Stato e prospettive della fusione nucleare

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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.

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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.

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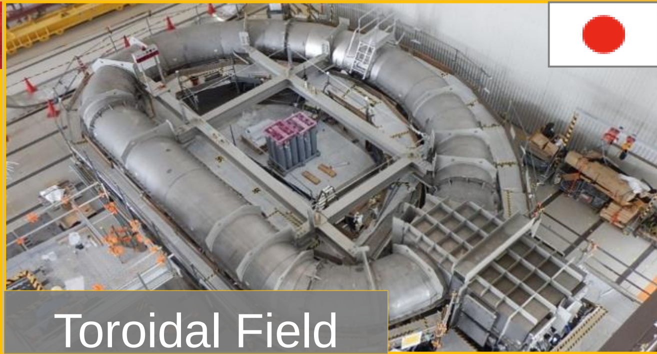
ITER Project – Manufacturing Progress

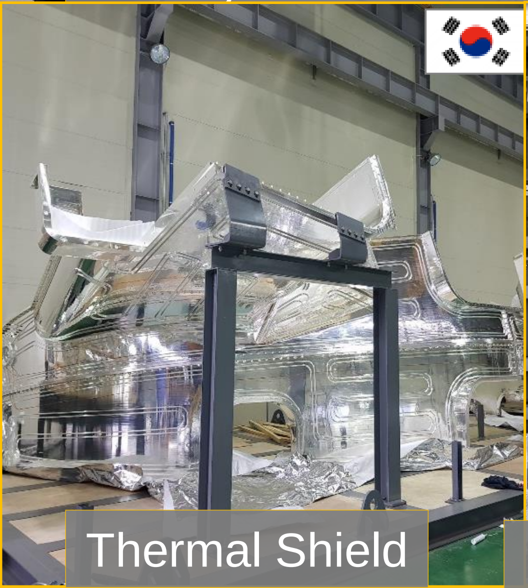
Total average component manufacturing through First Plasma is >65% complete.

Cryostat Lower

PF Coil #6



Toroidal Field



Thermal Shield

Central Solenoid

Port Stub Extension

Divertor Cassette Prototype

ITER Project – Manufacturing Progress

Vacuum Vessel Sector Assembly

Cryoline production

Magnet clamp fabrication

Insertion in TF cases

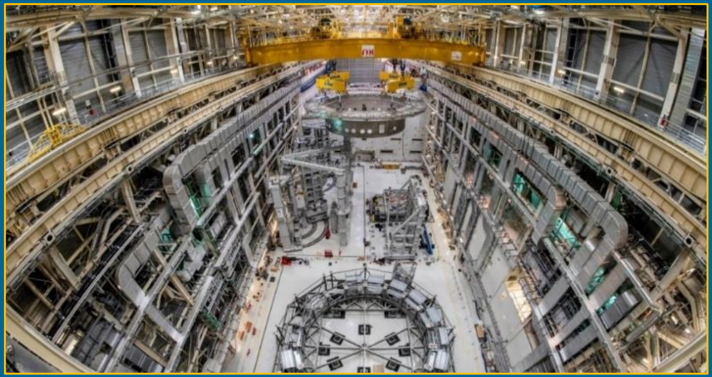
High heat flux testing

CS supports

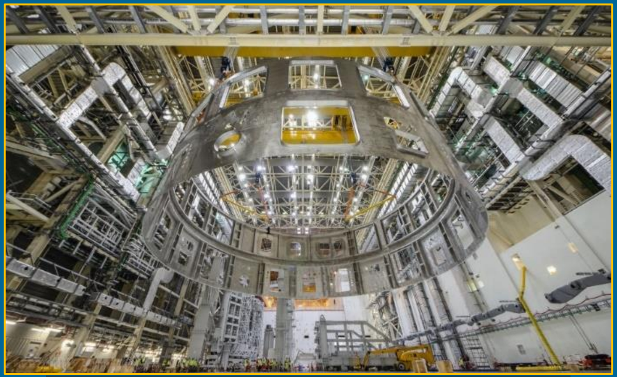
PF Coil #5

ITER Project – Assembly Progress

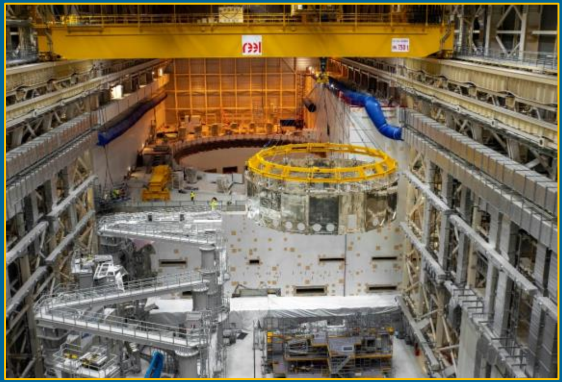
85% of total manufacturing finalized



26-27 May 2020 – Cryostat Base

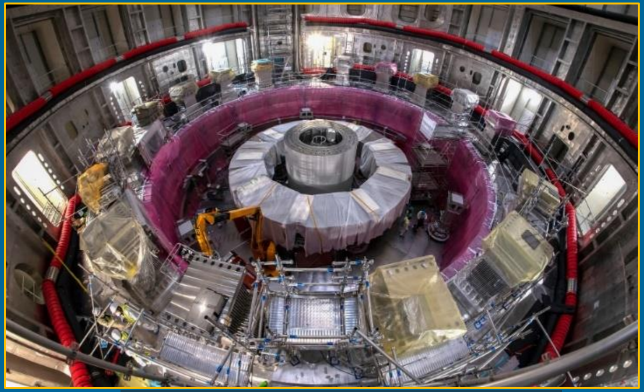


31 Aug 2020 - Cryostat Lower Cylinder



14 Jan 2021- Lower Cylinder Thermal Shield

8 September 2021 – Test positioning of radial beam

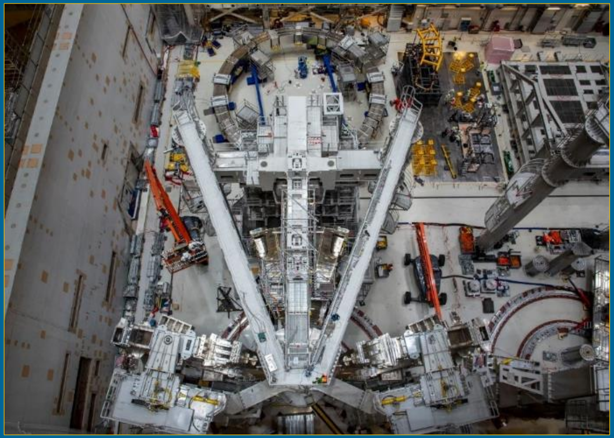


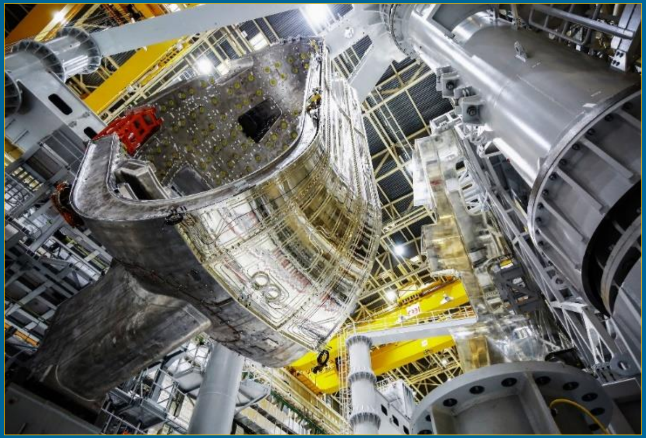
21 April 2021 – Poloidal field coil # 6

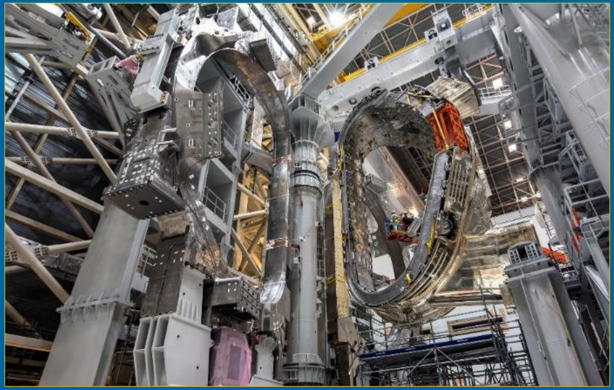
16 Sept 2021 – Poloidal field coil # 5

ITER Project - Progress
85% of total manufacturing finalized

Toward the first « sub-assembly »







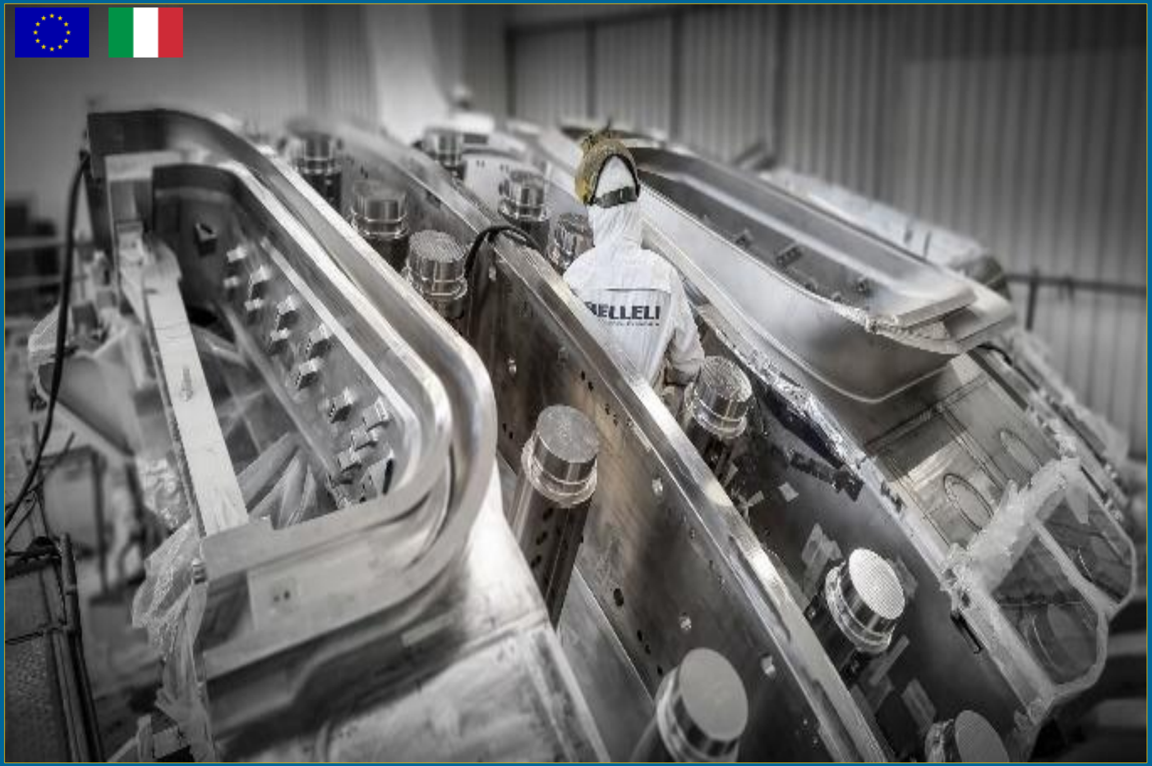
« Sub-assemblies » are the building bricks of the Tokamak's torus. They comprise one 40° vacuum vessel sector, two toroidal field coils and the corresponding thermal shield panels, and weigh in excess of 1,250 tonnes.

Nine pre-assemblies are required to close the torus.

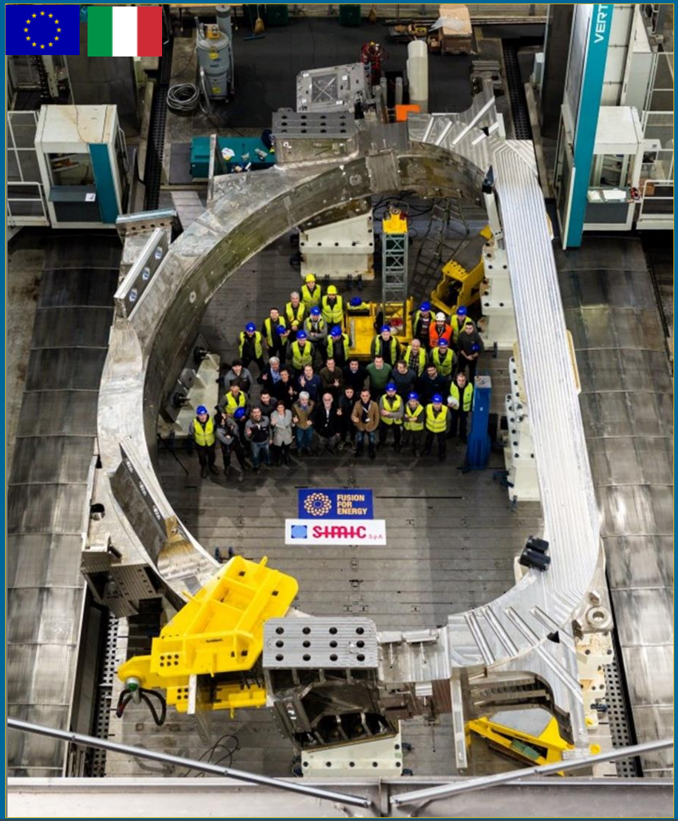
Final alignment was performed on 17 September within extremely tight tolerances: radial direction 0.14 mm; toroidal direction 0.25 mm; vertical direction 0.58 mm.

ITER Project – Progress

85% of total manufacturing finalized



Five vacuum vessel sectors are under fabrication in Italy (Ansaldo Nucleare, Mangiarotti, Walter Tosto). Completion rates range from 76 to 97%



Ten toroidal field coils are manufactured in Italy (ASG Superconductors, SIMIC). Five have been delivered. One is expected in the coming weeks.

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.

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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

A real game-changer for tokamaks has been the magnets used to produce the magnetic field.

"*We know how to make magnets that generate a very high magnetic field*
from copper or other kinds of metal,
but you would pay a fortune for the electricity.
*It would not be a net energy gain from the pla*nt,"
(Dr. Tim Luce, ITER- Operation)

- The solution is to use high-temperature, superconducting magnets made from superconducting wire, or 'tape', that has no electrical resistance.
- These magnets can create intense magnetic fields and do not lose energy as heat.

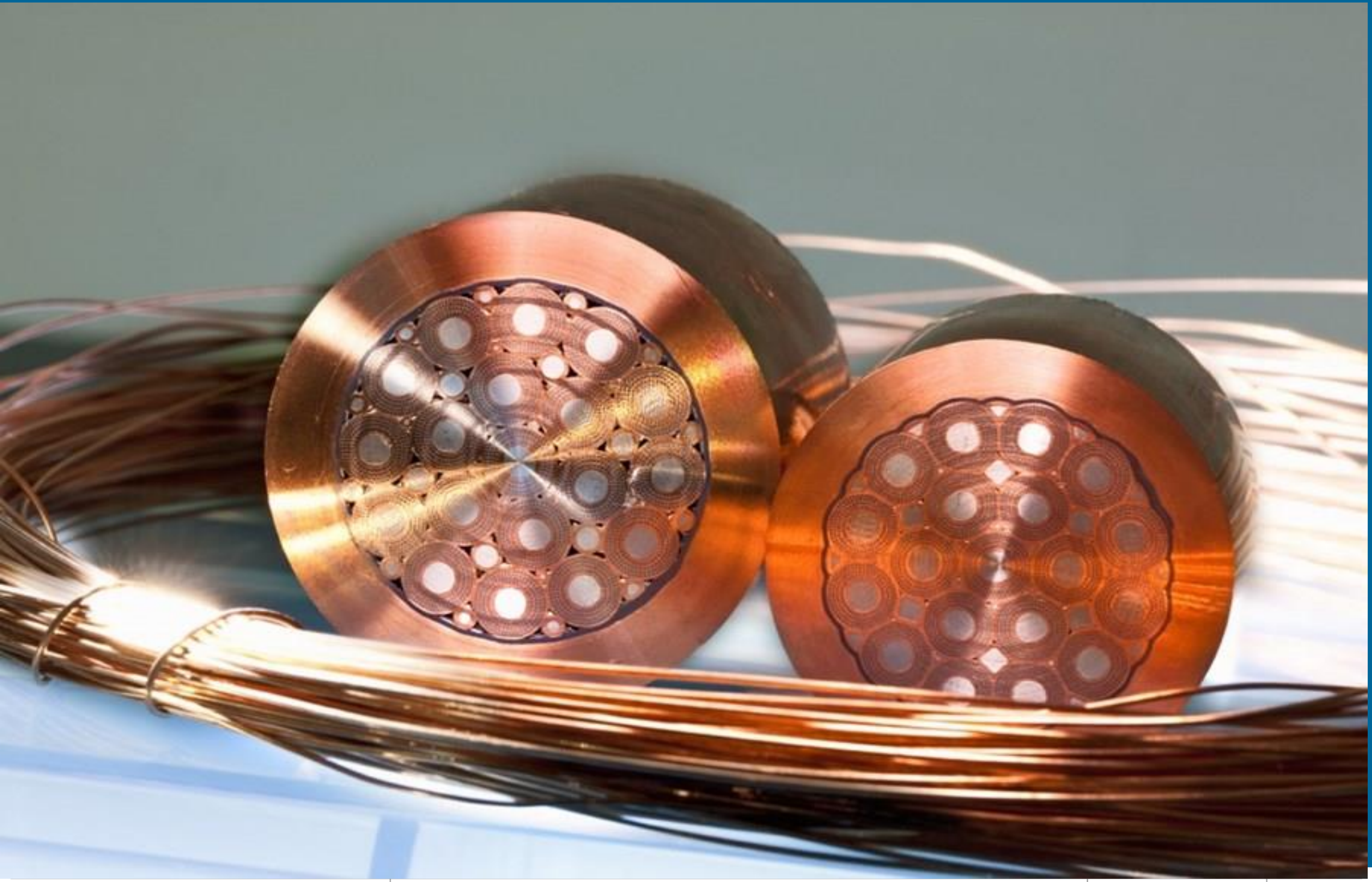
"High temperature superconductivity has been known about for 35 years.
But the manufacturing capability to make tape in the lengths
that would be required to make a reasonable fusion coil
has just recently been developed,"
(Dr. Tim Luce, ITER- Operation)

Stato e prospettive della fusione nucleare

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.

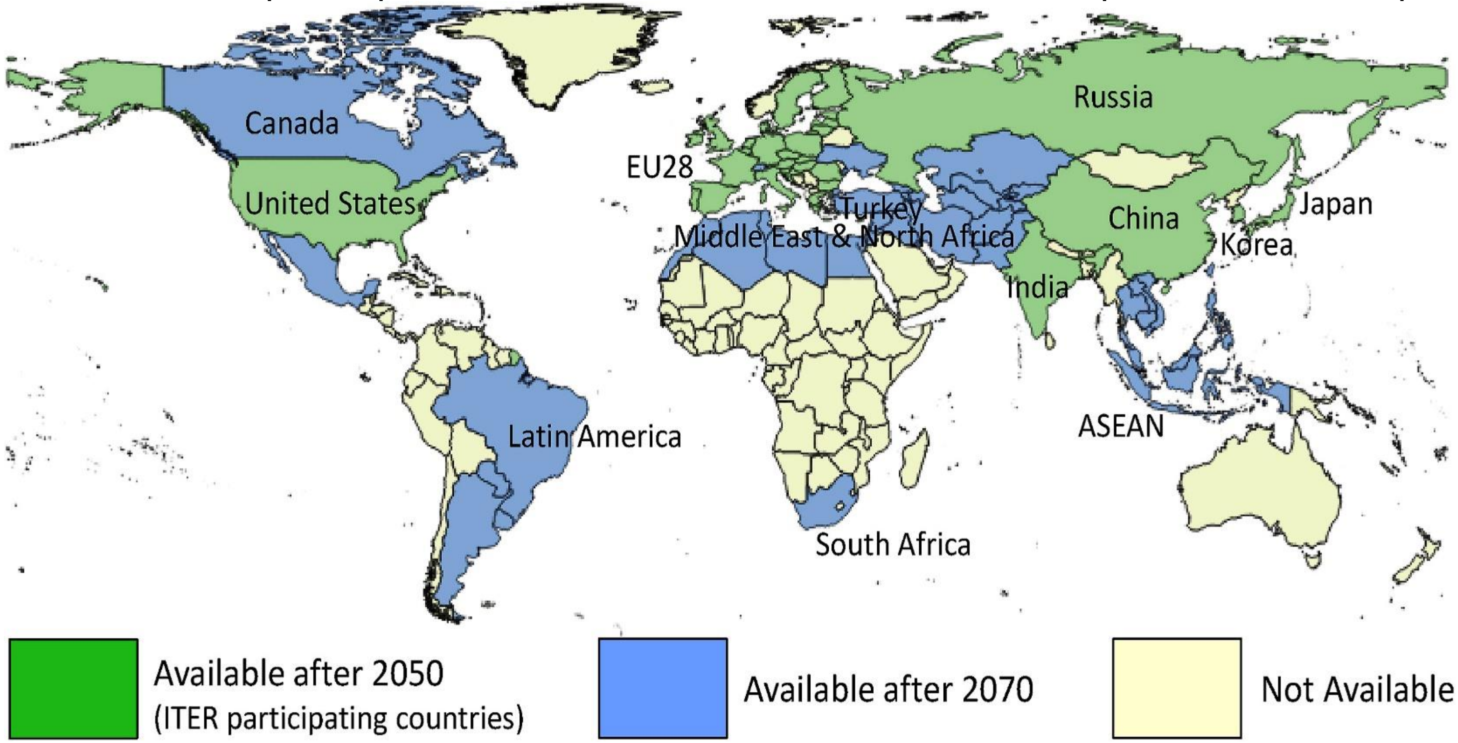
Superconducting Cables



Stato e prospettive della fusione nucleare

Available regions of fusion energy are showed in slide 10.

- The paper assumed maximum capacity expansion constraint based on historical experience of nuclear fission capacity expansion.
- There could be two major factors, which affect capacity expansion rate of fusion: initial loading of tritium and location of fusion power plants.
- This is the reason why countries like Canada, known for the large investments that they are operating on nuclear fusion, is showed in blue.
- Since the more fusion power plants exist, the more excess tritium can be produced for new power plants.



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.

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United Kingdom strategy for Nuclear Fusion

The UK strategy has the following targets:

- To demonstrate the commercial viability of fusion by building a prototype fusion power plant in the UK that is capable of putting energy on the grid.
- For the UK to build a world-leading melting industry capable of exporting melting technology around the world in the following decades.
- The JET experiments were instrumental in the design and construction of ITER, its international successor, which is under construction in France. ITER aims to demonstrate for the first time more energy produced by fusion than is needed to heat the fuel. Participation in the € 20 billion project gives the UK access to the intellectual property and business opportunities that support the development of the UK's fusion supply chain and the UK's national fusion program.
- In the Trade and Cooperation Agreement (TCA) with the EU agreed at the end of 2020, the UK announced its intention to associate the EU program supporting and funding the Euratom research and training program (Euratom) with the fusion energy research at European level.
- In addition to supporting the continued scientific exploitation of JET and preparation for ITER, the EUROfusion consortium is designing a demonstration fusion power plant called DEMO based on the ITER concept.
- The UK offers many leadership roles and is a major contributor to the DEMO program. DEMO, while being a different technological approach to STEP, has many synergies and commonalities in technical challenges, so UK participation is mutually beneficial.

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MAST UPGRADE

UKAEA's MAST-U (Mega-Amp Spherical Tokamak - Upgrade) is an innovative type of fusion plant designed to study the feasibility of fusion power generation at scale and cost. The original MAST experiment ran from 2000 to 2013. Its impressive performance led to a major upgrade, which was completed in 2020. Based at the Culham Center for Fusion Energy, MAST-U represents the largest investment in a single science experiment in the UK for decades. In 2021 MAST-U is testing a unique system that minimizes hot gas exhaust heat from fusion fuels - a key challenge for the first fusion power plants. MAST-U results will play a key role in the Spherical Tokamak for Energy Production (STEP) program.

STEP

The STEP program is going to design, develop and build a prototype fusion power plant that feeds energy into the grid by 2040. STEP will play an important role in demonstrating the commercial viability of fusion by integrating and managing industrial-scale fusion systems in a single power generation facility.

The first phase of the program is to produce a concept design by 2024.

It will be a spherical tokamak, connected to the national grid and producing net energy, although it is not expected to be a commercially operational plant at this stage

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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.

Stato e prospettive della fusione nucleare

- The Conference of Parties (COP) 26 saw the participation of 90% of the countries, including Brazil, which declared its commitment to reduce its emissions by 50%.
- Looking at energy production, for the transition to be possible by the middle of the century there is a need to develop technologies that are not yet fully available. It is time to work.
- Renewable energies will have to be implemented as far as possible without forgetting that each source, in order to be considered the main one, needs to present itself as ´safe, abundant and reliable´.
- At the same time, hydroelectricity will find a great development in the coming years, especially thanks to the investments that China is dedicating to this energy, defined by many as the only renewable energy capable of providing continuous and uninterrupted energy.
- The development of technologies in favour of Biofuels, Biomass or techniques such as Waste to Fuel will be equally important. Currently, it is mainly used to produce compost for agriculture and, to a lesser extent, biogas. An increasingly important sector, but with a rising cost for the community.
- Hydrogen, especially green, will be a vector that could play an important role in the years to come, although it is still difficult to define its contours well due to the technological developments it needs to reduce costs.

Stato e prospettive della fusione nucleare

- The energy transition can be the right opportunity to overcome the ideological obstacles linked to the only energy with zero emissions that can act as a baseload for the electricity system: nuclear energy.

- Nuclear power has a considerable advantage: it is able to supply large quantities of energy in a constant (24 hours a day) and controllable way. The same can also be done by hydroelectric and geothermal plants, which however require specific territorial characteristics that not all countries have.

- Most of the technologies that today provide baseload are fossil fuel power plants that will have to be gradually replaced to achieve the emission reduction target. It would be natural to think that renewable sources such as wind and solar can be good substitutes. Betting everything on them, however, would entail considerable technical difficulties: since they are variable and scarcely predictable sources (the wind does not always blow, the sun is not there at night and sometimes the sky is cloudy), they should be accompanied by numerous storage systems for the energy and / or complementary technologies capable of compensating for a possible drop in production, quickly and without producing CO2.

Stato e prospettive della fusione nucleare

- An energy system with a high amount of variable renewable energy would considerably increase energy costs for individual citizens and industries. If the goal is to reduce emissions, where large amounts of hydroelectric and geothermal energy are not available, nuclear is therefore one of the most efficient solutions to replace fossil fuel power plants in the production of energy suitable for baseload.

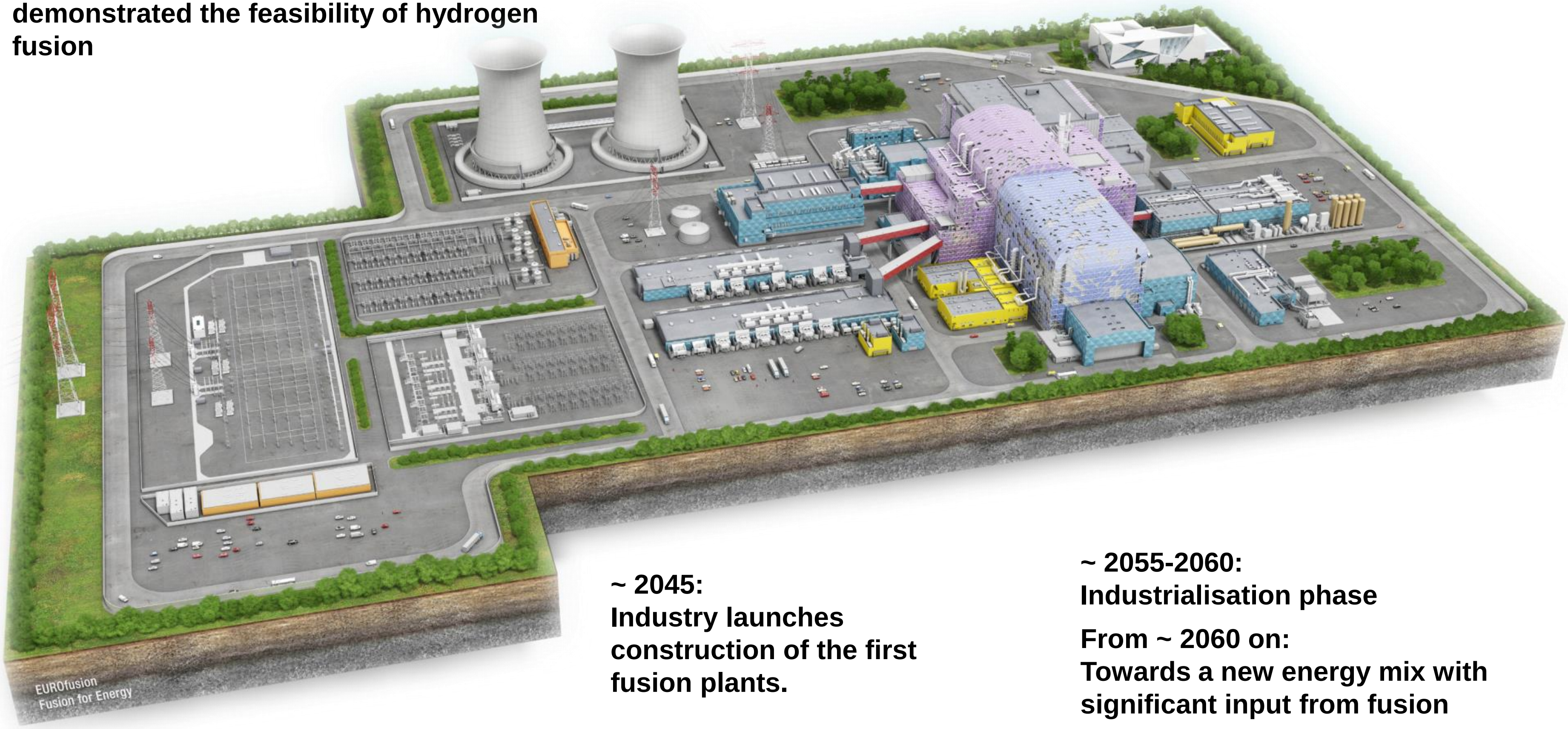
- Nuclear energy guarantees the stability of the electricity grids that other renewable sources are unlikely to be able to offer, and also makes it possible to reduce the dependence of a given country on the energy imports necessary to meet its energy needs (e.g. imports of electricity from neighbouring countries , fossil fuels from third countries, etc.).

- Nuclear energy sources are integrated fusion and fission technologies. In the frame of fission technologies attention is paid at Small Modular Reactors good for energy production for local / private needs integrating Generation III+ and IV with passive shutdown mechanism up to subcritical reactors at Thorium coupling a Fission Subcritical Reactor with Cyclotron working also as waste transmuter.

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

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