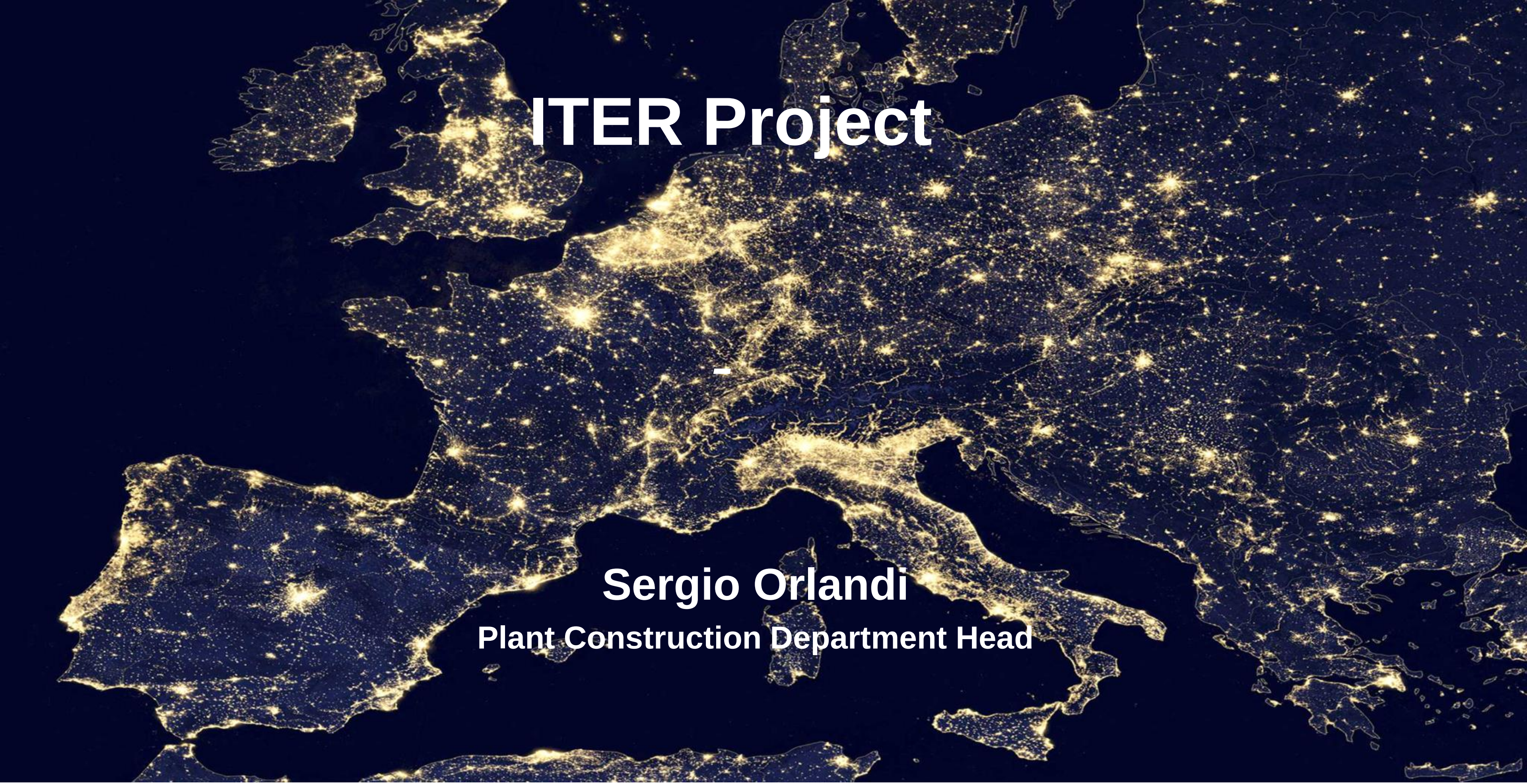


ITER Project

-

Sergio Orlandi

Plant Construction Department Head

Stato e prospettive della fusione nucleare

" 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.

What options for massive carbon-free production?

- Renewables: intermittent, low density, cannot meet the needs of industry and mega-cities.
- Nuclear fission: safety, acceptability (Nimby), long-term challenge of high-activity long-life waste management.
- Hydrogen fusion: must demonstrate industrial feasibility – ITER mission.

Stato e prospettive della fusione nucleare

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

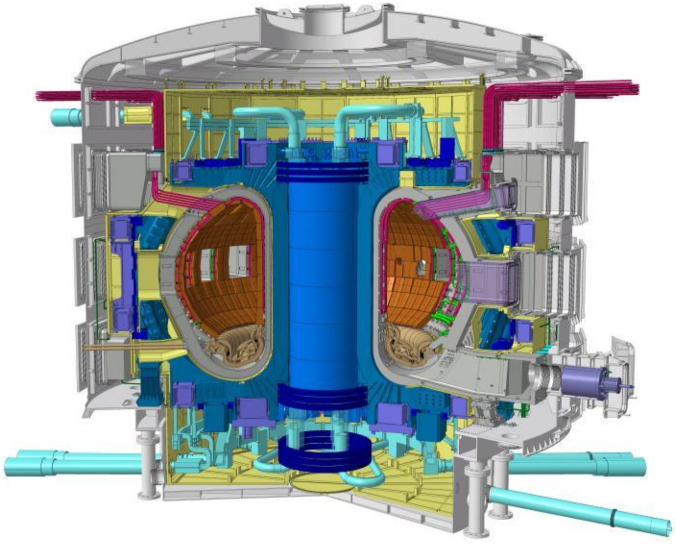
Inside a tokamak, a gas, often a hydrogen isotope called deuterium is subjected to intense heat and pressure, forcing electrons out of the atoms. This creates a plasma – a superheated, ionised gas – that has to be contained by intense magnetic fields. The containment is vital, as no material on Earth 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.

Stato e prospettive della fusione nucleare

ITER – Physics and Technology Goals

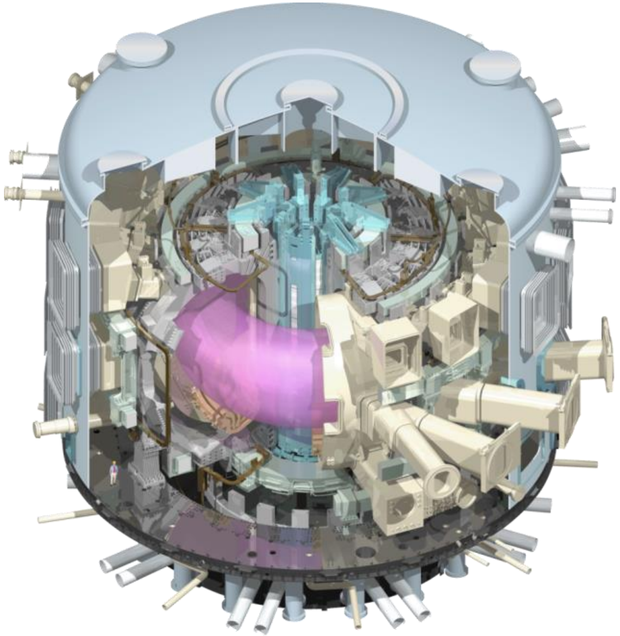
- ITER Program Objective:
  - to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes

- 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



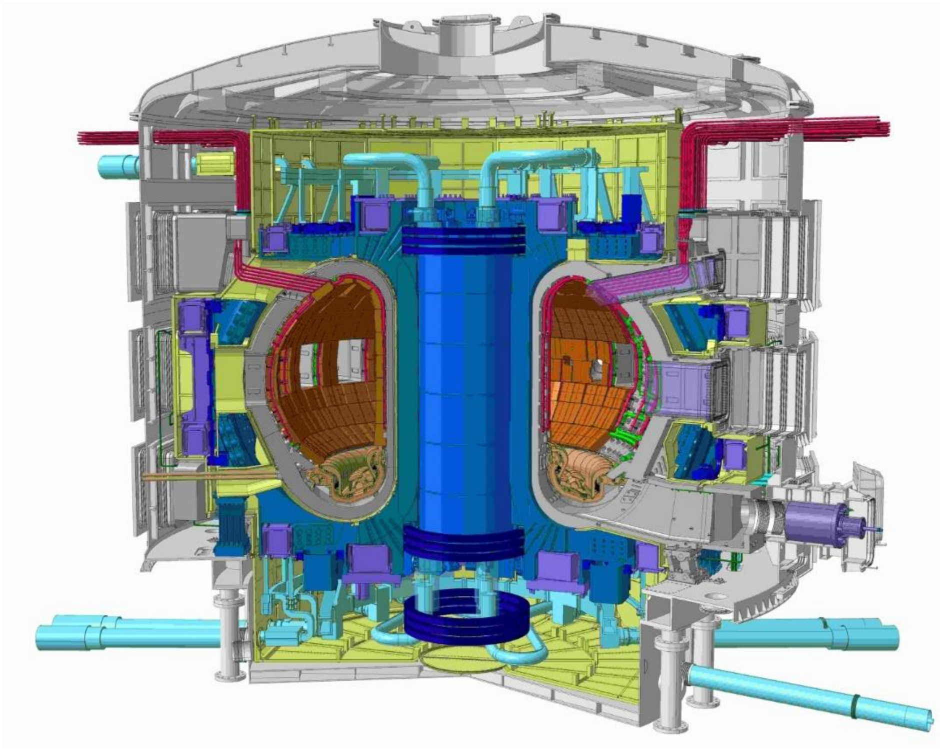
R=6.2 m, a=2.0 m, I_p=15 MA, B_T=5.3 T, 23,000 tons

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

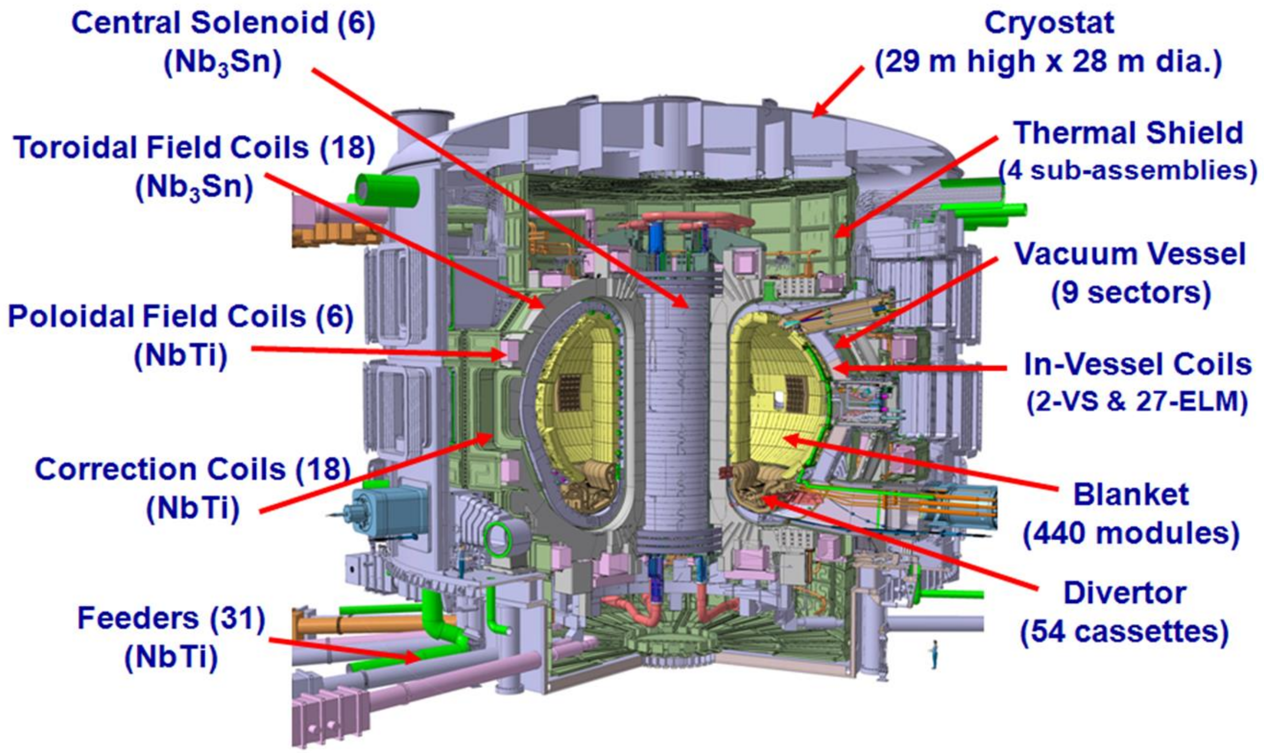
ITER Machine Layout

Plasma major/minor radius: 6.2/2 m
Total fusion power: 500 MW
Plasma current: 15 MA
Toroidal field @ 6.2 m radius 5.3 T
Fusion/auxiliary heating power: ≥ 10
Vacuum volume: ~ 1330 m^3
Plasma volume: ~ 837m^3

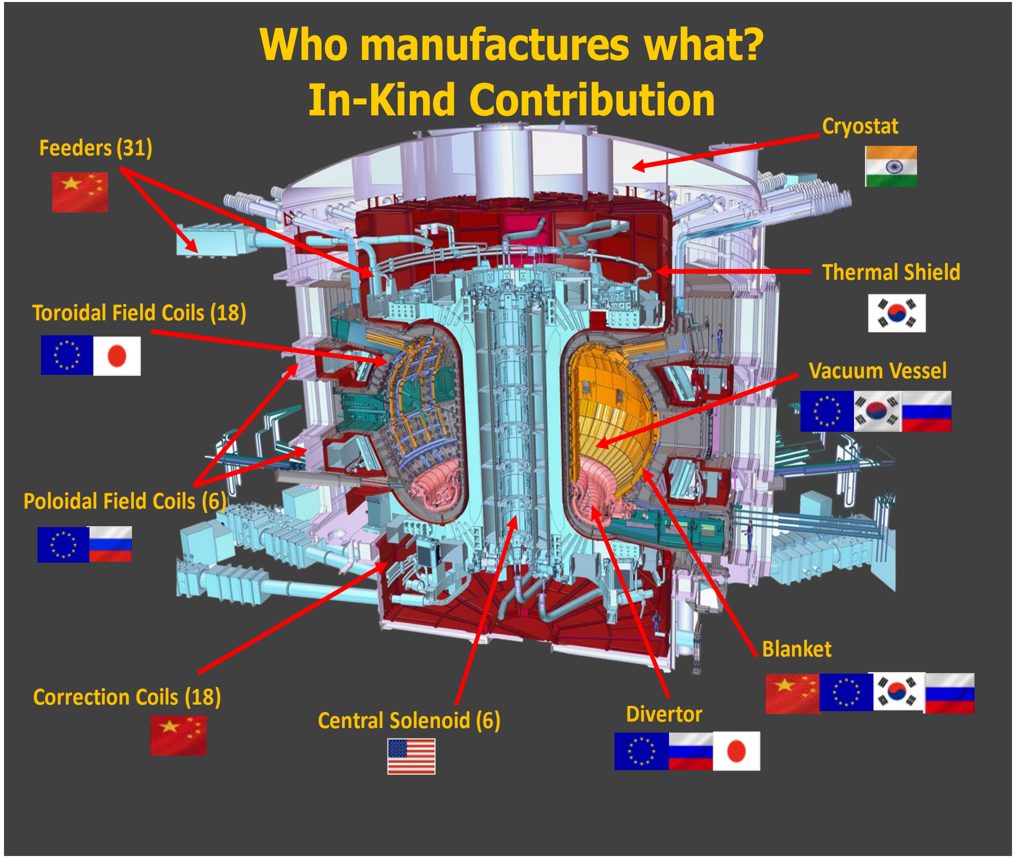
Plasma tritium throughput: ~ 1 kgh^{-1}
Plasma tritium inventory: ~ 0.2 g
Tritium site inventory: < 4 kg
Fuel cycle inventory: ~ 2 kg



The ITER Machine - Technology



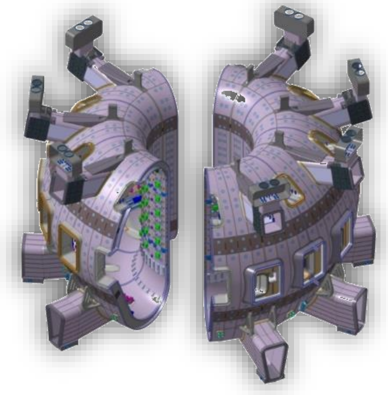
In-Kind Procurement

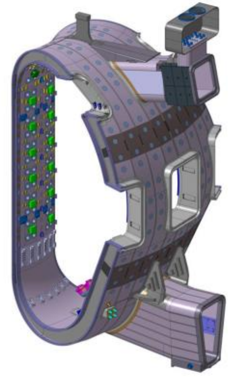


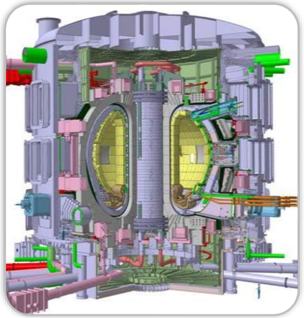
- **90% of the procurement for ITER is performed “in kind” by the seven procurement agencies.**
- **~85% is now contractually agreed and signed.**

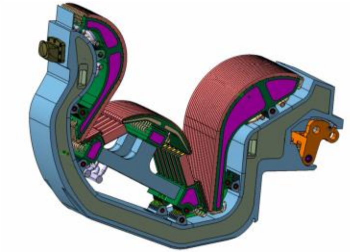
ITER : New Technology for a New Industry

Quality is required in fabrication and installation of the most critical ITER components:
Vacuum Vessel Sectors, Vacuum Vessel Assembly, Divertor



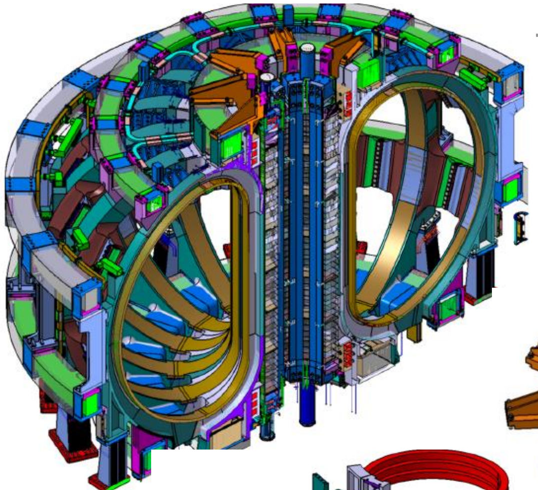


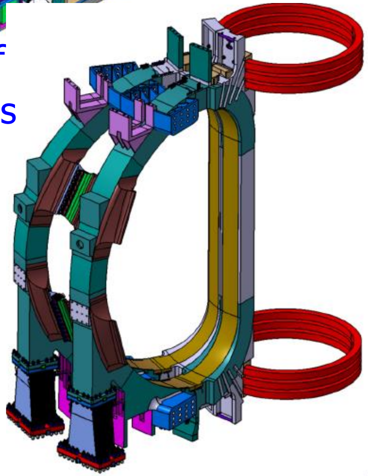




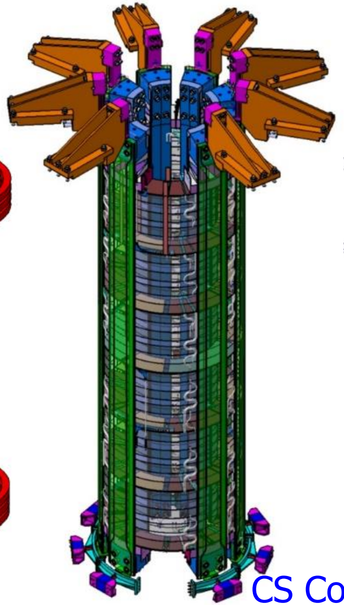
Magnets

- 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)

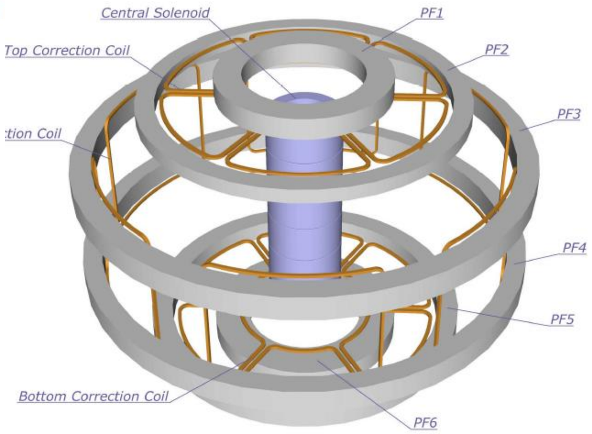




Pair of TF Coils

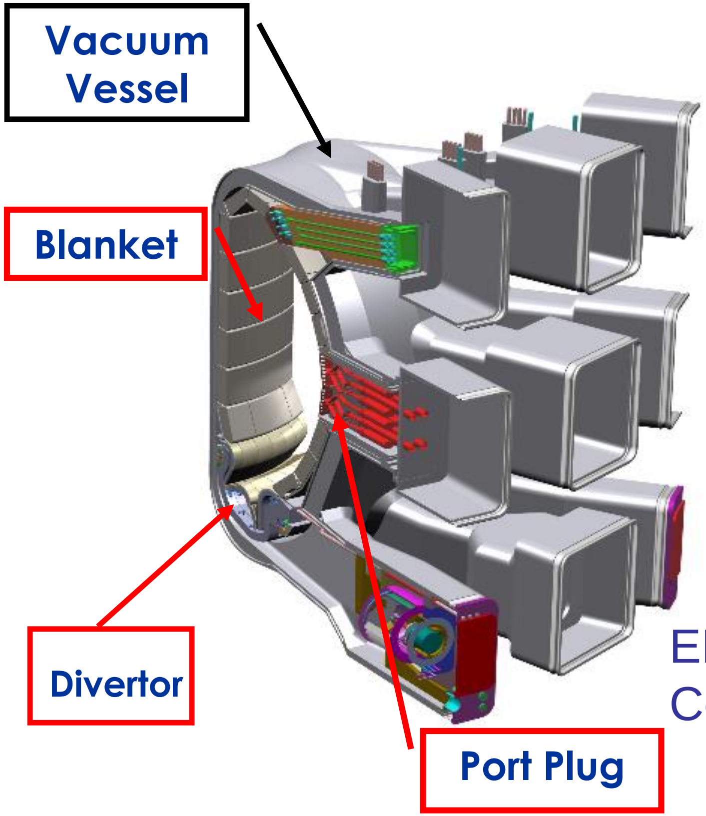


CS Coil

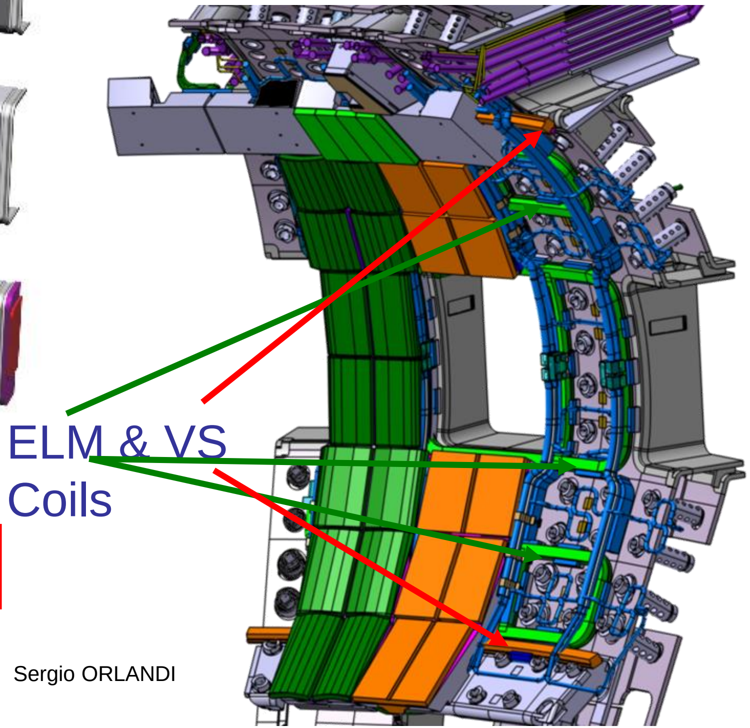


PF & CC Coils

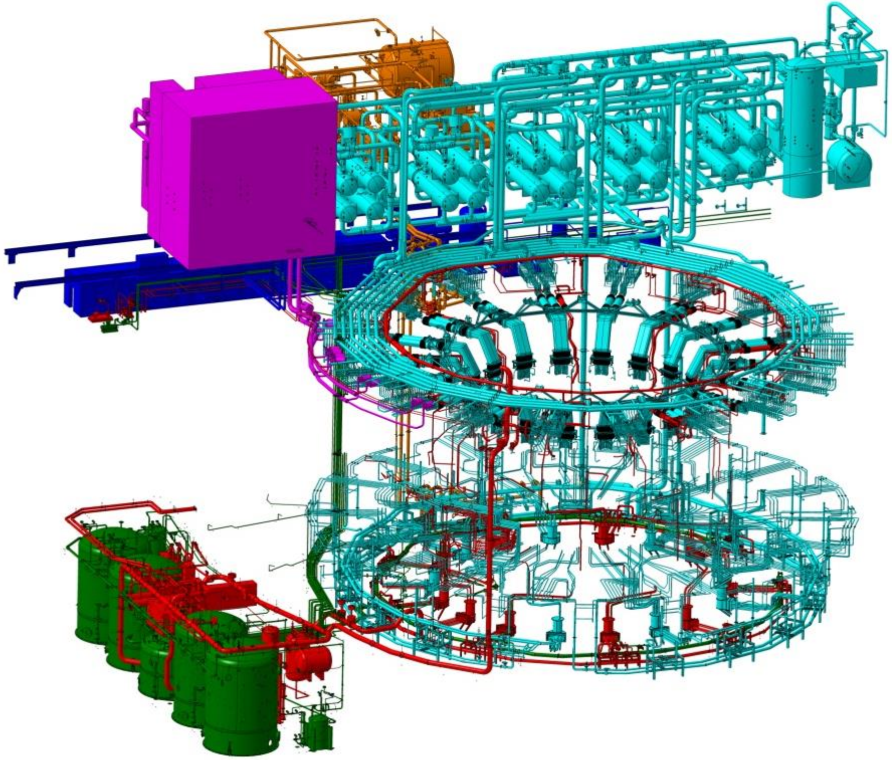
ITER Vacuum Vessel and Blanket



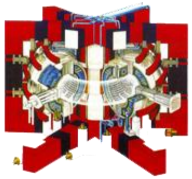
- The vacuum vessel is lined by modular removable components: **blanket modules, divertor cassettes, ELM / VS coils** and **port plugs** (heating antennae, diagnostics and test blanket modules)



ITER – Circulating Water System

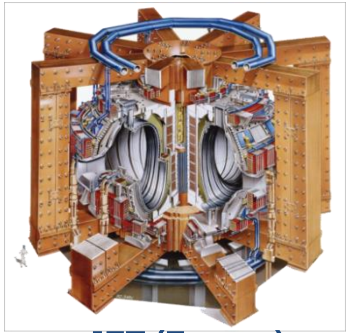


Size Matters



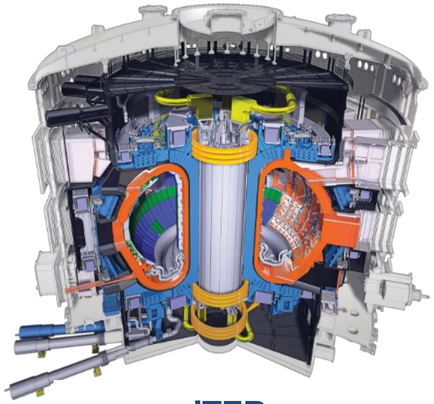
Tore Supra (Fr/EU)

Volume	25 m^3
Power	~0
Heating	~15 MW
Pulse	~400 s
Current	~1.7 MA



JET (Europe)

Volume	80 m^3
Power	~16 MW
Heating	~23 MW
Pulse	~30 s
Current	~5-7 MA



ITER

Volume	830 m^3
Power	~500 MW
Heating	~50 MW
Pulse	~400 s
Current	~15 MA

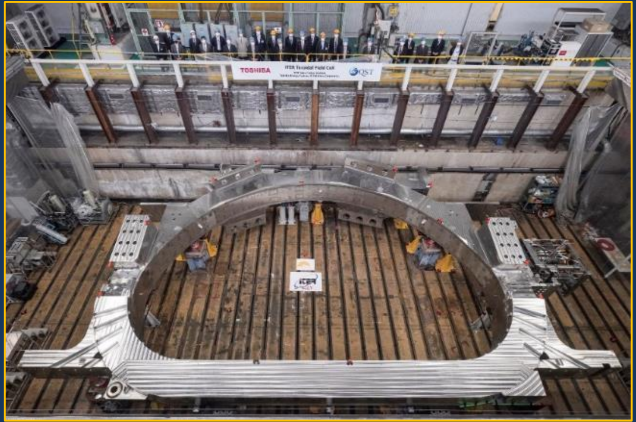
ITER Plant – Where we are

~ 85% of total manufacturing finalized

Five vacuum vessel sectors are under fabrication in Italy.
Completion rates range from 78% to 99%

Two vacuum vessel sectors delivered – a third one on its way to ITER; rate of completion of the remaining one : 98%

~ 85% of total manufacturing finalized



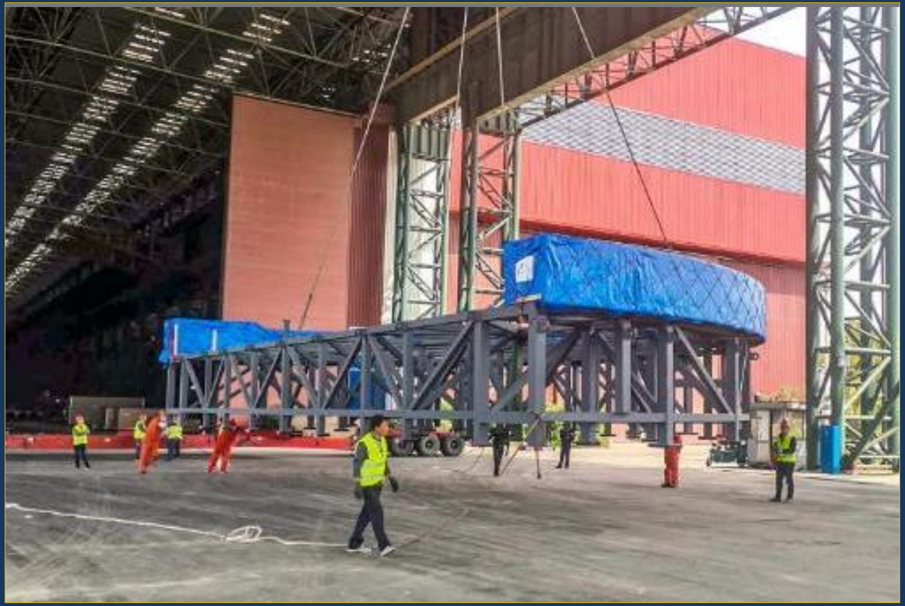
4 TF coils delivered, 1 en route

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

With the recent completion of the top lid, the Cryostat is now finalized. 2 sections out of 4 already installed.

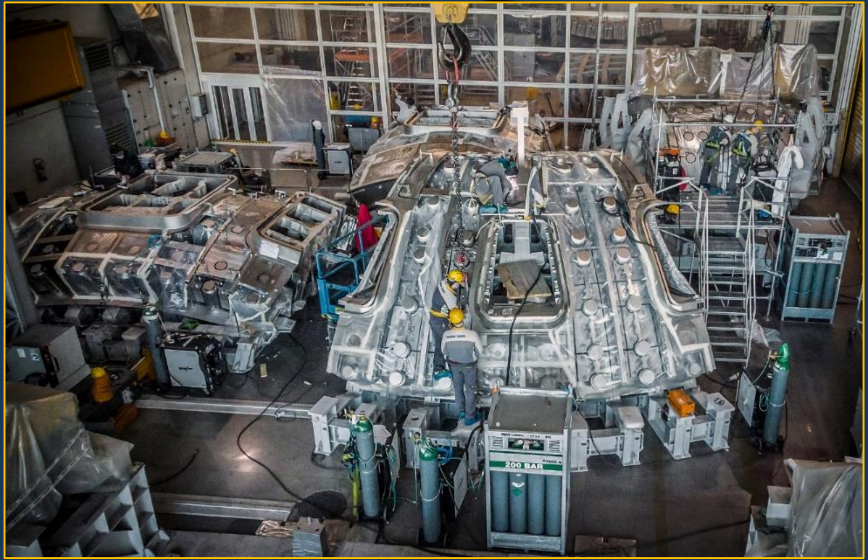
~ 85% of total manufacturing finalized

Two central solenoid modules delivered – 5 others (4 + 1 spare) nearing end of fabrication



Ongoing delivery of more than 1,600 tonnes of equipment for the magnet feeders

Italy's contributions

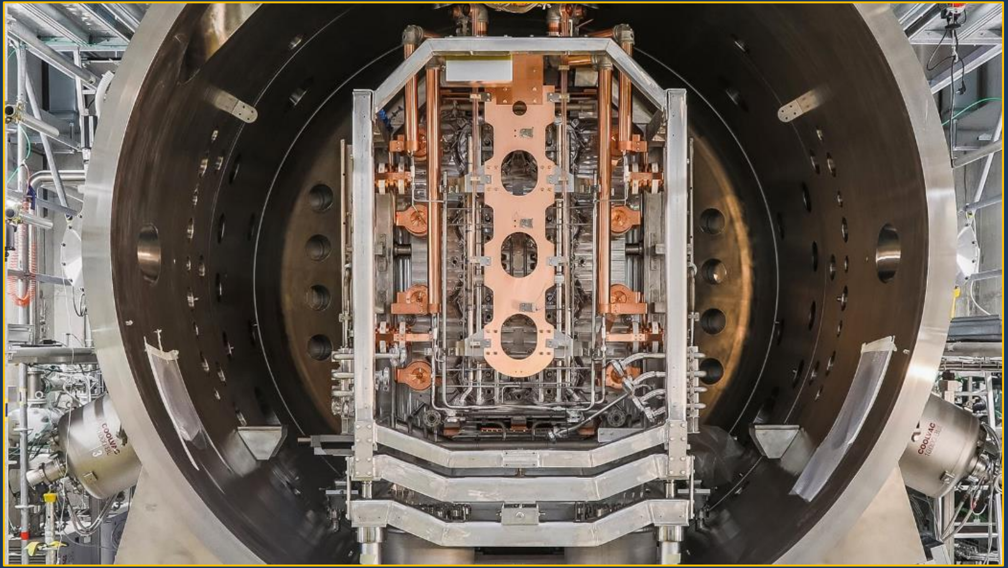


The 5 vacuum vessel sectors (out of a total 9) procured by Europe are manufactured by the AMW consortium (Ansaldo Nucleare, Mangiarotti, Walter Tosto) supported by an extended network of sub-suppliers located in France, Germany and Spain. First delivery expected in May 2022.

Europe is responsible for procuring 10 toroidal field coils out of 18 (+ one spare). The massive component is finalized in the European winding facility in La Spezia. ENEA, Tratos Cavi, Criotec, SIMIC, ASG Superconductors are among the Italian companies contributing to their fabrication. Seven toroidal field coils have already been delivered to ITER.

PRIMA test facility

Hosted by Consorzio RFX in Padua, two test-beds will contribute to the challenging physics and technology issues of neutral beam heating and validate concepts before the actual system is built at ITER



SPIDER is the world's most powerful negative ion source. It is manufactured by A European consortium consisting of Thales (France), CECOM Srl (Italy), Galvano-T GmbH (Germany) and E.Zanon SpA (Italy).

MITICA is the 1:1-scale neutral beam injector prototype for ITER. First integrated tests on the power supply system were carried out successfully in Nov. 2020

ITER Project – Manufacturing Progress

Vacuum Vessel Sector Assembly

Cryoline production

Magnet clamp fabrication

Insertion in TF cases

High heat flux testing

CS supports

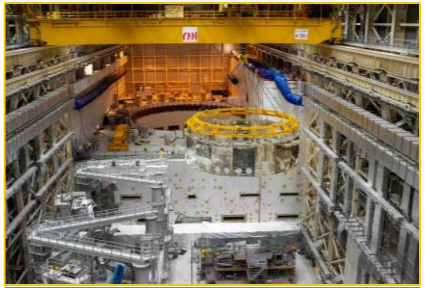
PF Coil #5

ITER Project – Assembly Progress

85% of total manufacturing finalized

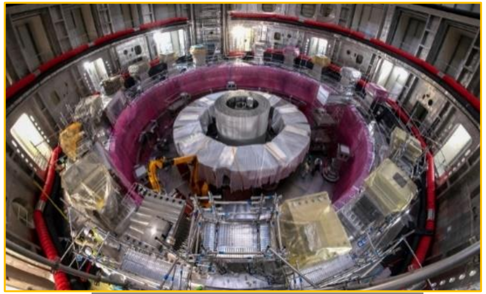
26-27 May 2020 – Cryostat Base

31 Aug 2020 - Cryostat Lower Cylinder



14 Jan 2021- Lower Cylinder Thermal Shield

8 September 2021 – Test positioning of radial beam



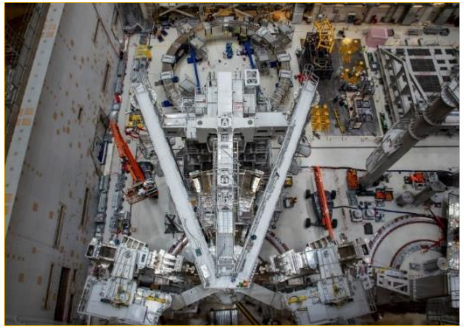
21 April 2021 – Poloidal field coil # 6

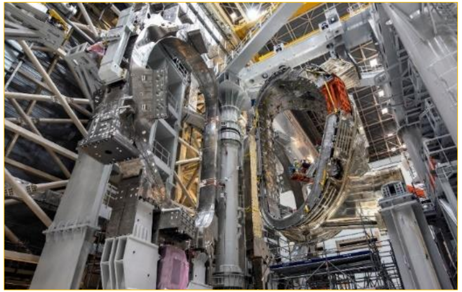
16 Sept 2021 – Poloidal field coil # 5

ITER Project – Progress

85% of total manufacturing finalized

Toward the first « sub-assembly »





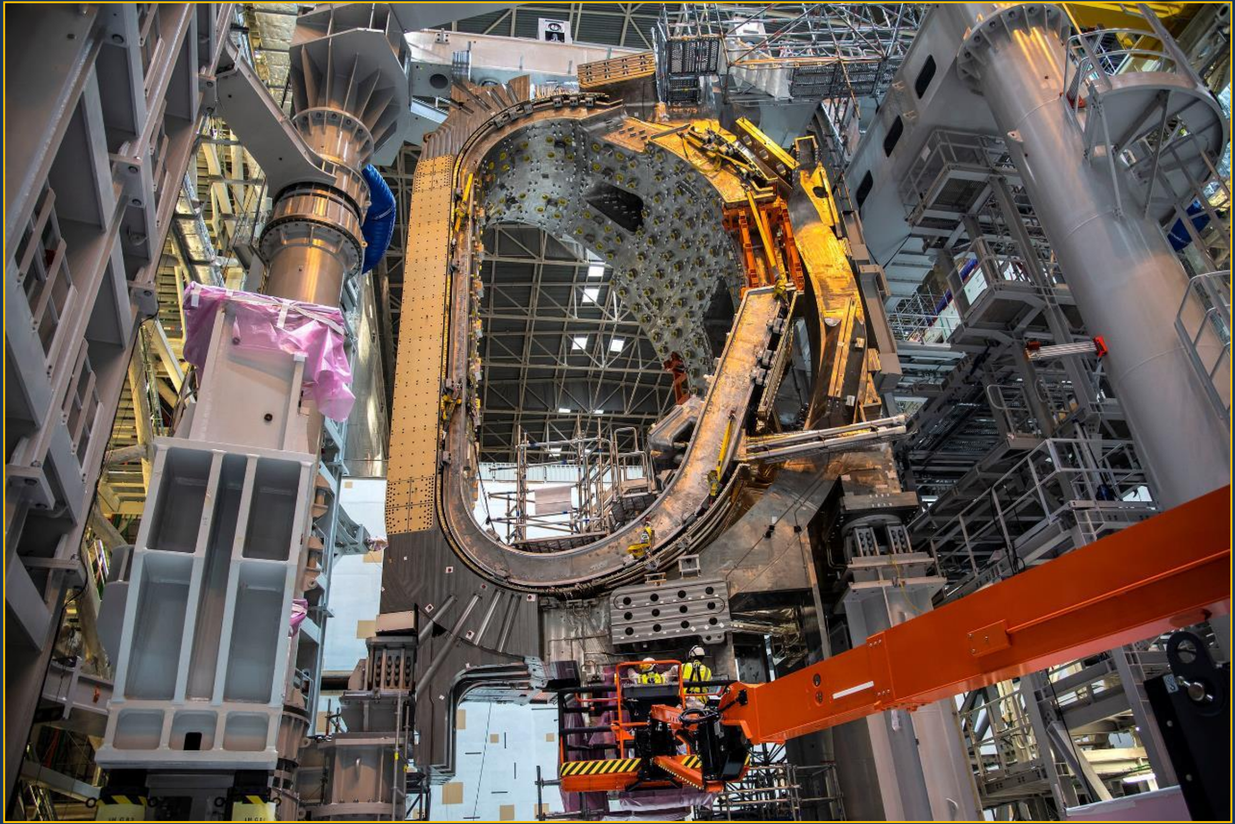
« Sub-assemblies » are the building bricks of the Tokamak's torus. They comprise one 40° vacuum vessel sector, two toroidal field coils and the corresponding thermal shield panels, and weigh in excess of 1,250 tonnes.

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.

First « sub-assembly » finalized



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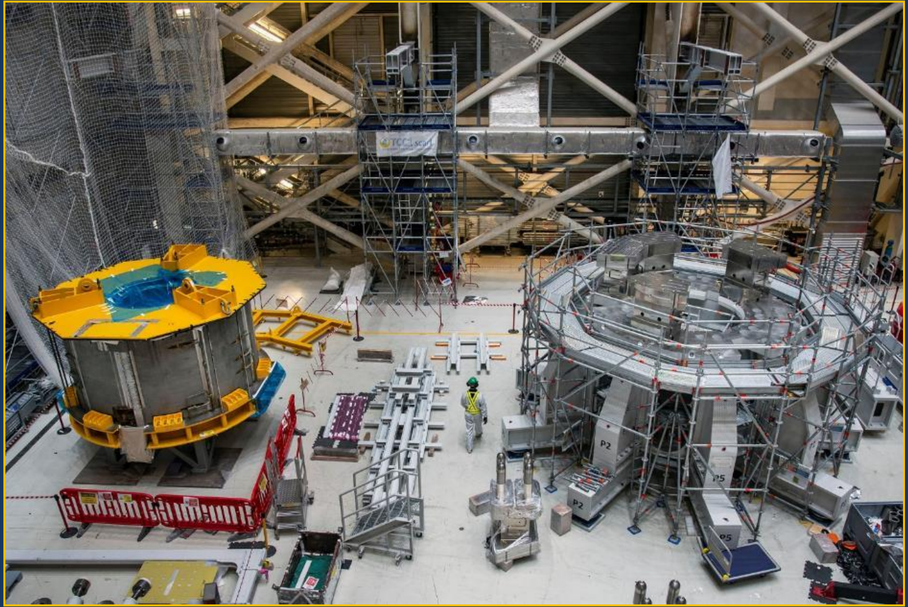
Nine pre-assemblies are required to close the torus.

Equipment phase begins on 1st Central solenoid module

10 Feb 2022 – 1st Central solenoid module (CSM) lifts



28 Feb 2022 – CSM on « table »; assembly platform readied

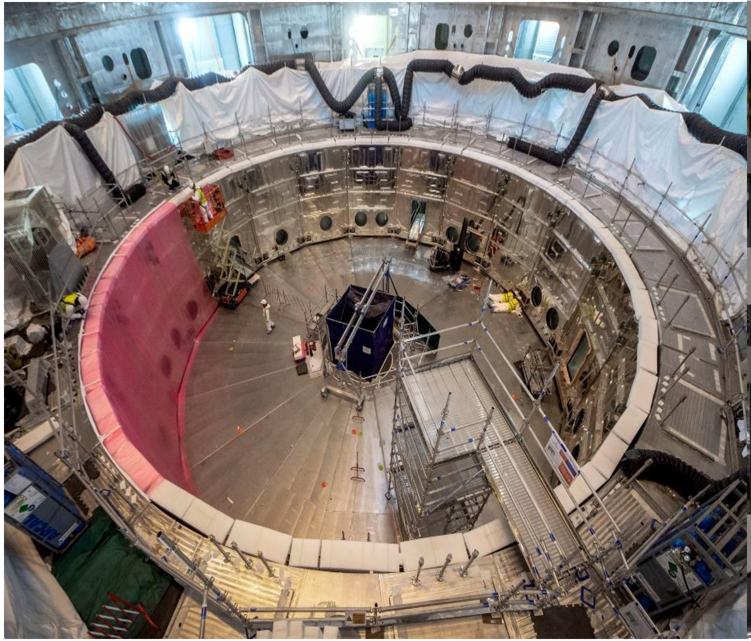
Manufacturing Updating

TOKAMAK ASSEMBLY HALL

Vacuum Vessel Sector #6 (September 2020)

Assembly Hall (April 2021)

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

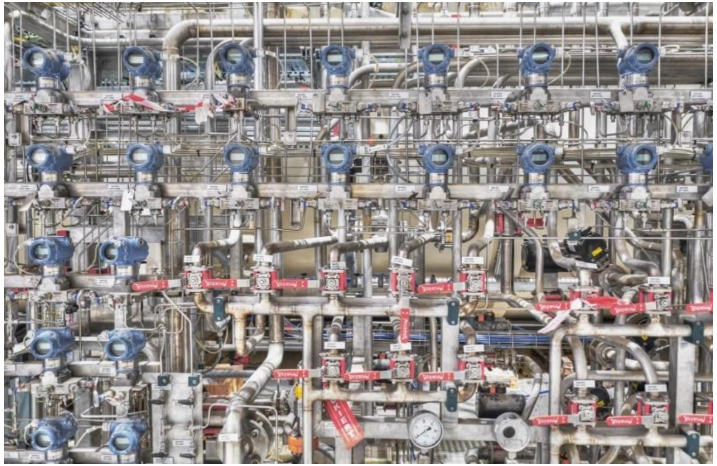
FIELD COILS - WINDING FACILITY

Balance of plant
Towards commissioning

Cryoplant:
5 000 tonnes of equipement

Manufacturing Updating

CRYOPLANT



Manufacturing Updating

POWER CONVERSION PLANT

Busbars

Manufacturing Updating

POWER CONVERSION PLANT – B33 (Completed with supports, busbars, links, plates, Cooling Water Hoses and Junction Boxes)

Cooperation agreements

- University of Genoa (Dept. Of Electrical, Electronics, telecommunications Engineering and Naval architecture)
- University of Pisa (Dept. Of Civil and Industrial Engineering)
- University of Rome – Sapienza
- Università degli studi di Palermo (UNIPA)
- Politecnico di Milano
- Politecnico di Torino (PoliTo)

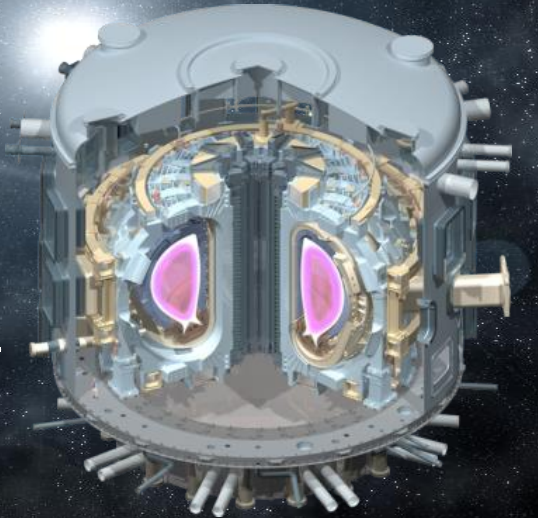
ITER Project - Progress

What to do in the next Years – Summary

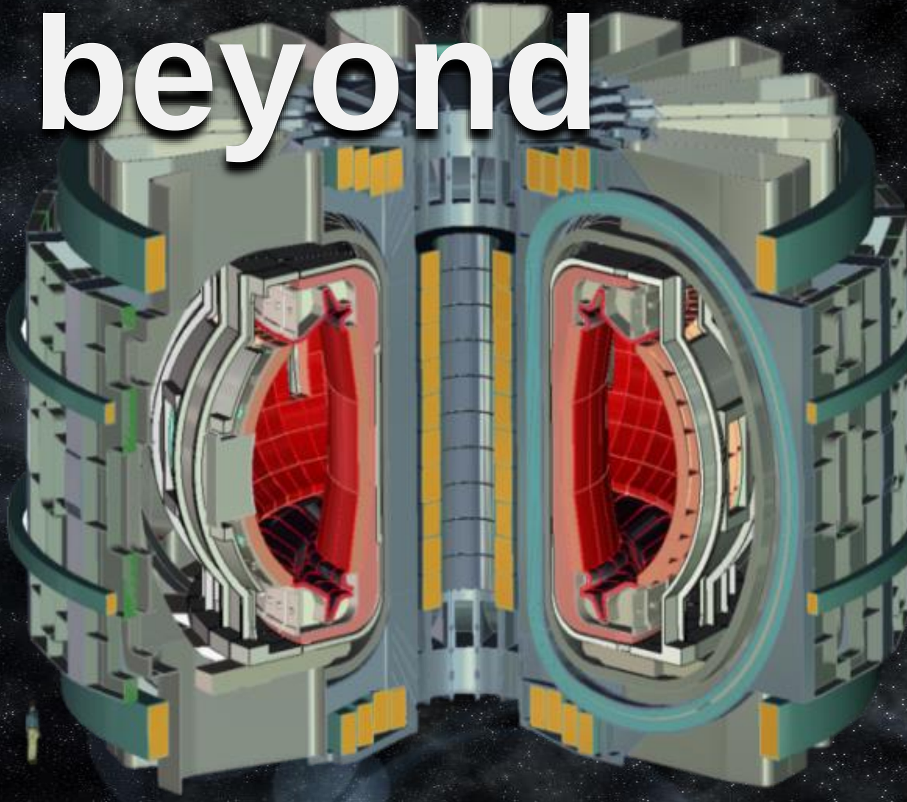
- To assure on time delivery of in kind contribution for Machine assembly and Systems installation
- To assure progressive completion of systems commissioning as the BOP installation is completed (Electrical power Distribution, Coil Power Supply, Component Cooling Water, Cryogenic System, Chilled Water 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 and beyond

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



ITER
800 m3
~ 500 MW th

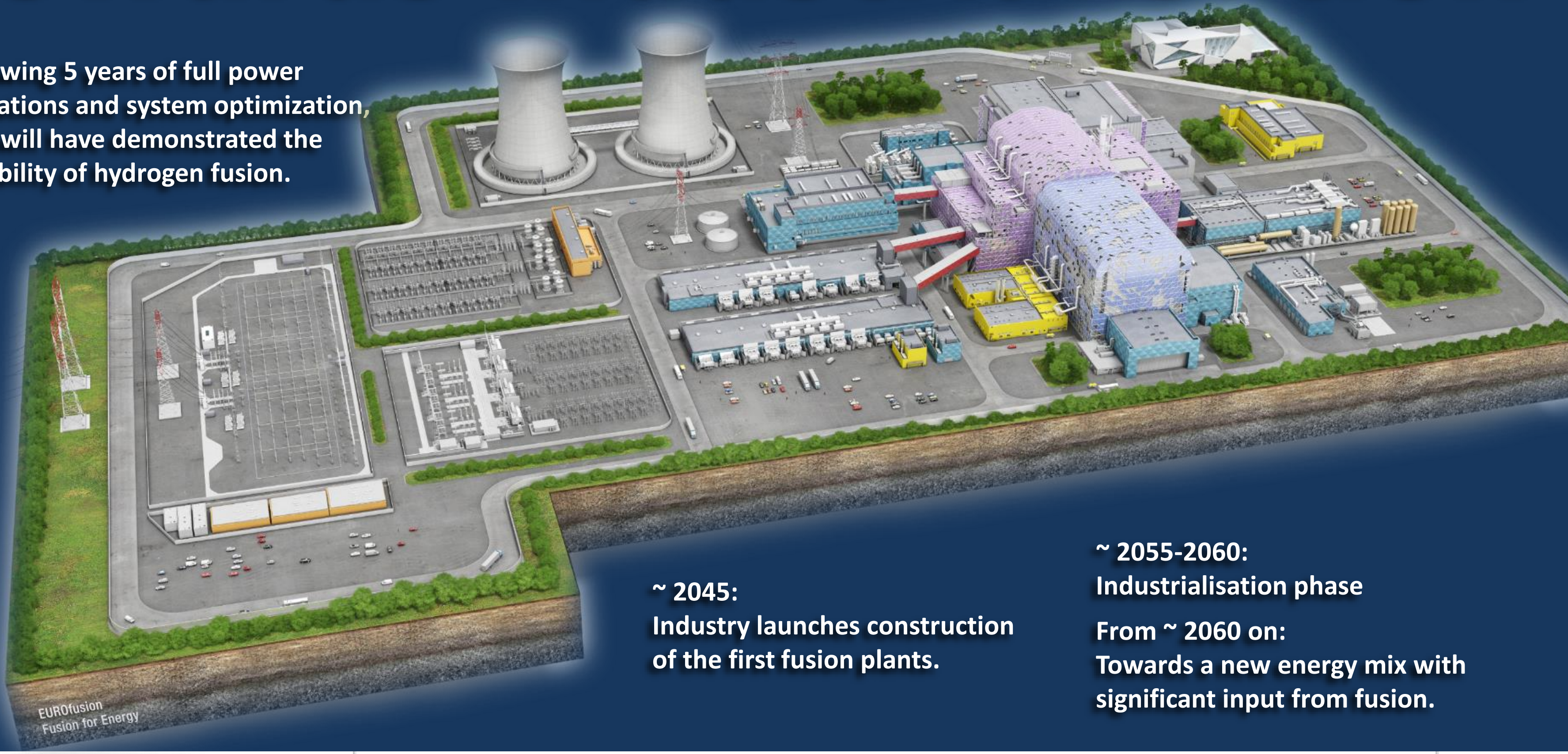


DEMO, next-step machine
~ 500 MWe, 1 200 MWth

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.

Private initiatives

Recent development of private initiatives, essentially in the anglo-saxon world and sometimes in collaboration with academia add credibility to the fusion option.

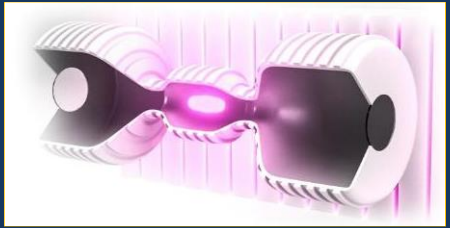
By exploring new and sometimes original avenues, some of these start-ups contribute to fundamental knowledge and technical developement.

ITER and the fusion community are attentive to these developments, as they can benefit to fusion as a whole.

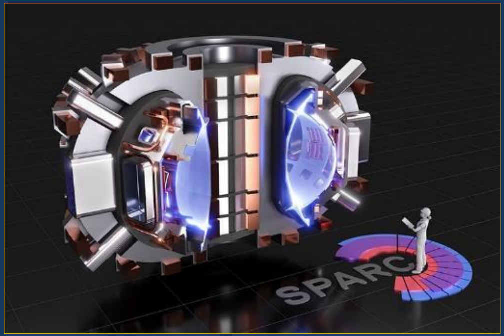
However, the laws of physics are the same for all, and some projects and announcements lack credibility

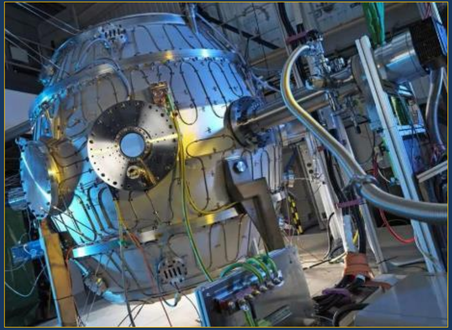
General Fusion, Canada

Helion Energy, US



Commonwealth Technologies, US





TAE Technologies, US

Tokamak Energy, UK

Stato e prospettive della fusione nucleare

Tokamaks are not the only fusion reactors being tried.

- Another type of reactor uses lasers to heat and compress a hydrogen fuel to initiate fusion.
- In August 2021, one such device at the National Ignition Facility, at the Lawrence Livermore National Laboratory in California, generated 1,35 Megajoules of energy.
- This record-breaking figure brings fusion power a step closer to net energy gain, but most hopes are still pinned on tokamak reactors rather than lasers.
- In June 2021, China's Experimental Advanced Superconducting Tokamak (EAST) reactor maintained a plasma for 101 seconds at 120,000,000 °C.
- Before that, the record was 20 seconds. Ultimately, a fusion reactor would need to sustain the plasma indefinitely – or at least for eight-hour 'pulses' during periods of peak electricity demand.

Stato e prospettive della fusione nucleare

United Kingdom strategy for Nuclear Fusion

- The UK is widely recognized as a world leader in the most promising fusion technologies. In the UK, fusion research programs have supported over £ 1 billion of UK economic activity over the past decade.
- Building on decades of study at unique research facilities worldwide, the UK government has launched the world-leading STEP (Spherical Tokamak for Energy Production) program, to build a prototype fusion power plant in the UK by 2040.
- In 2020, the total electricity generated by the UK was 312.8TWh, of which 59% was generated by low-carbon technologies.
- By 2050, due to the increasing use of electric vehicles and electric heating, coupled with population growth, the UK's total electricity demand is expected to rise to between 570-630TWh - roughly double the current electricity demand.
- This UK trend will develop globally due to the electrification of the world economy. As part of its net zero goals, the UK government is aiming for a fully decarbonized energy system in the UK.
- The UK's merger ambitions have been set out in the Ten Point Plan for a Green Industrial Revolution and the 2020 Energy White Paper. The UK Government's Fusion Strategy now defines these ambitions in more detail.

Stato e prospettive della fusione nucleare

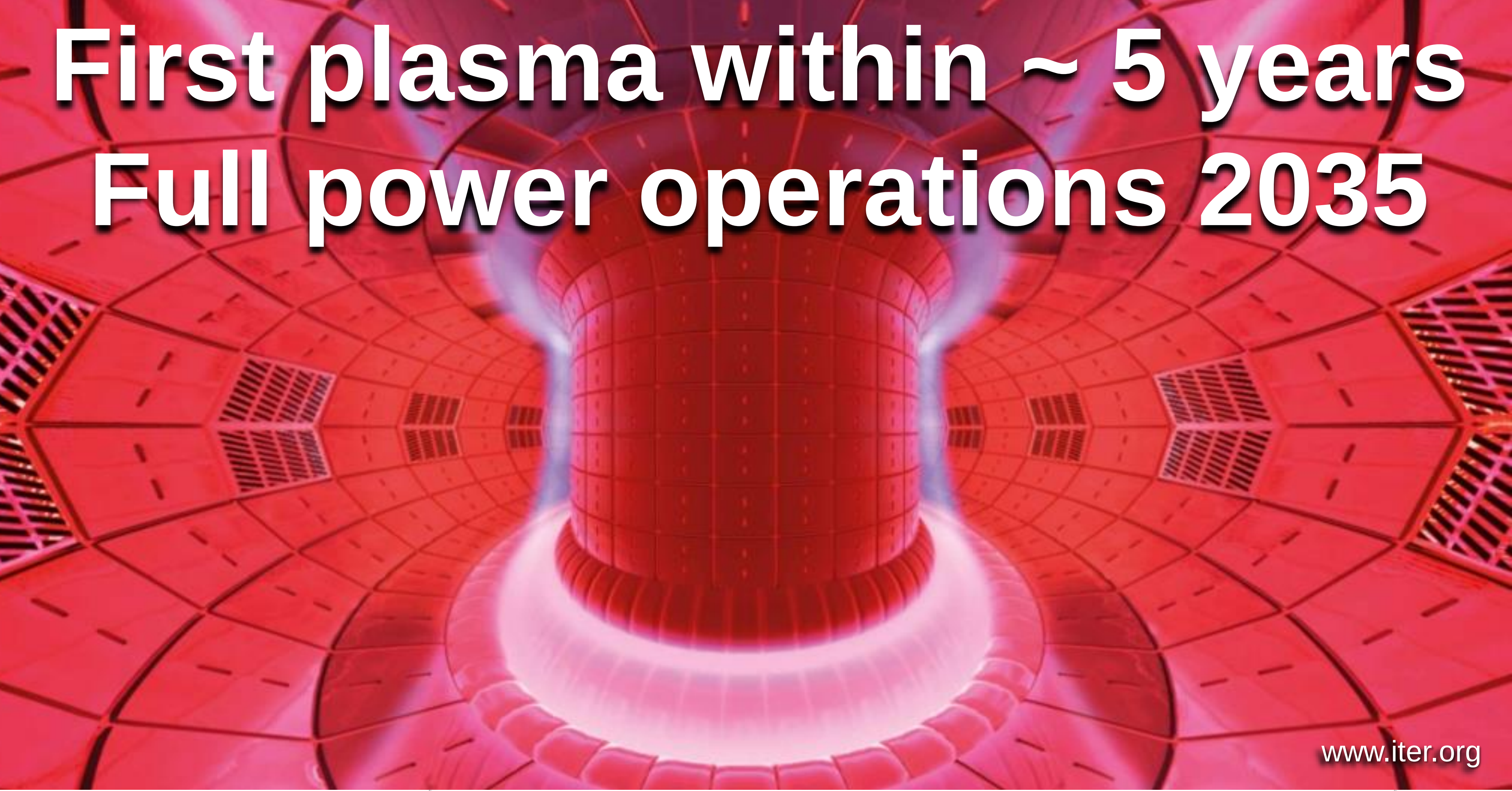
Summary

- 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.

First plasma within ~ 5 years
Full power operations 2035



Thank you for your attention