ITER:
the way to look at the Future

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ITER: The way to look at the future

" We must pursue the objectives of the energy transition.
But we must also know that the technologies,
necessary to achieve this, are not available yet"

Bill Gates, **How to avoid a climate disaster** *(2020)*

In agreement with this statement,
the Fusion Community is working on Fusion technology
in order to be able to create the sun on earth:
it is a dream which is going to become reality.

ITER: The way to look at the future

Energy System Transition. The technology of Nuclear Fusion

The use of nuclear fusion as a source of energy production has numerous advantages:

- *Almost all of the waste produced has low radioactivity values, eliminating the problem of storage.*
- *Does not produce greenhouse gases, radioactive gases or plutonium.*
- *The fuel, which is extracted from the water, can be said to be inexhaustible.*
- *The risk of major accidents is lowered: if control of the reactor were to be lost, it would cool down spontaneously.*

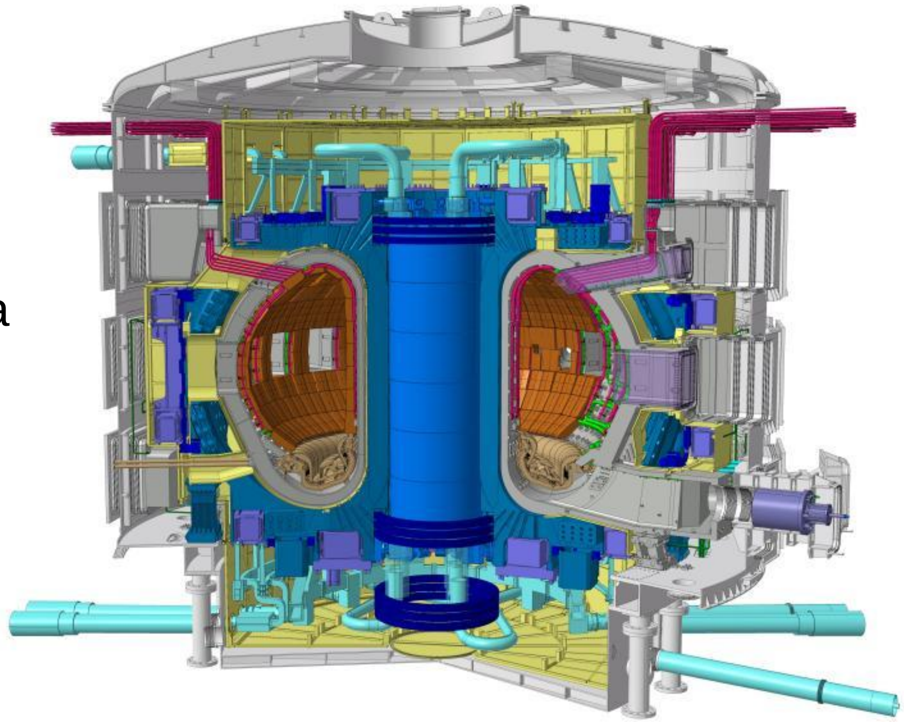
ITER is a tokamak reactor

Inside a tokamak, a gas, often a hydrogen isotope called deuterium is subjected to intense heat and pressure, forcing electrons out of the atoms. This creates a plasma – a superheated, ionised gas – that has to be contained by intense magnetic fields. The containment is vital, as no material on Earth could withstand the intense heat (150,000,000°C and above) that the plasma has to reach so that fusion can begin. It is close to 10 times the heat at the Sun's core, and temperatures like that are needed in a tokamak because the gravitational pressure within the Sun cannot be recreated. When atomic nuclei do start to fuse, vast amounts of energy are released. While the experimental reactors currently in operation release that energy as heat, in a fusion reactor power plant, the heat would be used to produce steam that would drive turbines to generate electricity.

ITER – Physics and Technology Goals

- ITER Program Objective:
  - to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes

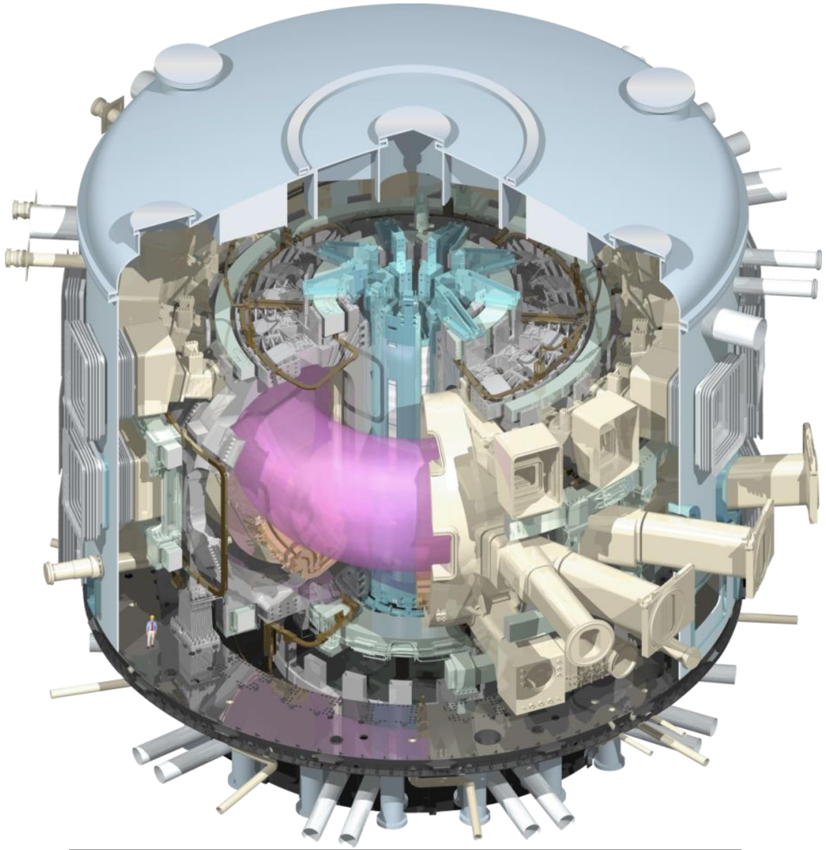
- Key Technical Goals:
  - achieve extended burn of a DT plasma with dominant alpha-particle heating
  - develop steady-state fusion power production as ultimate goal
  - integrate and test all essential fusion power reactor technologies and components
  - demonstrate safety and environmental acceptability of fusion



What will ITER do?

- ITER will demonstrate the availability and integration of science and technologies, and safety features for a fusion reactor
- The self-sustained D-T burning plasma in ITER generates 10 times more power than it receives
- Input 50 MW > Output 500 MW
- ITER is a power amplifier
- ITER is a necessary step on the way to commercial fusion reactor
- Schedule

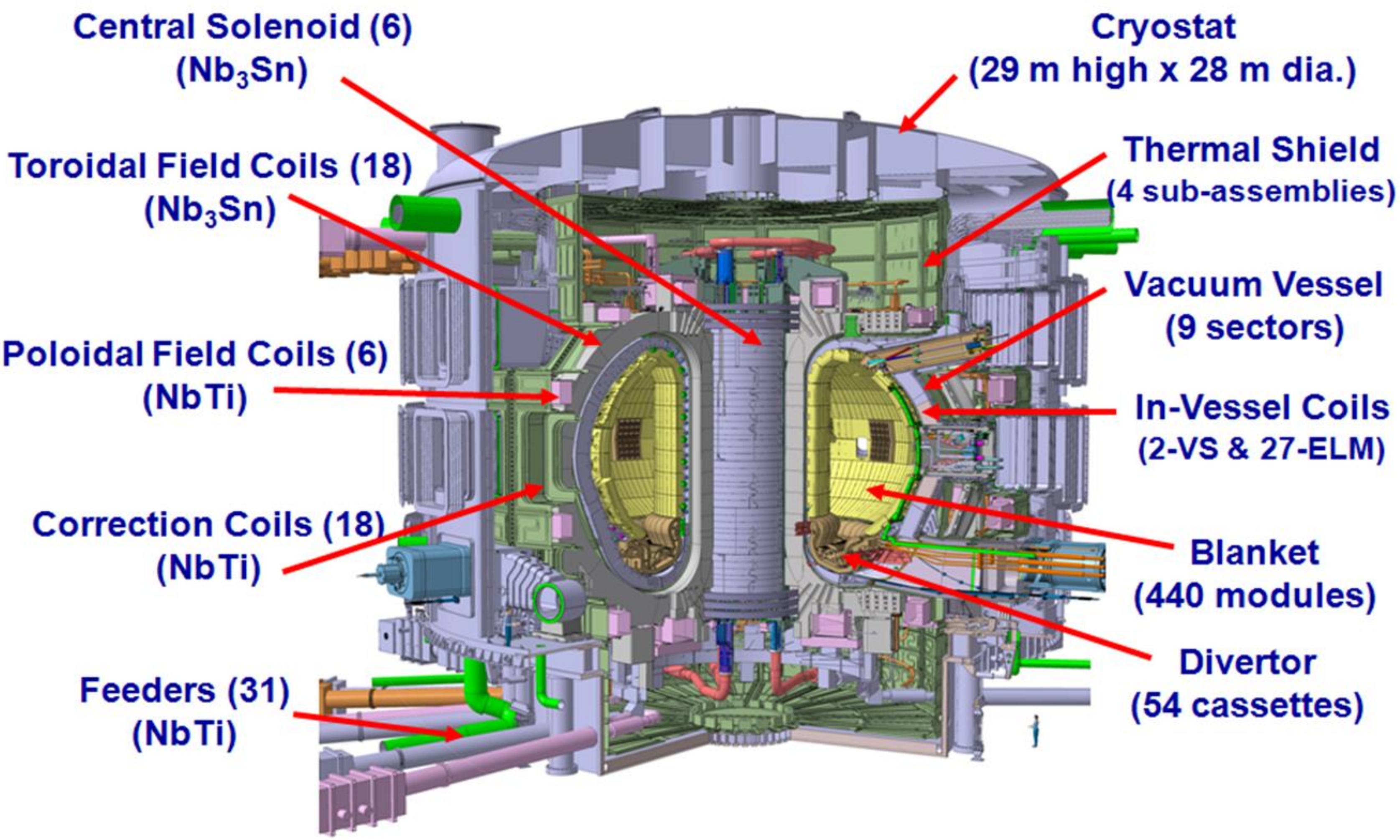
Construction:	2010-2020
First Plasma:	2020
DT Operations:	2027



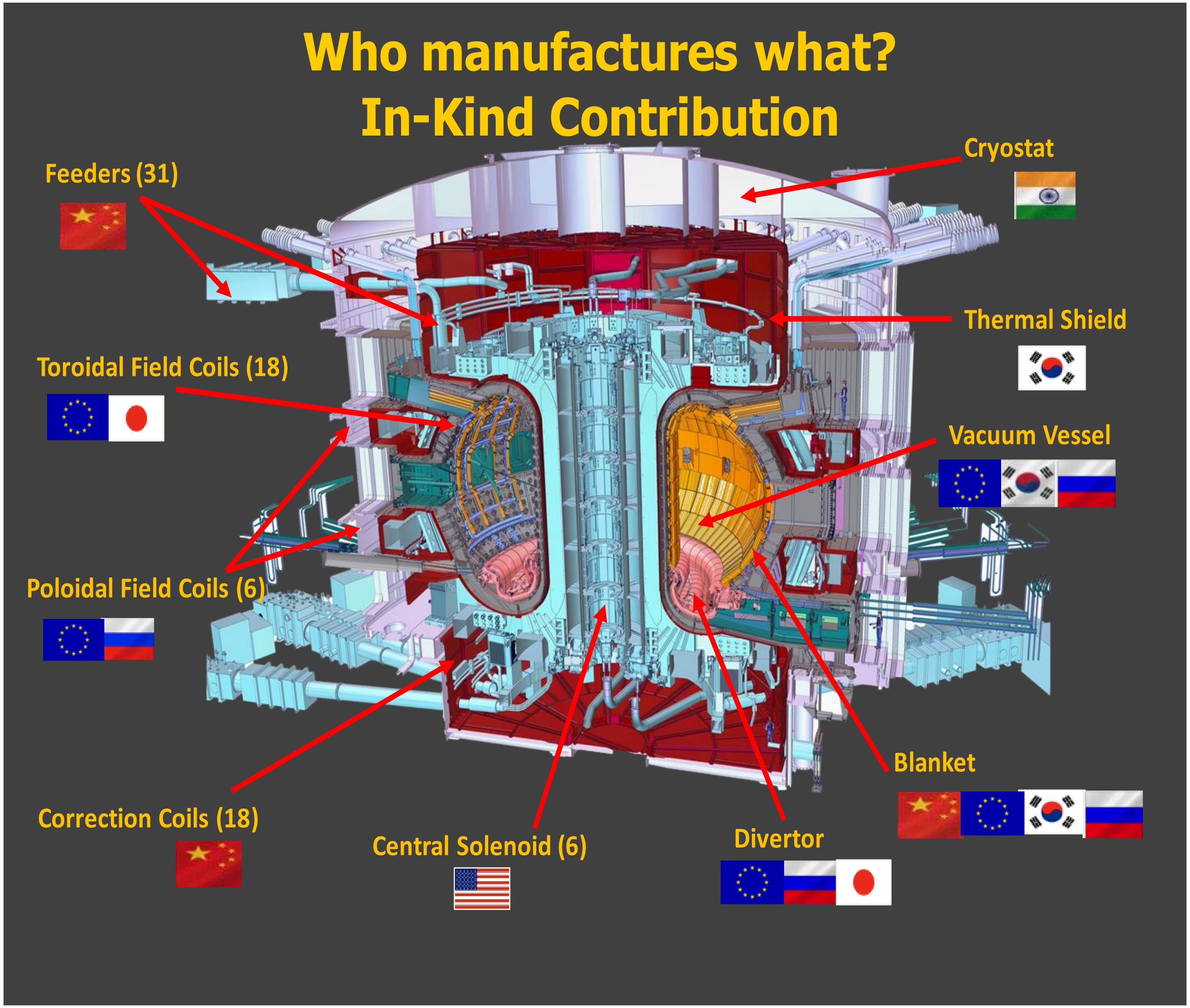
R=6.2 m, a=2.0 m, I_p=15 MA, B_T=5.3 T, 23,000 tons

Bringing a Sun to St. Paul-lez-Durance…

The ITER Machine - Technology

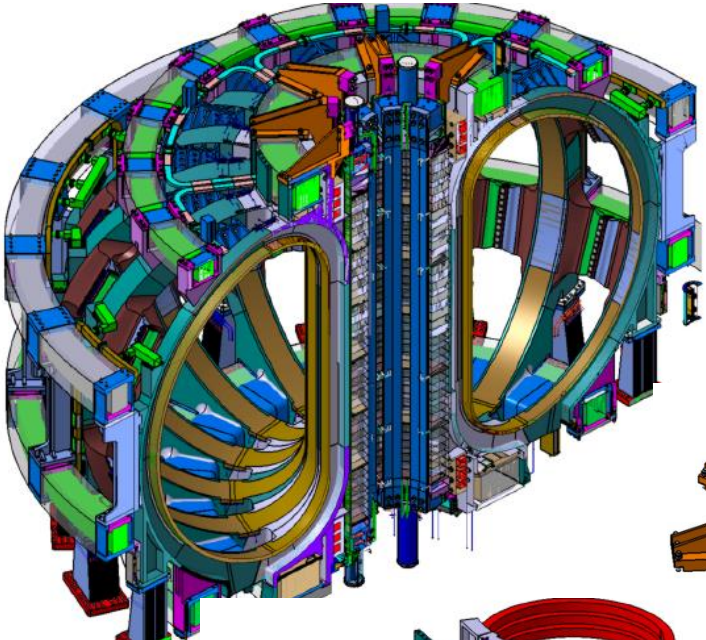


In-Kind Procurement

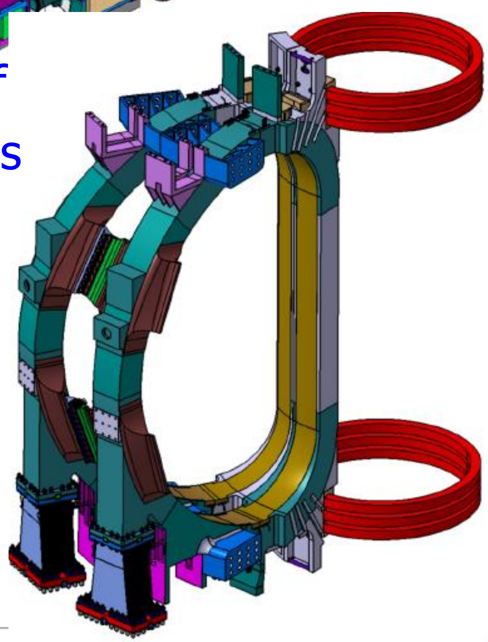


- 90% of the procurement for ITER is performed "in kind" by the seven procurement agencies.
- ~85% is now contractually agreed and signed.

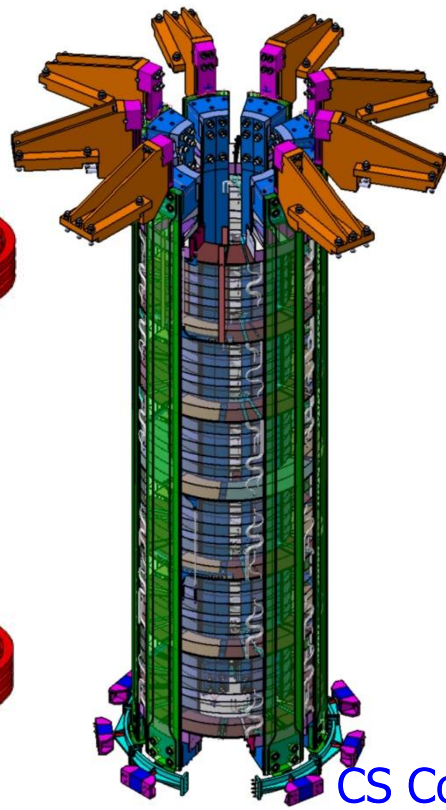
Magnets



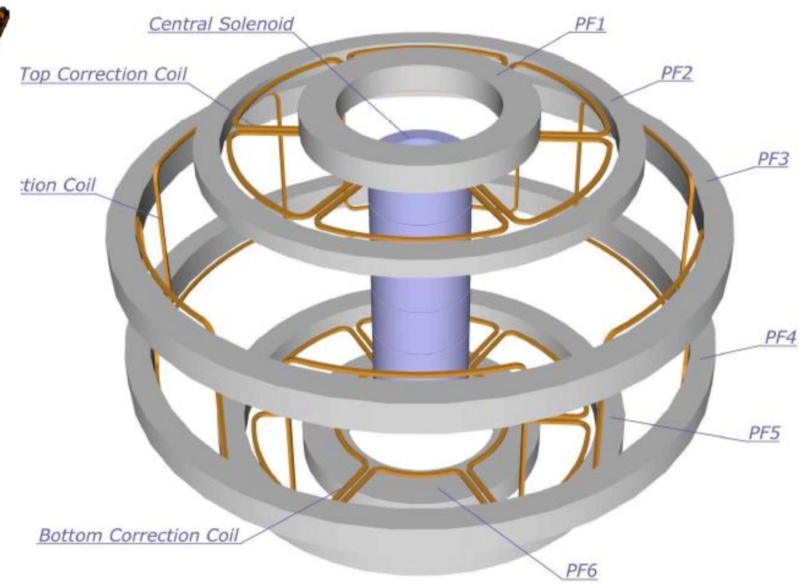
- The ITER magnet system is made up of
  - 18 Toroidal Field (TF) Coils, (EU&JA)
  - a 6-module Central Solenoid (CS), (US)
  - 6 Poloidal Field (PF) Coils, (EU&RF)
  - 9 pairs of Correction Coils (CC). (CN)
  - 31 Feeders (CN)



Pair of TF Coils



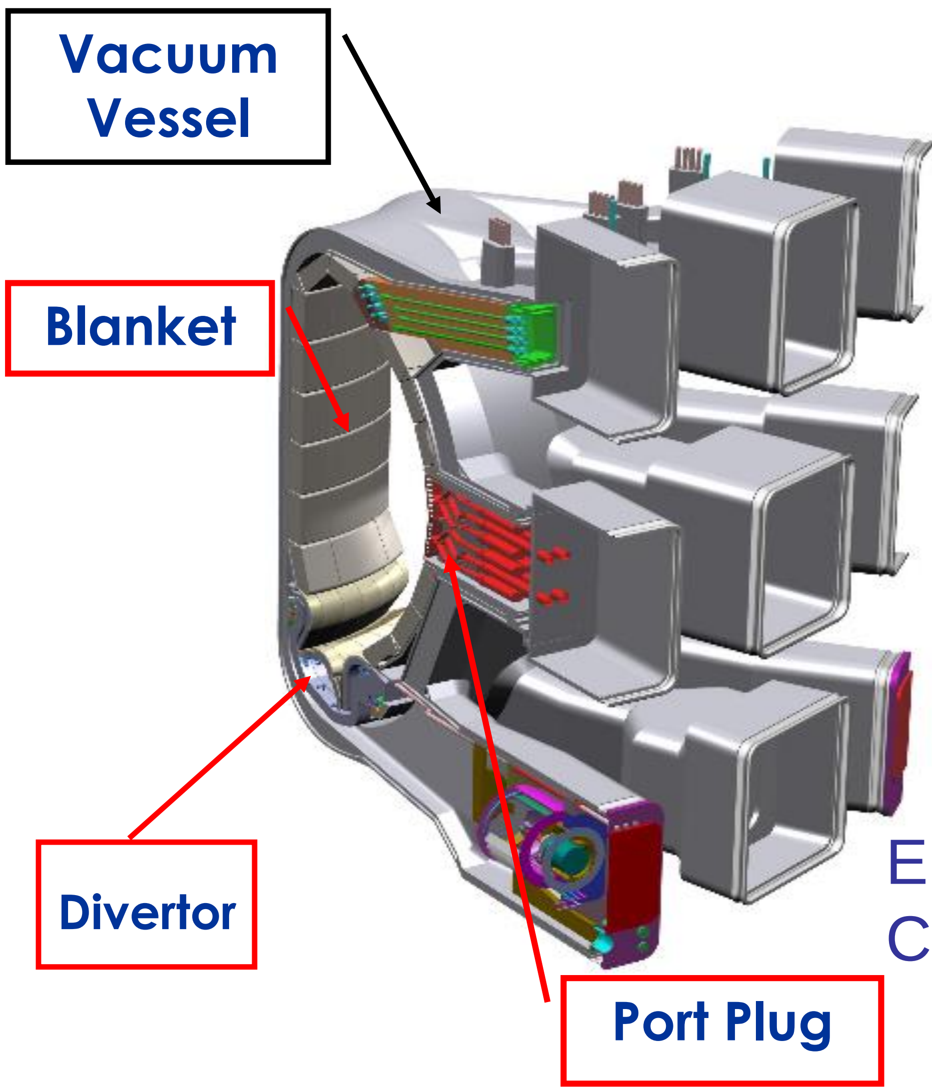
CS Coil

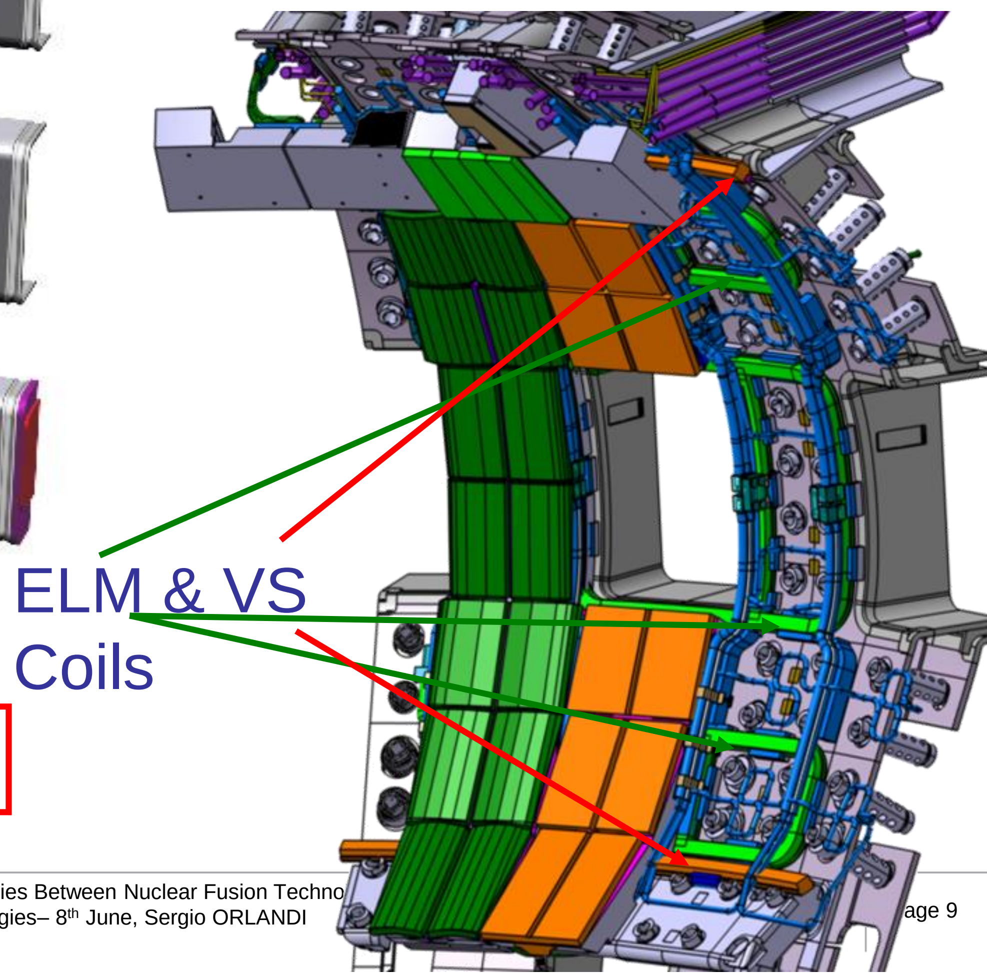


PF & CC Coils

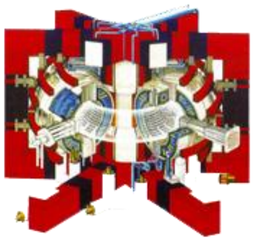
ITER Vacuum Vessel and Blanket

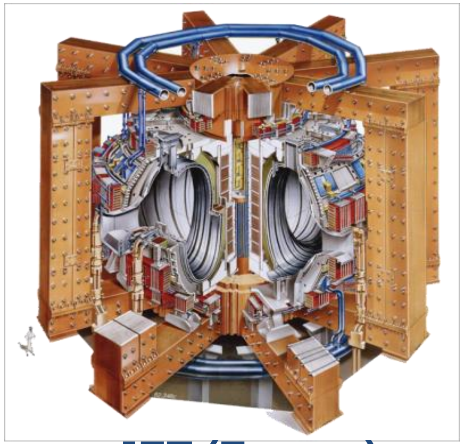
- The vacuum vessel is lined by modular removable components: **blanket modules, divertor cassettes, ELM / VS coils** and **port plugs** (heating antennae, diagnostics and test blanket modules)

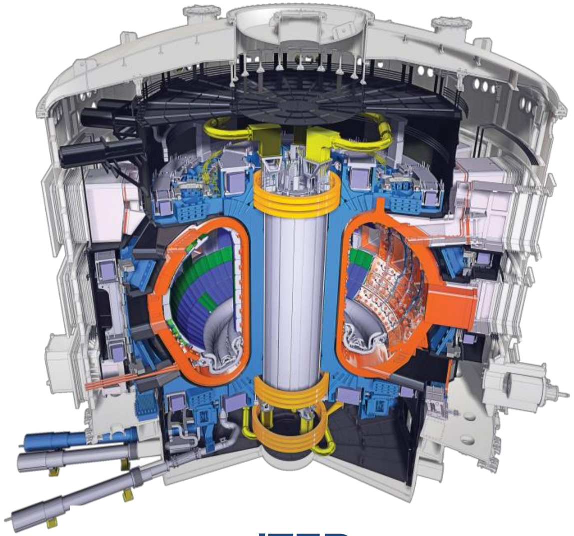




Size Matters







Tore Supra (Fr/EU)		JET (Europe)		ITER	
Volume	25 m^3	Volume	80 m^3	Volume	830 m^3
Power	~0	Power	~16 MW	Power	~500 MW
Heating	~15 MW	Heating	~23 MW	Heating	~50 MW
Pulse	~400 s	Pulse	~30 s	Pulse	~400 s
Current	~1.7 MA	Current	~5-7 MA	Current	~15 MA

ITER Plant – Where we are

ITER Project – Manufacturing Progress

Vacuum Vessel Sector Assembly

Cryoline production

Magnet clamp fabrication

Insertion in TF cases

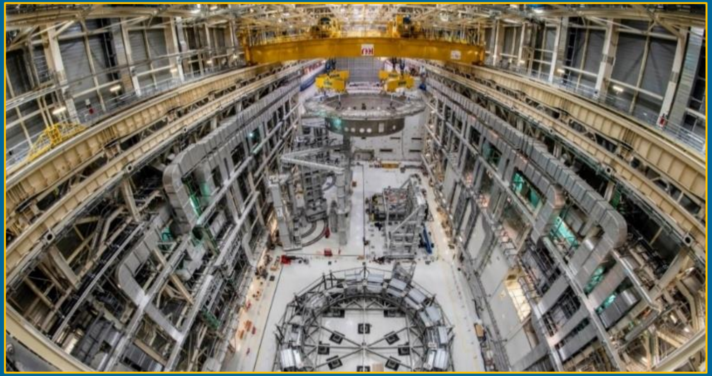
High heat flux testing

CS supports

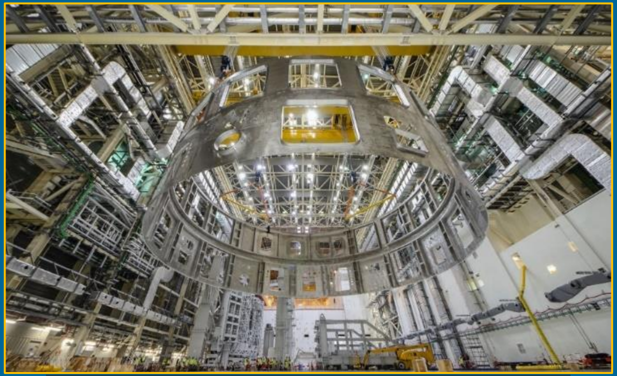
PF Coil #5

ITER Project – Assembly Progress

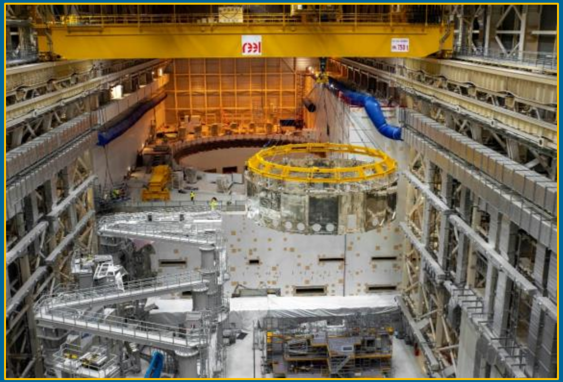
85% of total manufacturing finalized



26-27 May 2020 – Cryostat Base

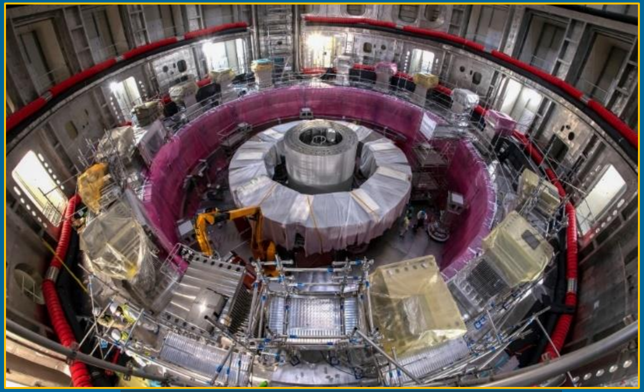


31 Aug 2020 - Cryostat Lower Cylinder



14 Jan 2021- Lower Cylinder Thermal Shield

8 September 2021 – Test positioning of radial beam

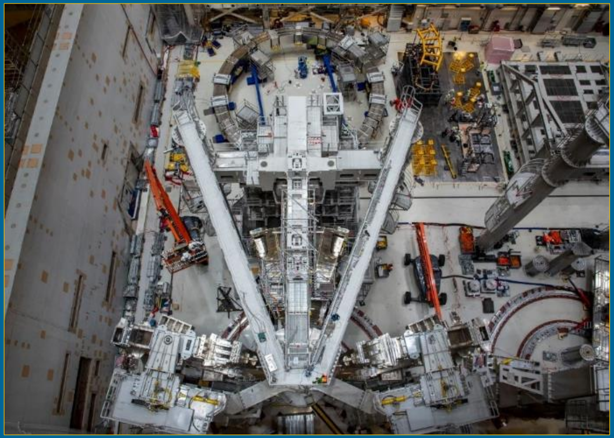
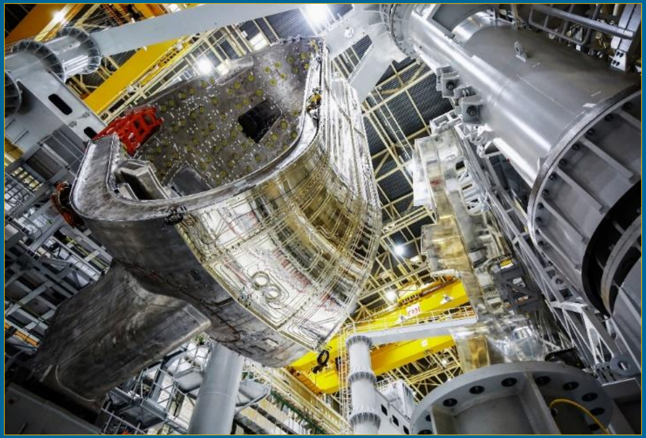


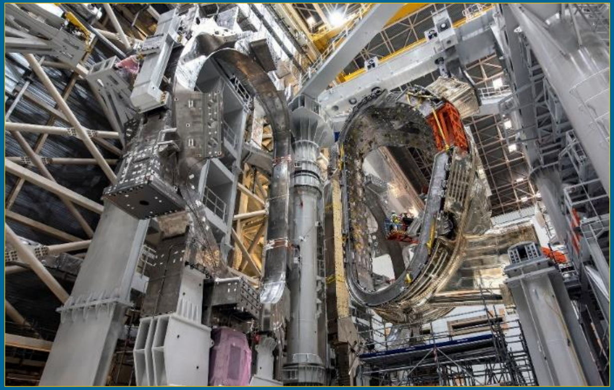
21 April 2021 – Poloidal field coil # 6

16 Sept 2021 – Poloidal field coil # 5

ITER Project - Progress
85% of total manufacturing finalized

Toward the first « sub-assembly »

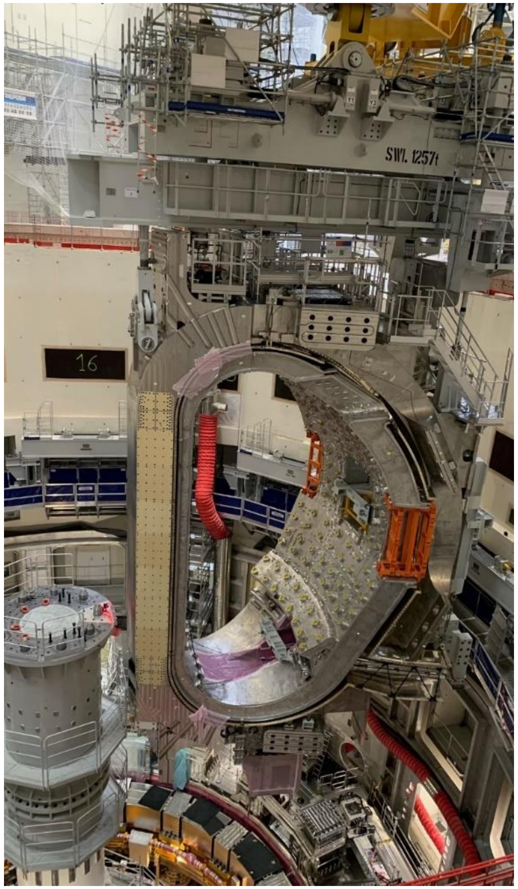


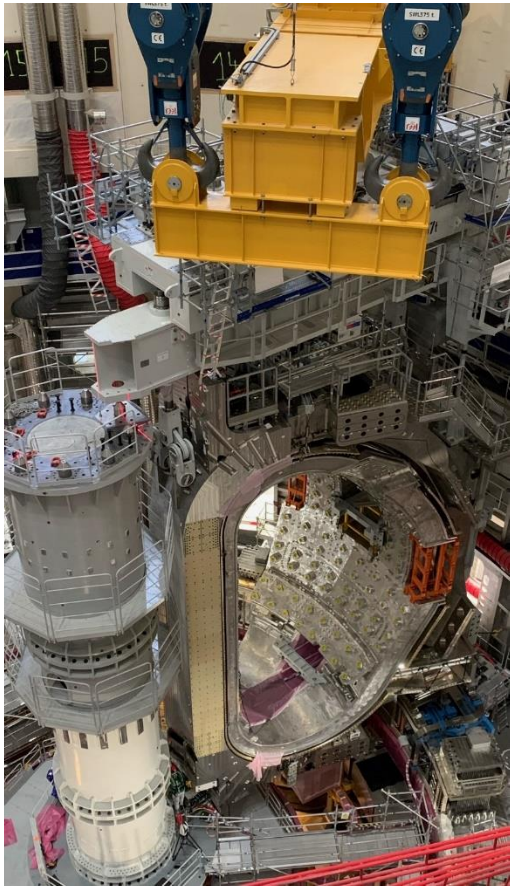
« Sub-assemblies » are the building bricks of the Tokamak's torus. They comprise one 40° vacuum vessel sector, two toroidal field coils and the corresponding thermal shield panels, and weigh in excess of 1,250 tonnes.

Nine pre-assemblies are required to close the torus.

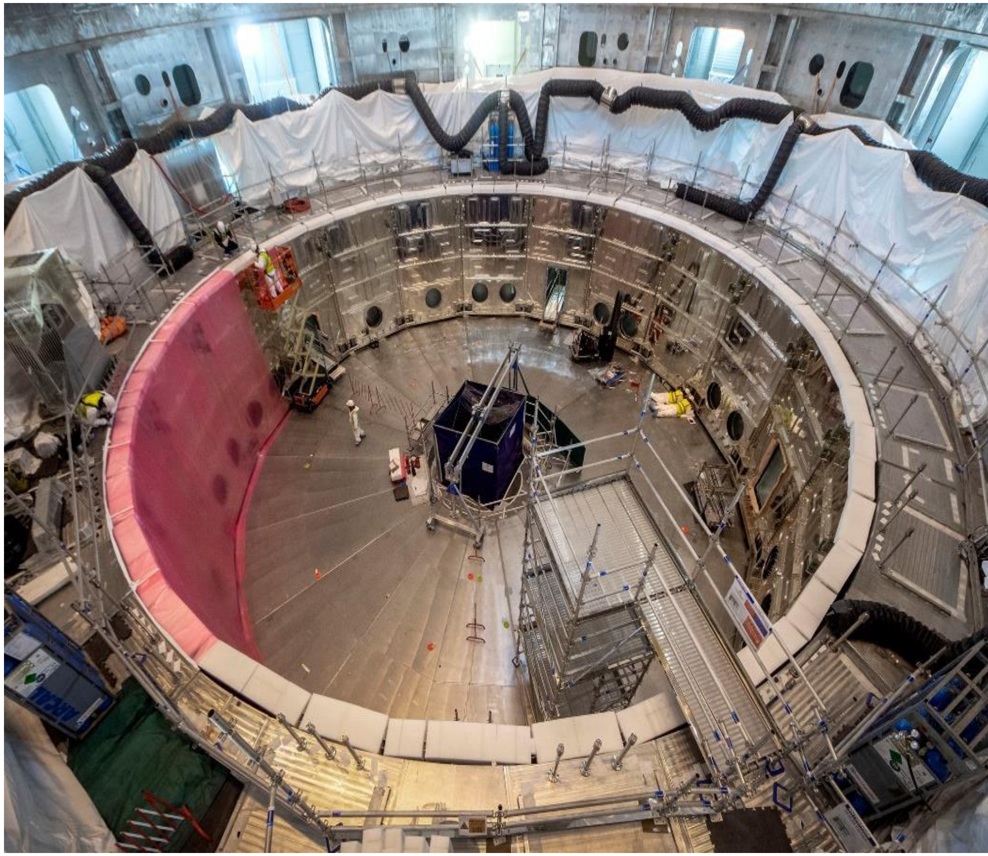
Final alignment was performed on 17 September within extremely tight tolerances: radial direction 0.14 mm; toroidal direction 0.25 mm; vertical direction 0.58 mm.

SM#6 Lifting and Lowering (11 May 2022)

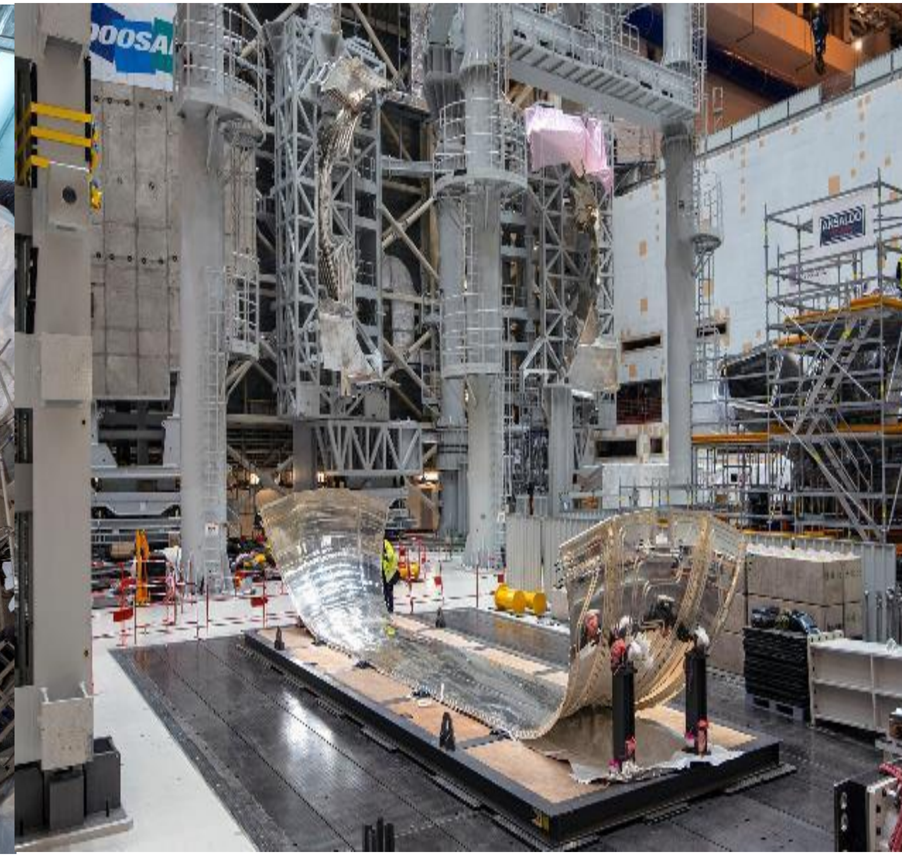




Manufacturing Updating



The lower cylinder thermal shield is now installed at the bottom of the Pit



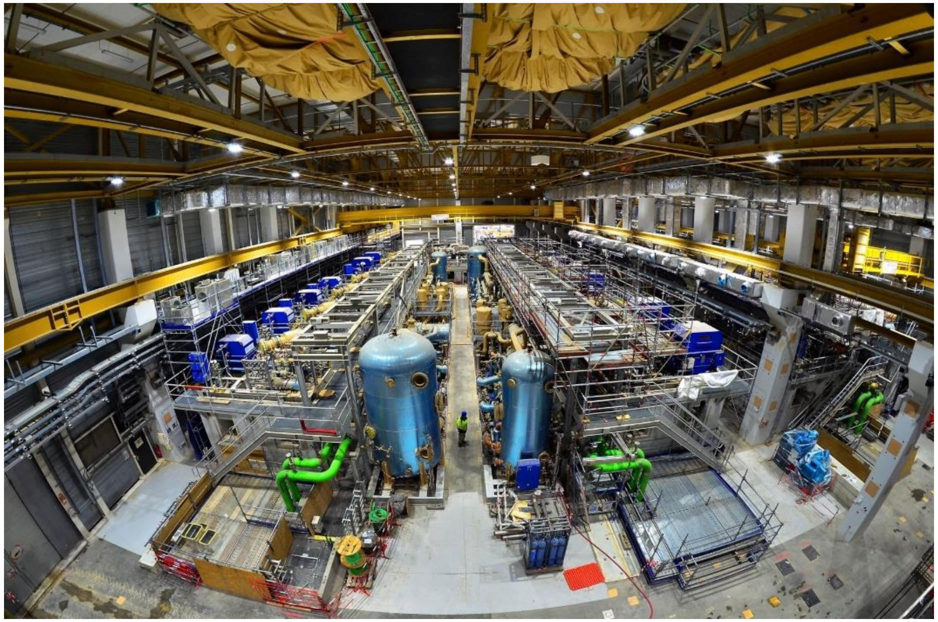
A silver-plated vacuum vessel thermal shield inboard section that will be exchanged in the coming month with the outboard right hand section presently held inside the sector sub-assembly tool (visible in the background)

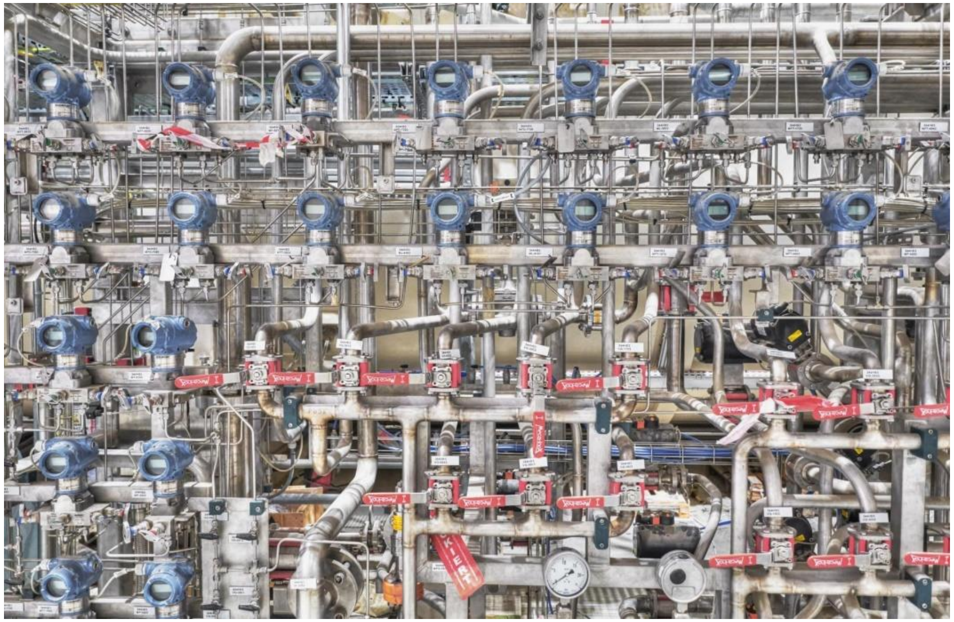
Manufacturing Updating

FIELD COILS - WINDING FACILITY

Manufacturing Updating

CRYOPLANT





Manufacturing Updating

POWER CONVERSION PLANT

Busbars

ITER Project - Progress

What to do in the next Years – Summary

- To assure on time delivery of in kind contribution for Machine assembly and Systems installation
- To assure progressive completion of systems commissioning as the BOP installation is completed (Electrical power Distribution, Coil Power Supply, Component Cooling Water, Cryogenic System, Chilled Water System , Bus Bars connections)
- To assure Machine Assembly Completion on quality , on time and on costs
- To assure Systems installation completion also inside the Tokamak implementing the same Model as per BOP on quality, on time and on costs;
- To assure Buildings Auxiliary completion in Design / Procurement / Installation and Commissioning on quality, on time and on cost;
- To assure global control of the Costs in Engineering, Procurement and Installation managing properly all contracts and related unplanned claims (installation Contracts, Engineering services, Procurement on authorized budget, Construction Management Advisor (CMA) Contract managed as Support to Owner;
- To assure proper evolution of Design of the Hot Cell Complex following the Conceptual Design Review of December 2021 according to the latest systems / buildings design requirements fixed by the IO and Stakeholders as a Whole.

ITER : the way to look at the future

Superconducting Cables

- One of ITER's magnets, the central solenoid, will produce a field of 13 tesla – 280,000 times Earth's magnetic field.
- Superconducting cables are becoming a preferred solution in nuclear fusion with respect to conventional busbar systems when very large electrical currents are transported over relatively long distances, thanks to:
- The much larger current densities: 200 A/mm2 instead of 2 A/mm2 for conventional busbars leading to a drastic reduction of footprint and weight.
- The mechanical flexibility of superconducting cables when compared to rigid busbars, simplifying installation & upgrade operations.
- The drastic reduction/ elimination of intermediate electrical joints (depending on length of the circuit) present in large numbers in conventional busbars.
- The elimination of energy losses in the powering system, making the nuclear plant overall efficiency higher.
- The displacement of the transition from room to cryogenic temperature from the 'hot' tokamak area to a 'cold' region of the power converters, where it can be more easily controlled and eventually maintained.
- The integration of the superconducting cable cooling system within the cryogenic plant of ITER, which would result in a further optimized solution, leading to a virtually' maintenance-free' operation of the powering system.

ITER: the way to look at the future

Summary

- Today we are at the stage in which nuclear fusion can pass within the middle of the century from the experimentation phase to the demonstration phase.

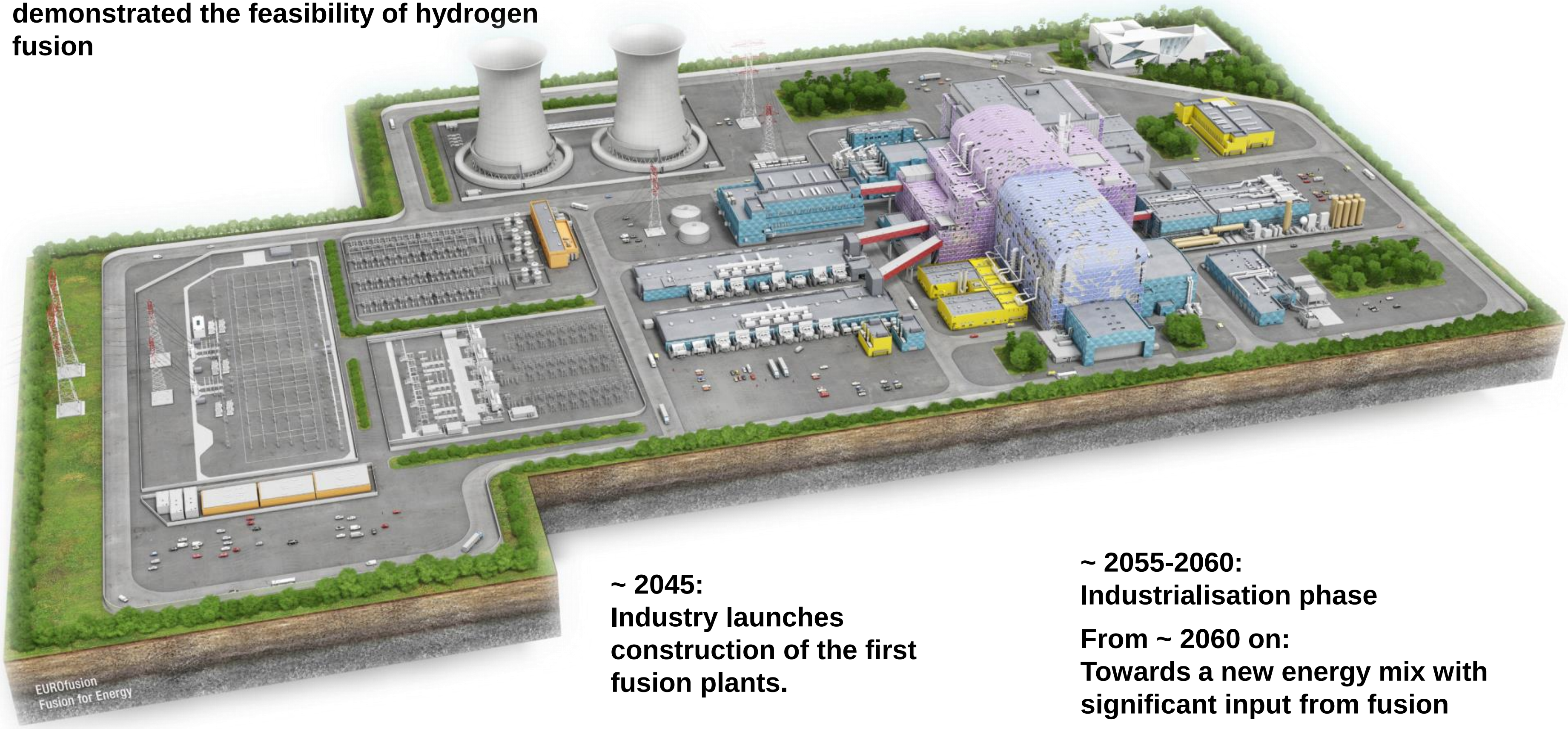
- This awareness is pushing several private companies to invest in nuclear fusion, sometimes presented as the only alternative that meets all the requirements in terms of emissions and production. Today these realities owe their awareness to the choice that developed countries made decades ago, with the founding of ITER. In a time when there was still no talk of decarbonization, the choice to build a reality like that of ITER proved prescient, and still works today as a source from which to draw on to speed up the investment processes and construction of new experiments for fusion nuclear.

- For this reason, the need to continue investing in research and development is emphasized, in order to guarantee the realization within the middle of the century.

Towards industrialization

~ 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

CONCLUSION

Achieving climate goals would theoretically be possible even without further investment in nuclear energy.

However, excluding this energy source from the equation would require a much larger mobilization of resources.

If between now and 2040 it were decided to stop any investment in nuclear power, it would be necessary to compensate for the lack of electricity production with a quantity of wind and solar energy equal to five times the total installed capacity in the last 20 years globally.

This is the main reason why European Union cannot miss the opportunity to introduce the Nuclear Energy into the Taxonomy


Thank you
for your attention