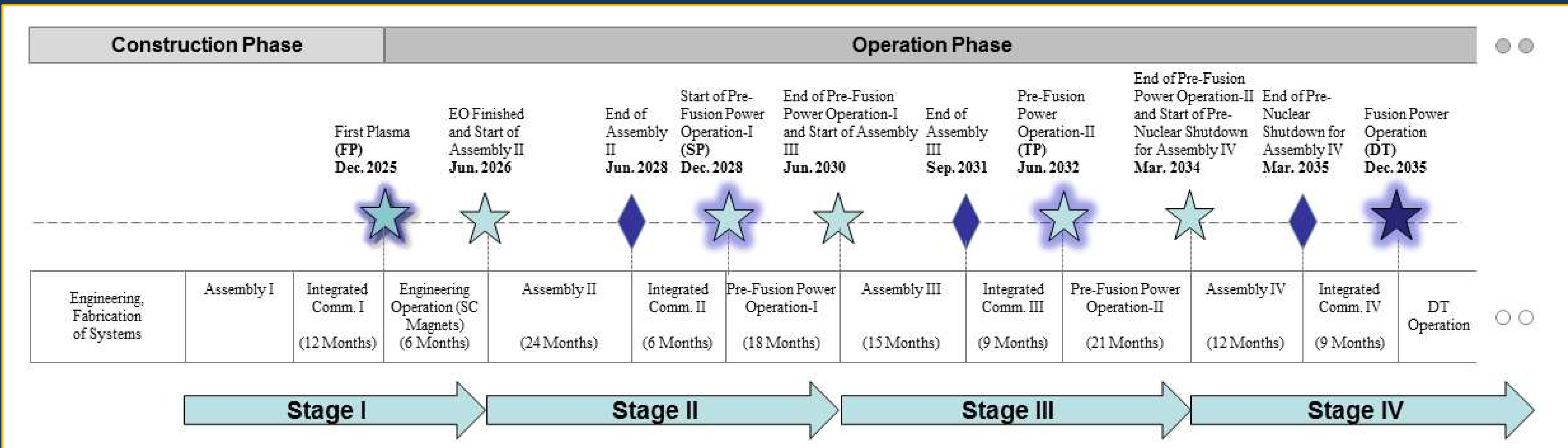
Baseline Schedule (*COVID impacts under investigation)



A staged approach to DT plasma

Extensive interactions among IO and DAs to finalize revised baseline schedule after COVID-19

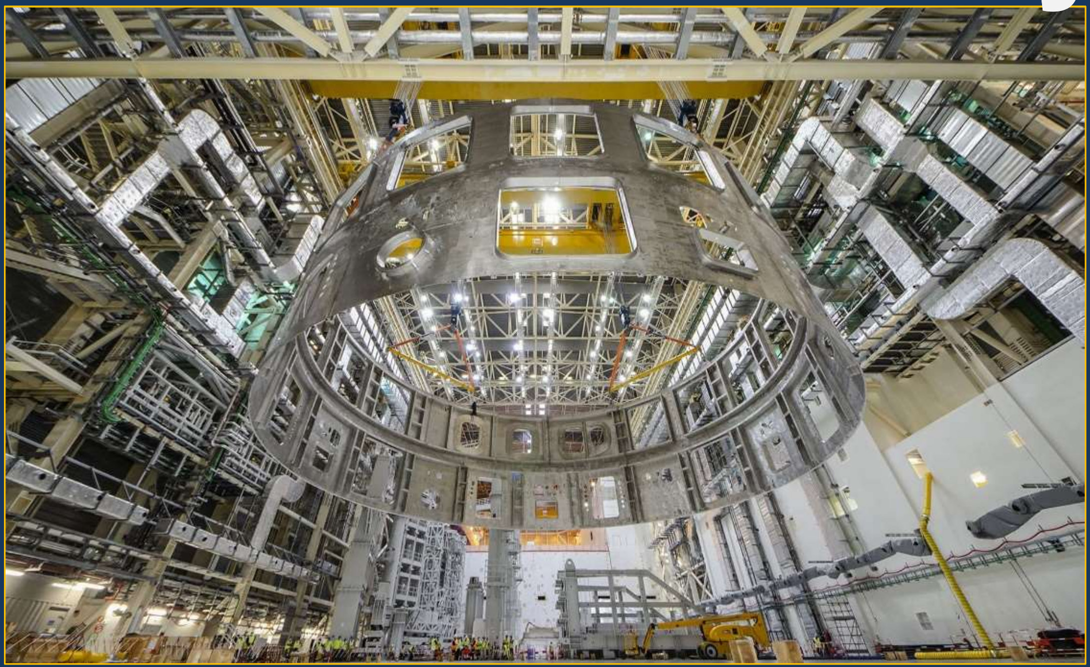
- ✓ **Schedule and resource estimates through First Plasma consistent with Members' budget constraints**
- ✓ **Proposed use of 4-stage approach through Deuterium-Tritium (2035) consistent with Members' financial and technical constraints**



Start of assembly: A crucial milestone

On May 26-27 2020, the base of the Cryostat (1,250 t; procured by India) was successfully inserted into the Tokamak Assembly Pit.

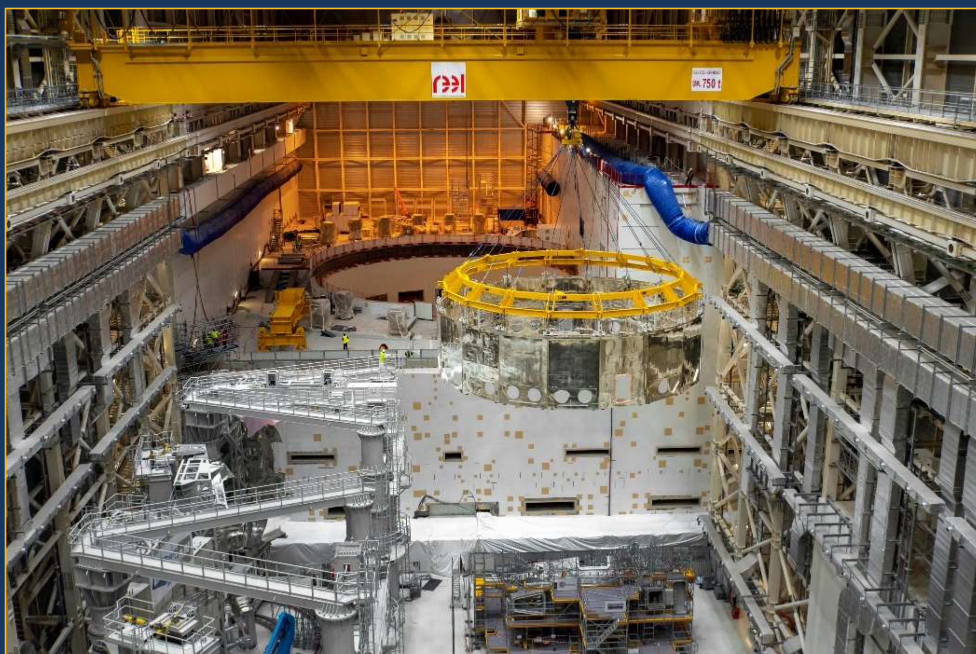
Assembly progress: Lower cylinder insertion

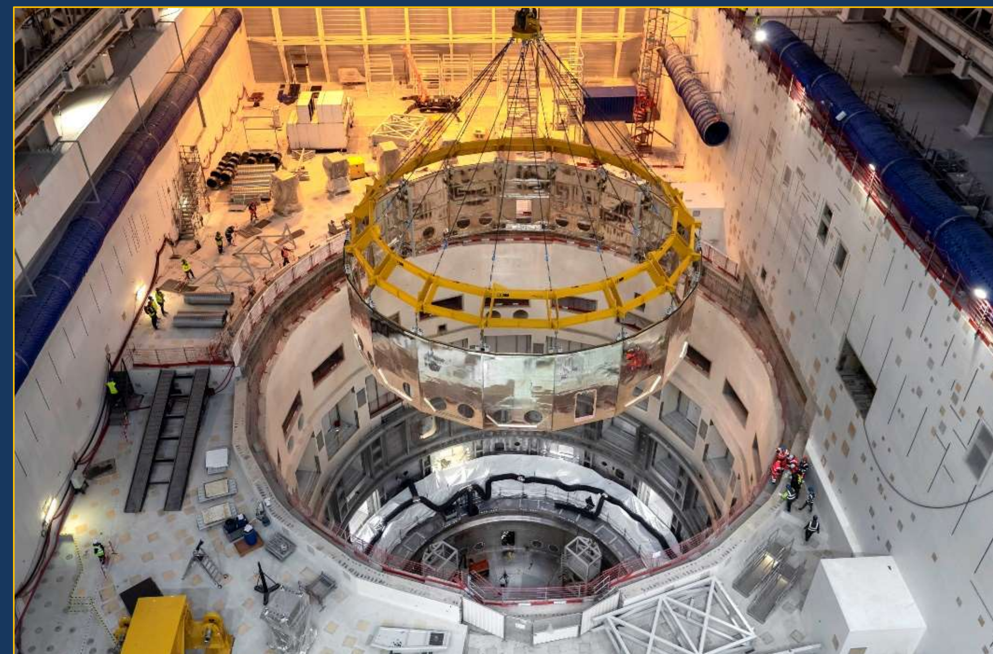


Cryostat Lower Cylinder lift,
31 August 2020

Inserting the Cryostat Lower Cylinder into the Tokamak Pit.
Perfect fit with the Base
31 August 2020

Assembly progress: Thermal shield insertion





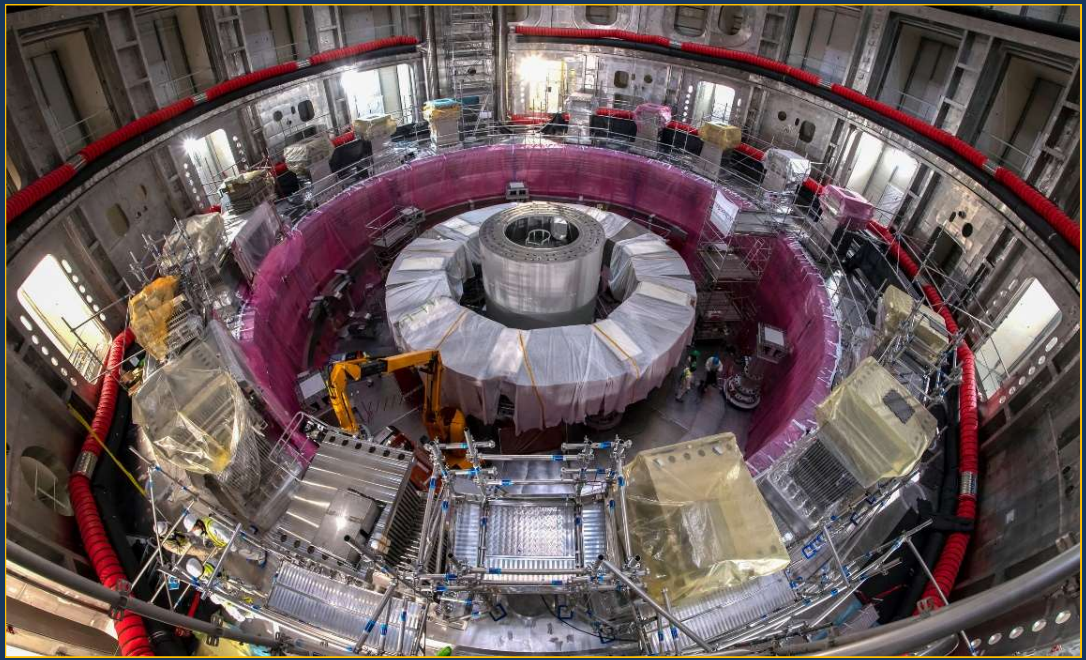
The lower cylinder thermal shield (LCTS) was installed on 14 January 2021. A silver-plated component, the LCTS stands between the lower section of the Cryostat and the machine to act as an obstacle to thermal radiations.

Assembly progress: Tooling

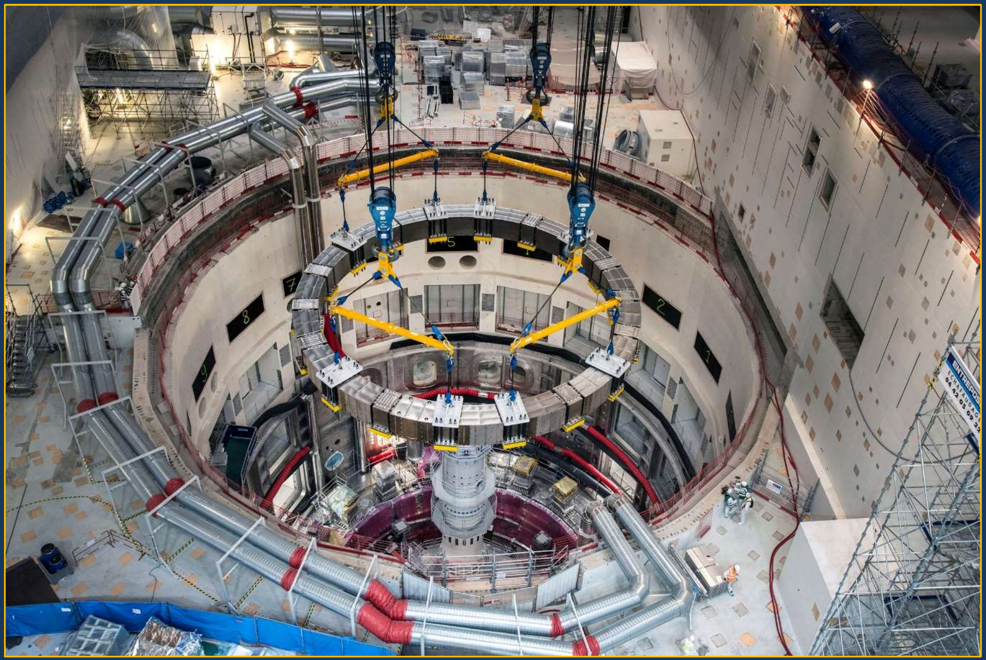
20 August 2021 – Central column (an in-pit assembly tool)

7-8 September 2021 – Test positioning of radial beam

Assembly progress: 2 ring-shaped coils (out of 6)

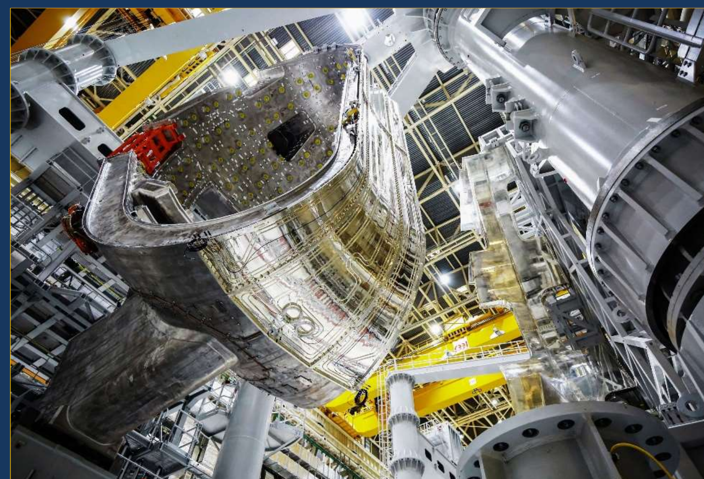


21 April 2021 – Poloidal field coil # 6



16 September 2021 – Poloidal field coil # 5

Toward the first « sub-assembly »



« Sub-assemblies » are the building bricks of the Tokamak’s torus. They comprise one 40° vacuum vessel sector, two toroidal field coils and the corresponding thermal shield panels, and weigh in excess of 1,250 tonnes.

Nine pre-assemblies are required to close the torus.

Final alignment was performed on 17 September within extremely tight tolerances: radial direction 0.14 mm; toroidal direction 0.25 mm; vertical direction 0.58 mm.

Components deliveries

Main components delivered in 2020-2021:

- 10 TF coils (out of 18+1)
- 2 PF coils (out of 6)
- 2 vacuum vessel sectors (out of 9)
- 2 Central solenoid modules (out of 9+1)

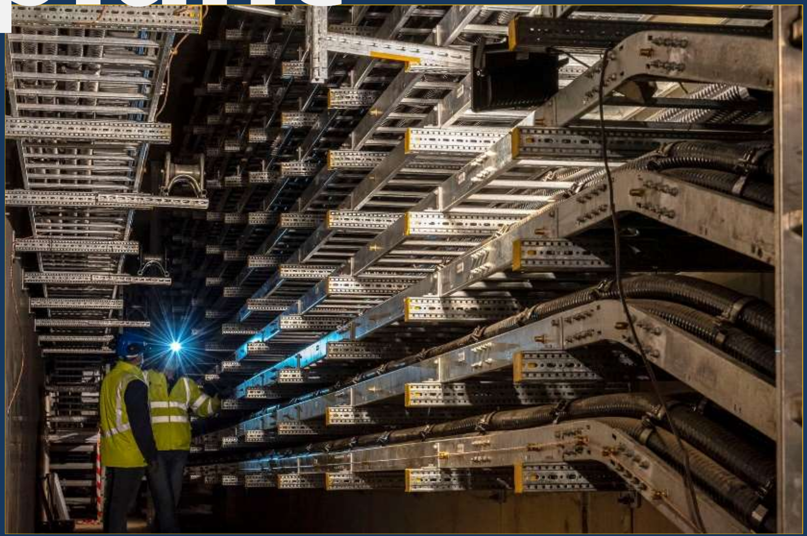
Main components expected in the coming weeks:

- 1 TF coils

Balance of plant

5,5 km of cryogenic lines

10,000 km of electrical cables

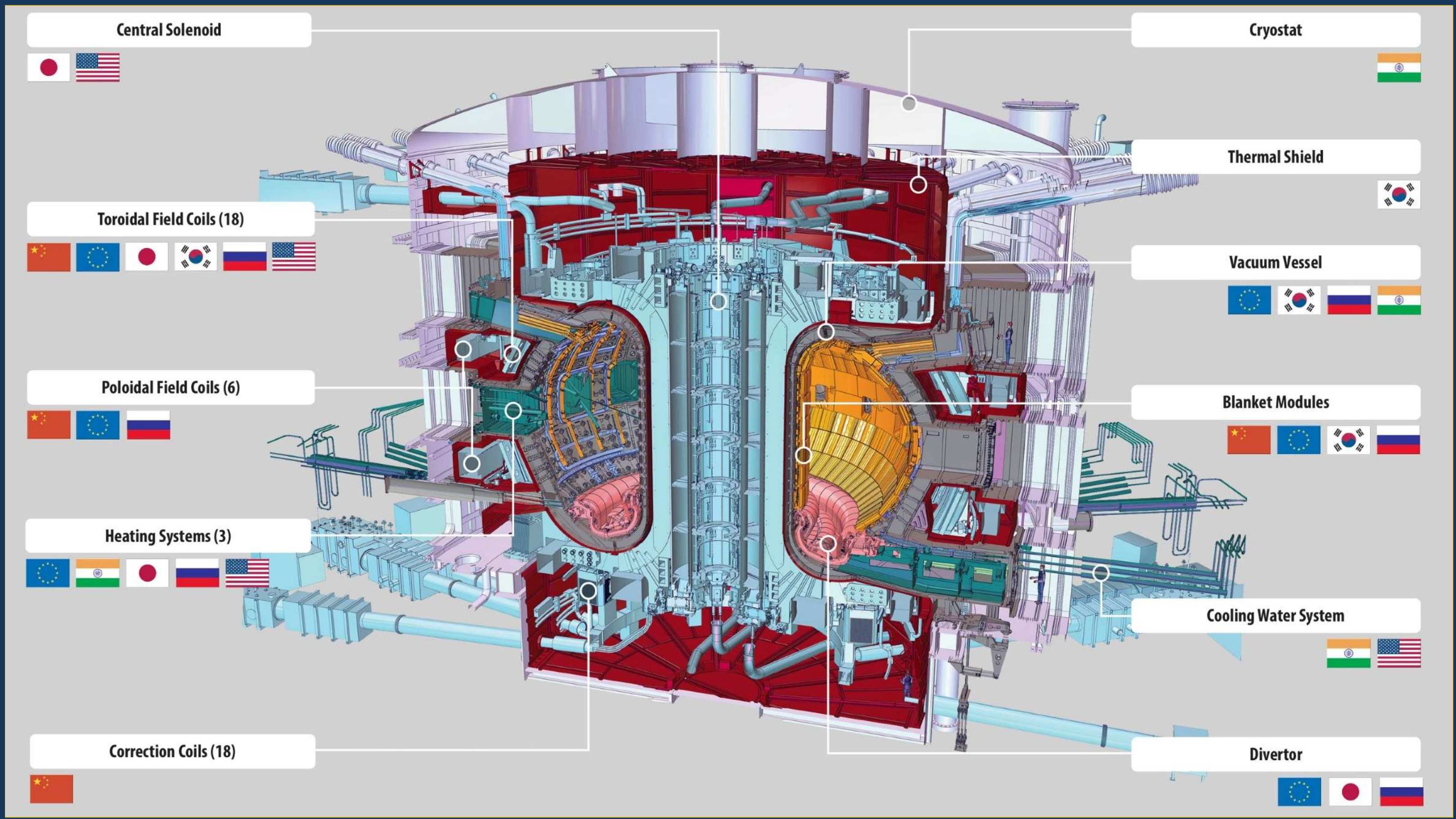


Heat Rejection System (1 200 MW)

Reactive Power Compensation

AC/DC conversion (8 km of busbar)

Who manufactures what?



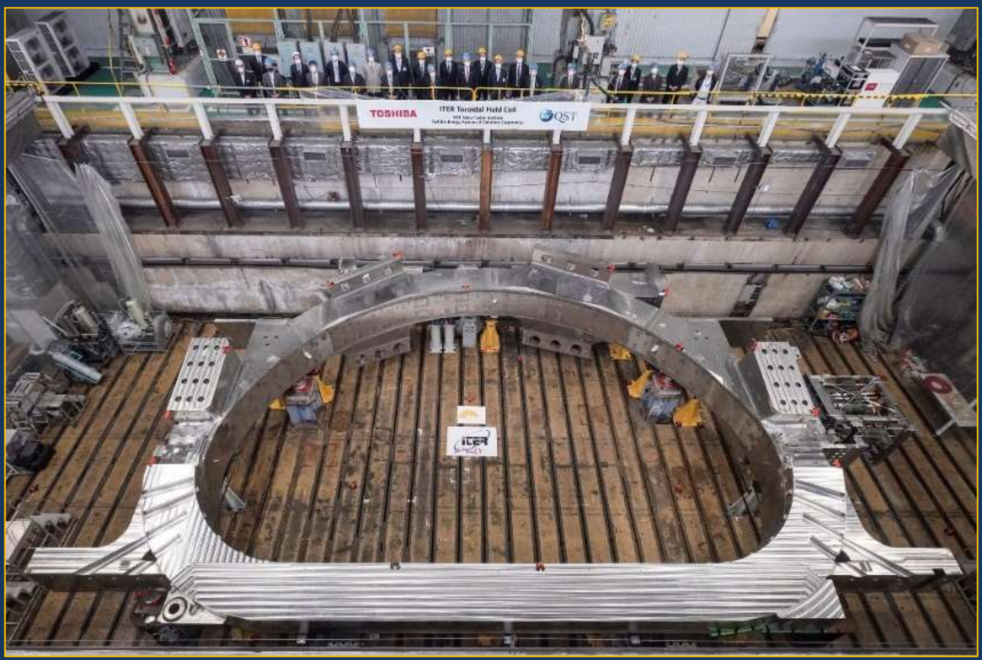
The ITER Members share all intellectual and industrial property

85% of total manufacturing finalized

Five vacuum vessel sectors are under fabrication in Italy.
Completion rates range from 76 to 97%

Two vacuum vessel sectors delivered - rate of completion of the remaining two : 98% and 92%

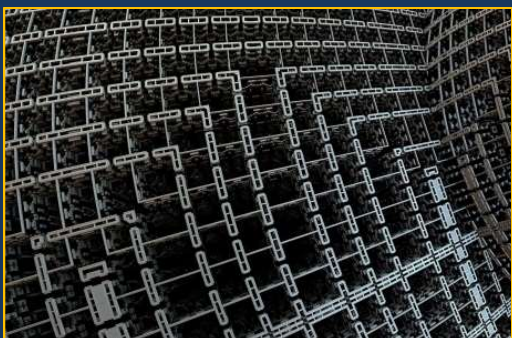
85% of total manufacturing finalized



4 TF coils delivered, 1 en route

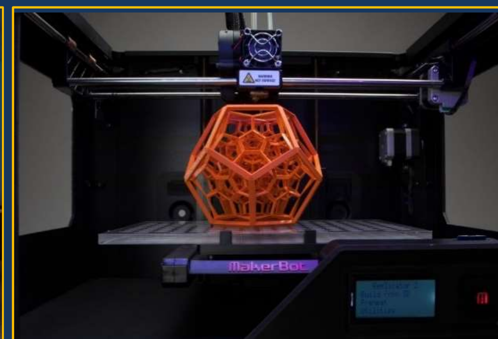
Poloidal field coil #1 is entering the final stages of fabrication in Saint-Petersburg.

Innovation & spin offs



High technology filters

Medical magnetism



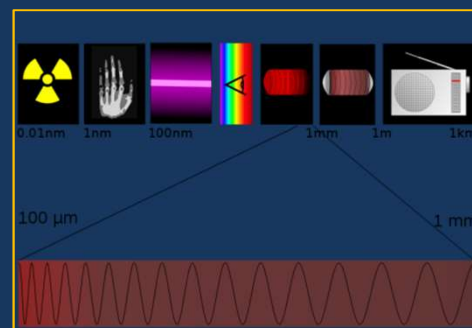
3D printing for complex shapes

Robotics in extreme environments

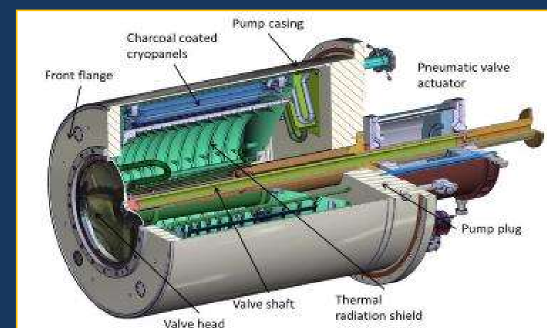
Etc.

Power electronics

Explosive forming



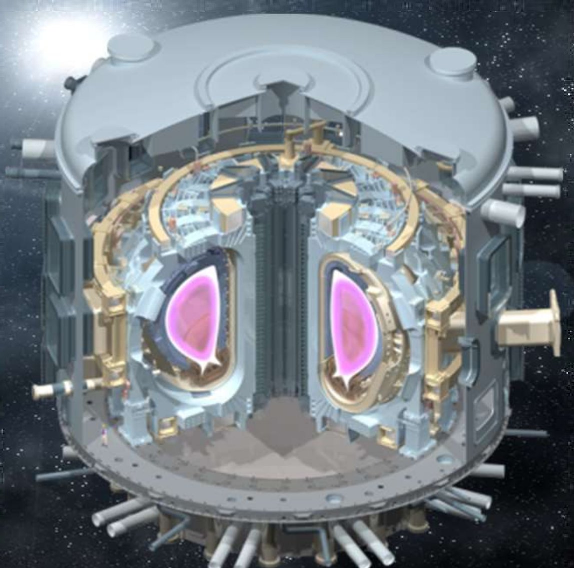
Ultra high-speed transmission



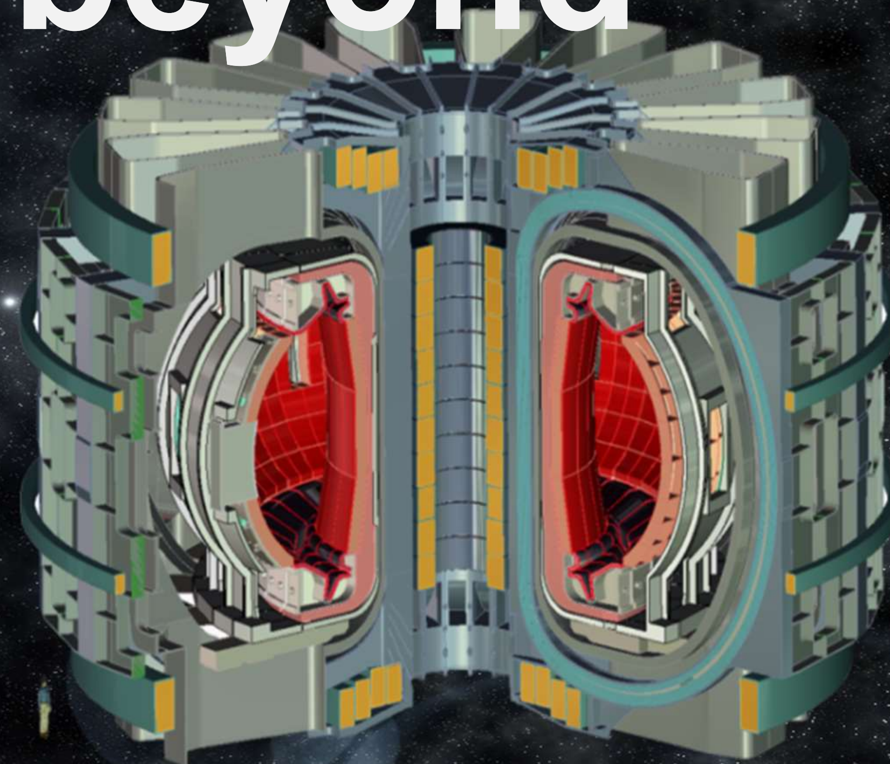
Cryopumps – Vacuum systems

ITER and beyond

The ITER Members are developping conceptual designs for the « next-step » machine (DEMO).

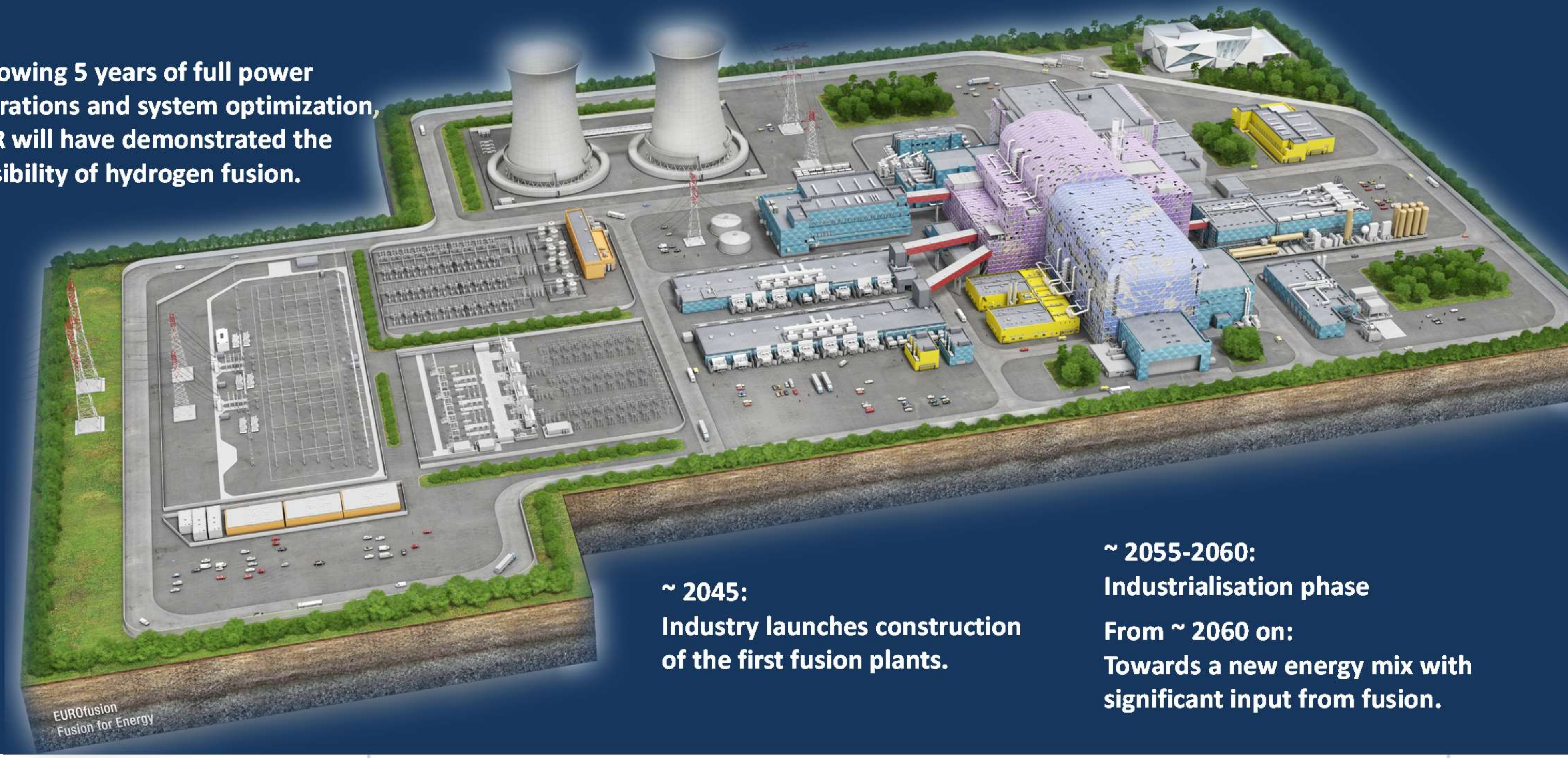


ITER
800 m3
~ 500 MW th



DEMO, next-step machine
~ 500 Mwe, 1 200 MW th

Towards industrialisation



~ 2040:

- **Following 5 years of full power operations and system optimization, ITER will have demonstrated the feasibility of hydrogen fusion.**

~ 2045:
Industry launches construction of the first fusion plants.

~ 2055-2060:
Industrialisation phase

From ~ 2060 on:
Towards a new energy mix with significant input from fusion.


First plasma within ~ 5 years
Full-power operation in 2035
www.iter.org