Industry Workshop on Cryogenics in Big Science

Cyogenics applications in aeroespace

SUPRASYS

iFAST

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Location

- SUPRASYS is located in Bilbao, Spain.

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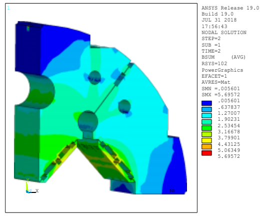
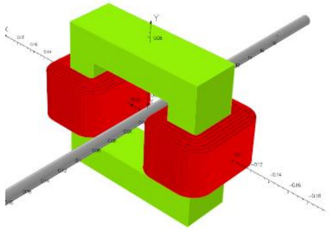
Technology based

Electromagnetic systems

- Superconducting, resistive and permanent magnets
- Kickers & septa

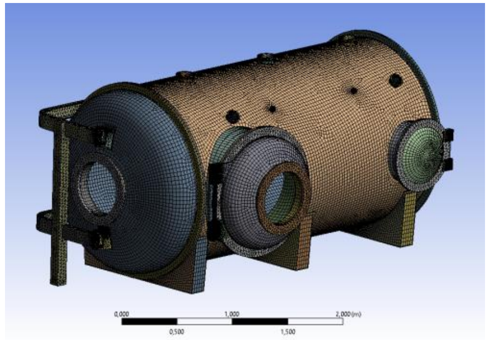




Multiphysics analysis

- Thermal, structural, electromagnetics and CFD

- ANSYS™
- OPERA™.
- CST Studio™
- OpenFOAM®



Cryogenics, Vacuum & Superconductivity

- Cryostat & vacuum chambers
- Cryogenic rotary joints
- Superconducting power applications

Laboratory instrumentation and testing

- Thermometry
- Magnetic measurements
- Strain gauges measurements
- Control and acquisition systems
- Quench detection and protection

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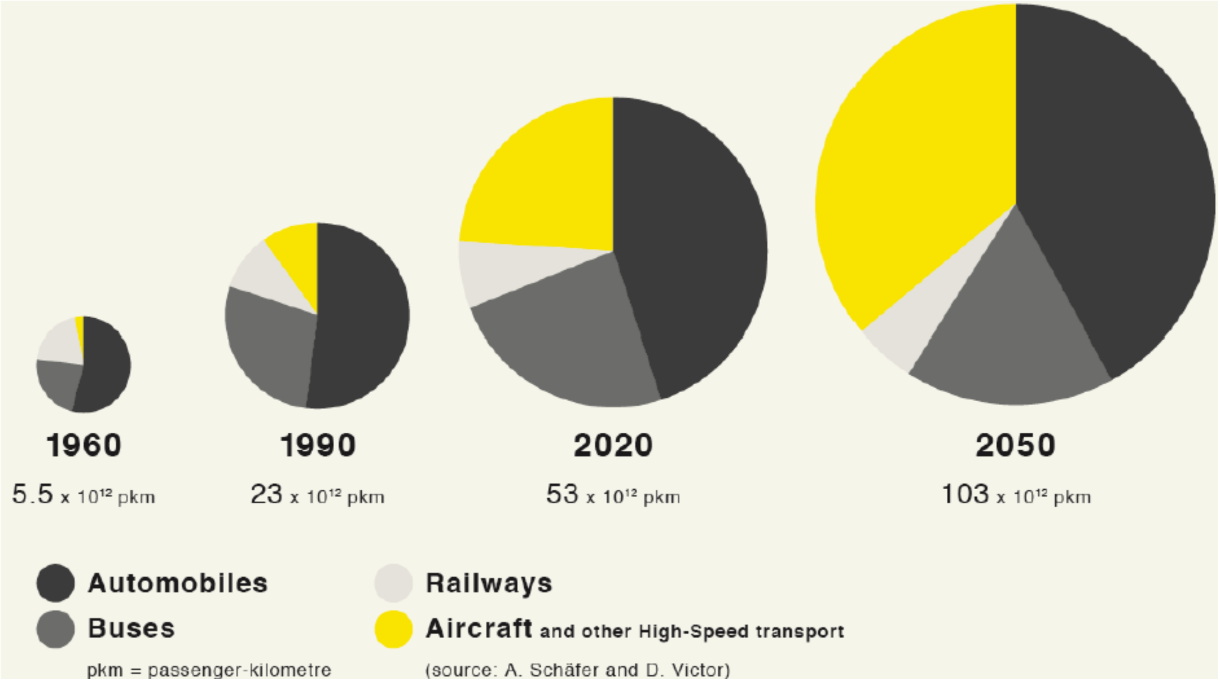
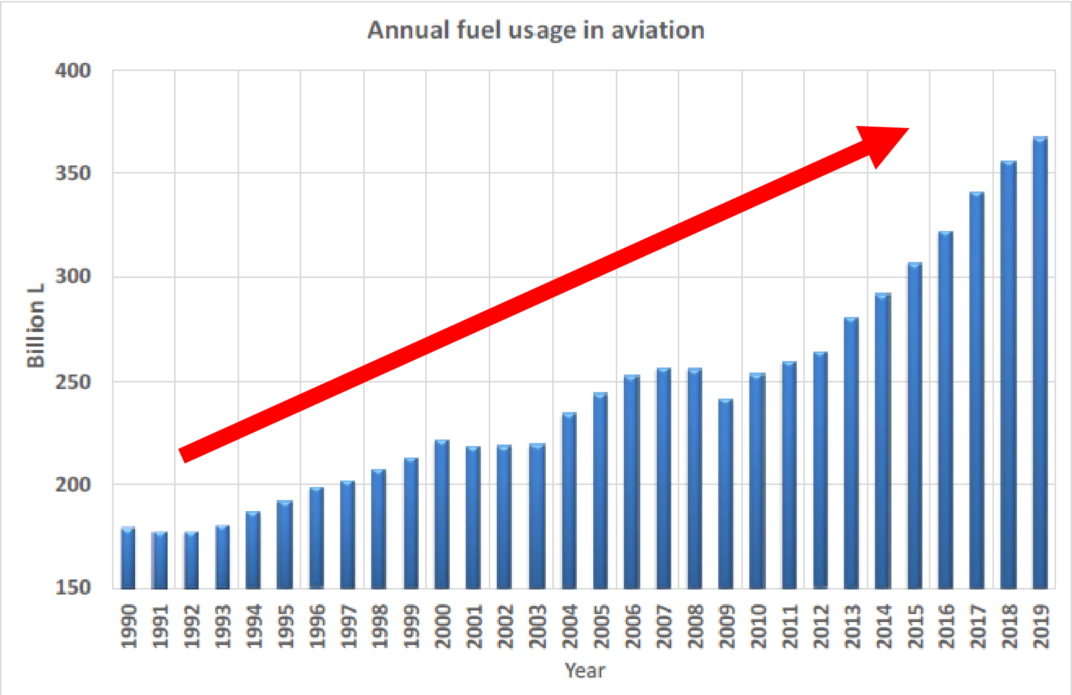
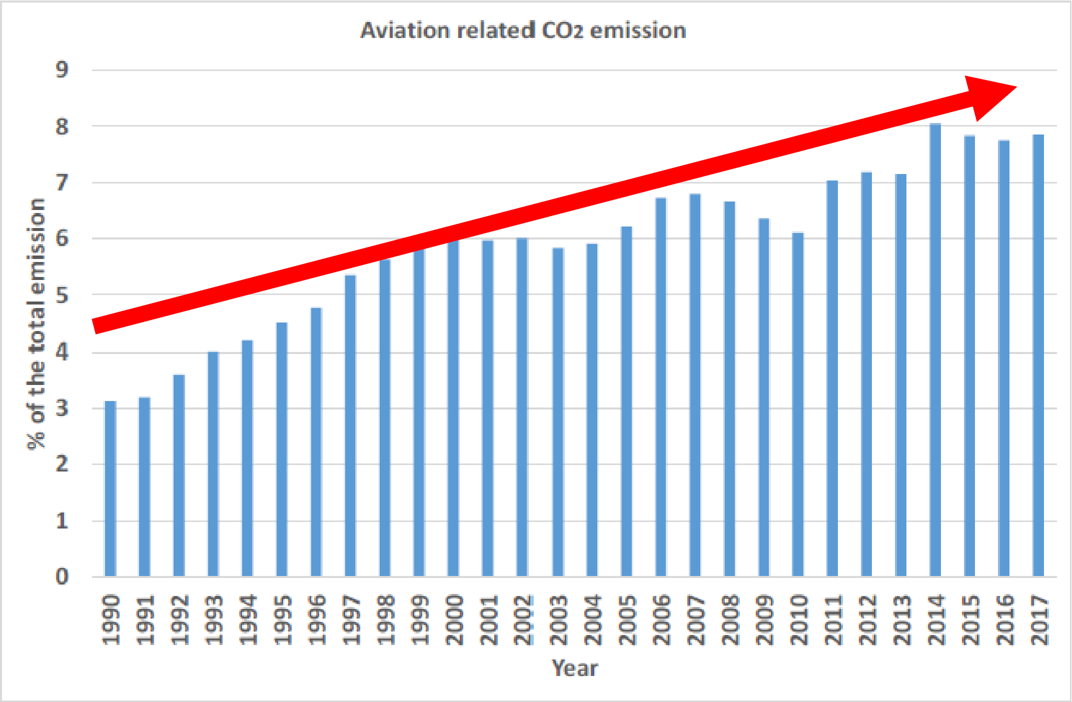
- SUPRASYS
- STATE OF THE ART- TOWARD A CLEAN AVIATION
- STORAGE
- POWERTRAIN

- In 2019, around 4.5 billion passengers travelled through the air
- However, at the same time, aviation was also responsible for around 5% of anthropogenic causes of global warming.
- Increasing trend in passenger transport for different modalities over the past decades and the expected trend in the future
- On 2050 expected almost the doble. FROM 53 PKM (Passenger Kilometre) up to 103 PKM.





- Increasing trend in annual fuel usage in aviation is shown from 1990.
- A Increasing trend is also expected for upcoming years.

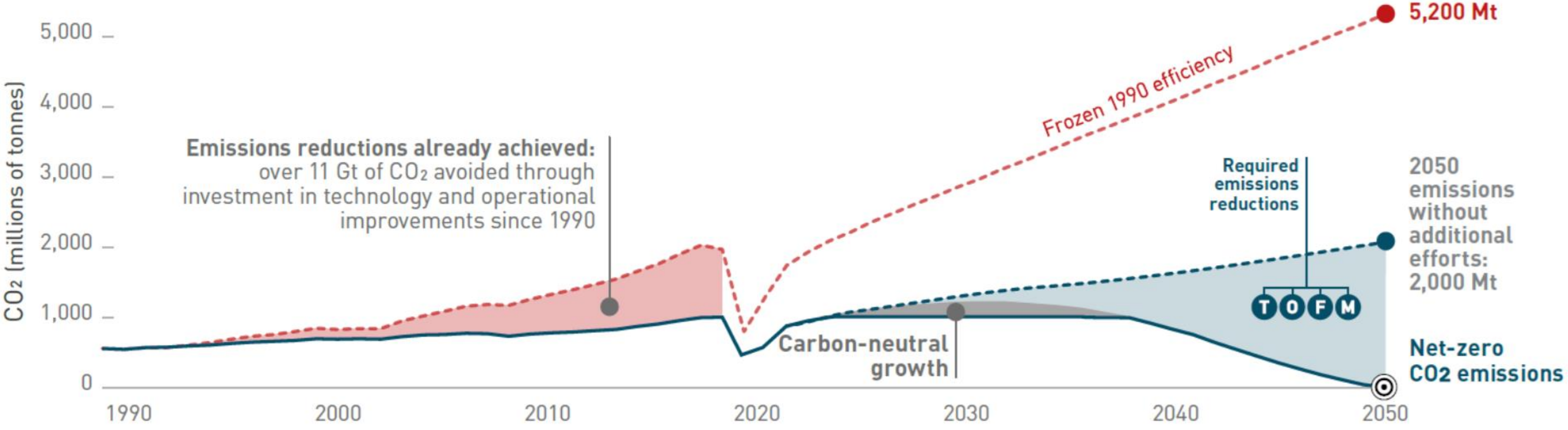


- 2 times billion Litre more for annual usage.
- 3 times more on % of the total CO_2 emissions.

- Low-carbon fuels are among the goals set by the European Commission in its Sustainable and Smart Mobility Strategy.

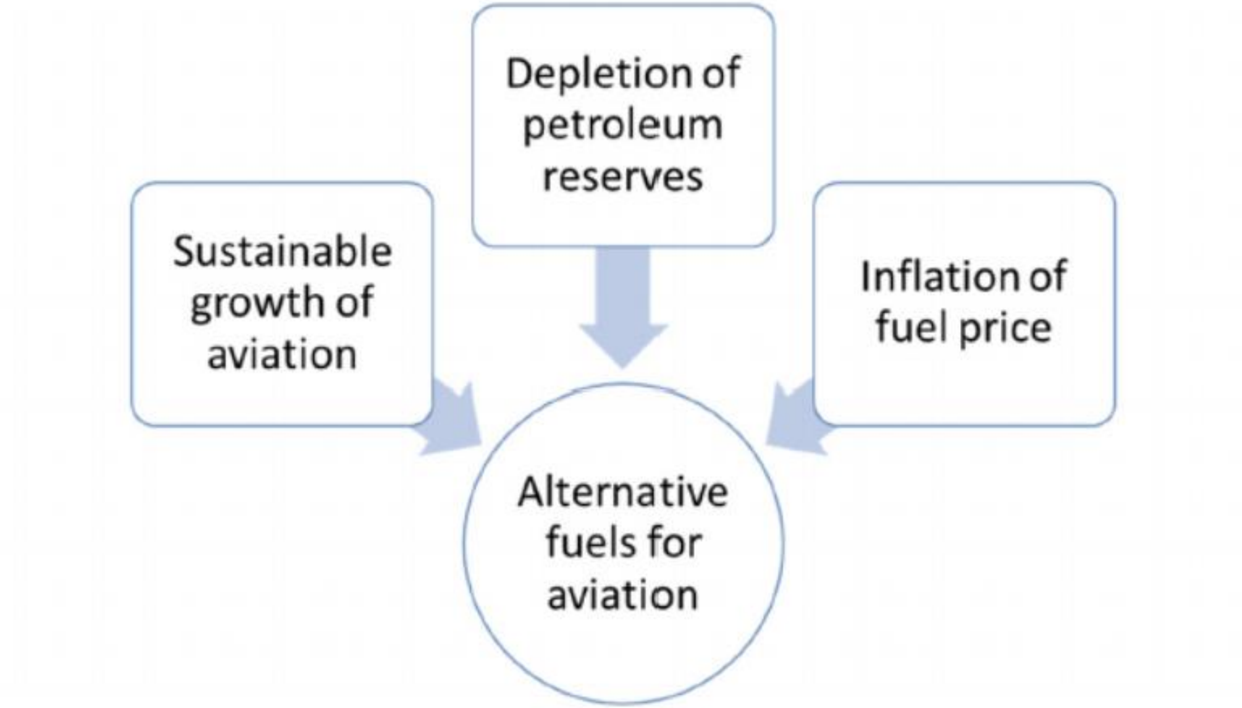
- The strategy, which was published on 9 December 2020, is aimed at delivering a 90% reduction in emissions from the European Union's transport sector by 2050.

- Targets outlined in the Green Deal that relate to aviation include a "zero-emission large aircraft" that "will become ready for market" by 2035. The goal for 2030 is that "scheduled collective travel of under 500km should be carbon neutral within the EU".

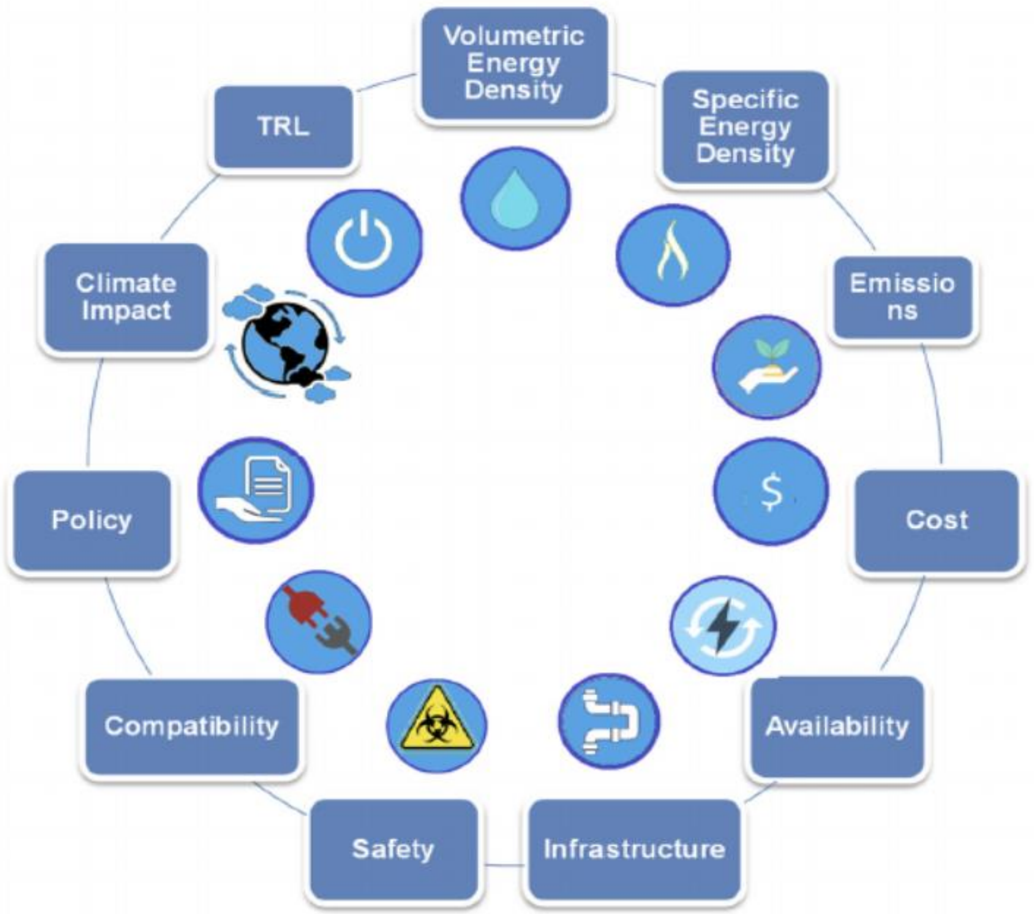


- The **aeronautical industry** presents an important impact on the environment, with 2% of global emissions being associated with aviation.
- **Decarbonization** efforts are thus targeting aerospace technology and looking for ways to generate a cleaner, greener industry.
- **Liquid hydrogen** stands at the core of this transition. Acknowledged as one of the **best alternatives** today to reduce the aeronautical industry's environmental impact.
- Companies are experimenting with incorporating **cryofuels** like **liquid hydrogen**, just like other industrial sectors have already done, such as liquid hydrogen power for cars.

- **Fuel selection** is acted by several factors, including fuel **price**, fuel **availability** and **emissions** characteristics.



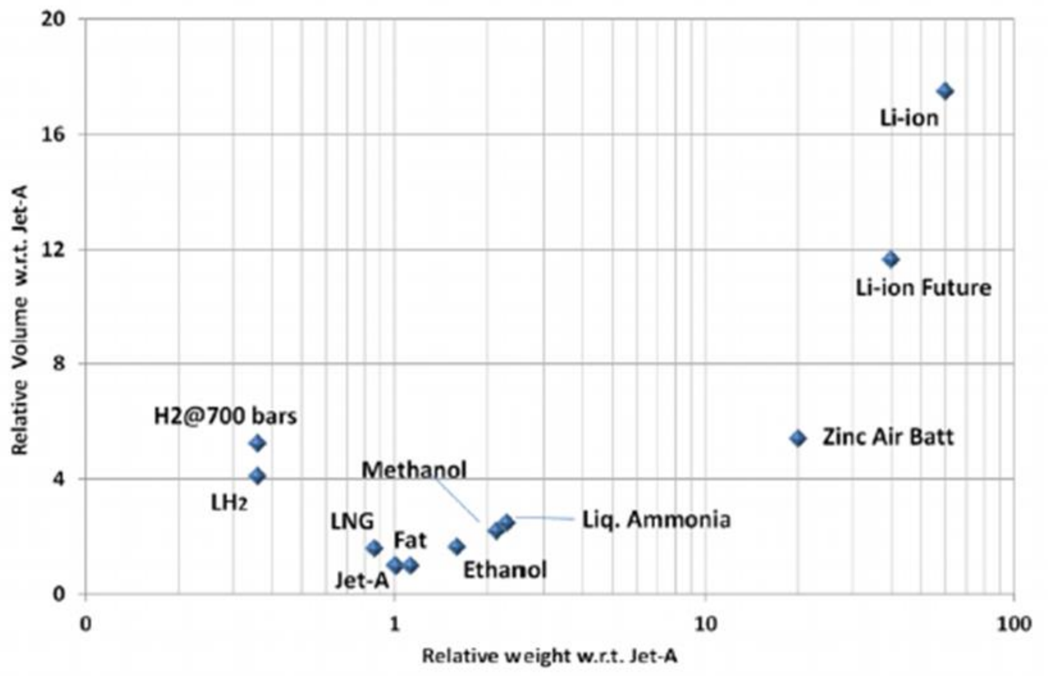
- Some essential criteria to select fuel for aviation.



- One of the main criteria is the **energy density**, as reducing **weight** and **volume** is of paramount importance for aviation.

- Cryogenic or Liquid hydrogen has high SED (SED, amount of energy per unit mass of the fuel) but a poor VED (VED, amount of energy per unit volume).

- Implying that we would require a large volume to carry any reasonable Amount of LH2.



Comparison of various energy sources for aviation with respect to Jet-A [15]. LH_2—cryogenic hydrogen; LNG—liquefied natural gas.

Property	Aviation Fuel @ 300 K	LH2 @ 1 bar, 15 K
Density (kg/m^3)	775-840	76.2
Volumetric energy density (MJ/L)	31	9
Specific energy density (MJ/kg)	45	120
Operating temperature (K)	226 – 423	15 – 20.3
Latent heat of vaporization (kJ/kg)	-	450
Specific heat capacity (C_p) (J/g K)	-	7.31
Cost ($/L)	0.4-0.5 0.26-0.5	0.06

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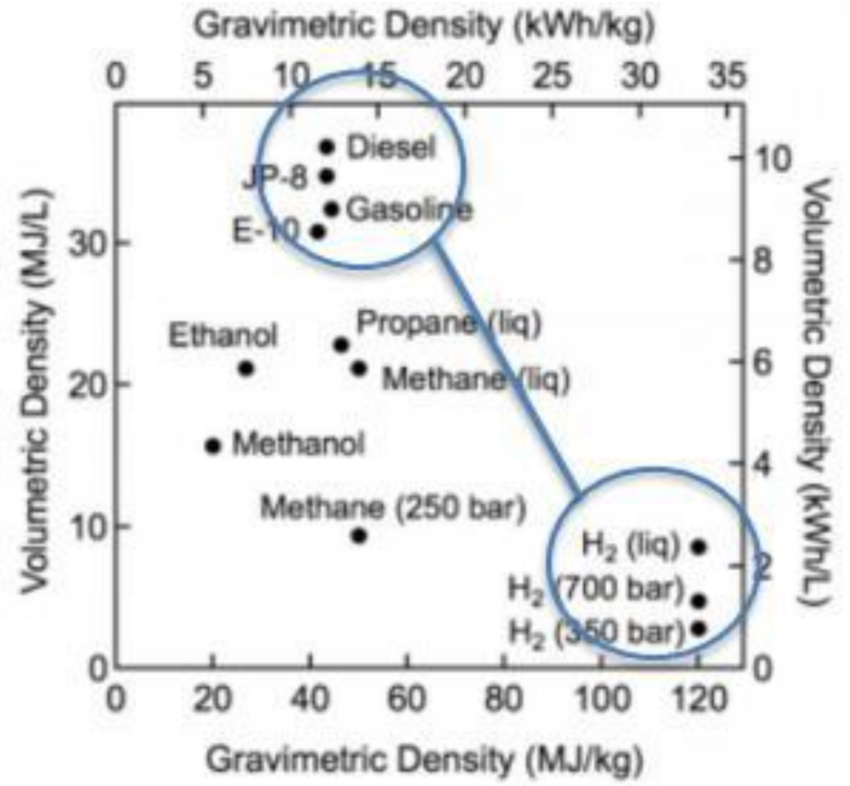
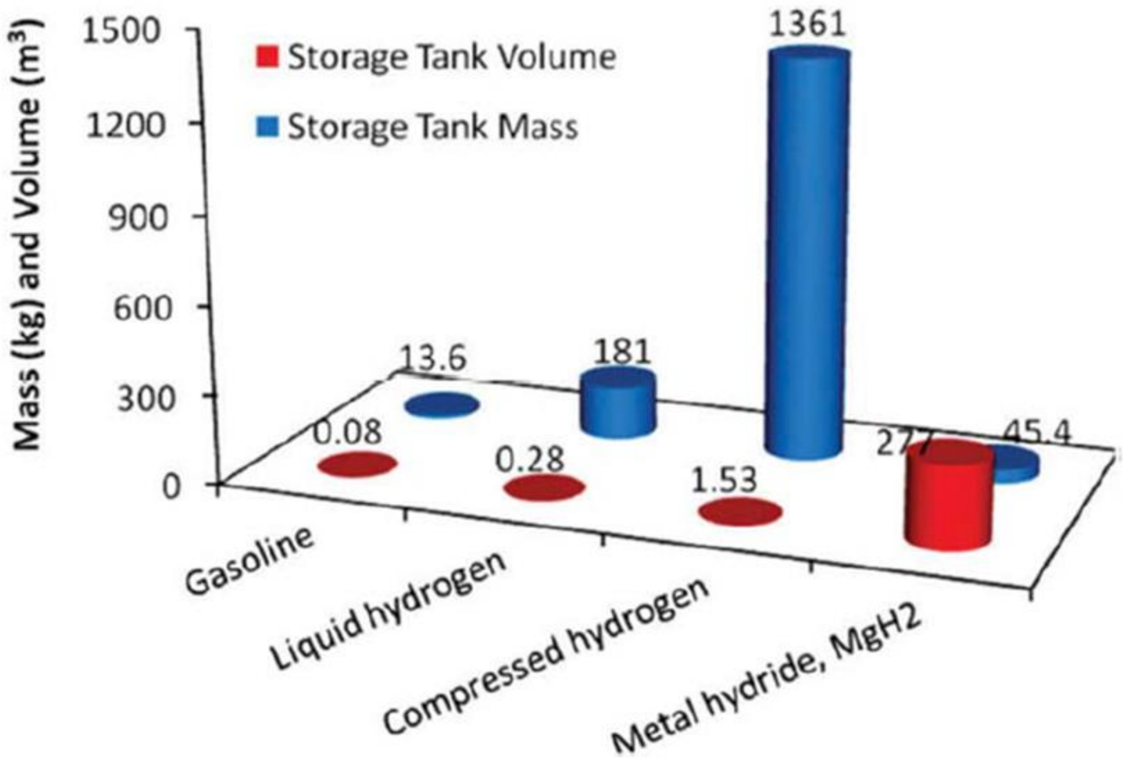
- Another important challenge to be carried out is the storage of hydrogen.
- Requires up to four times more volume than conventional fuel, which forces you to look for additional spaces in the plane.

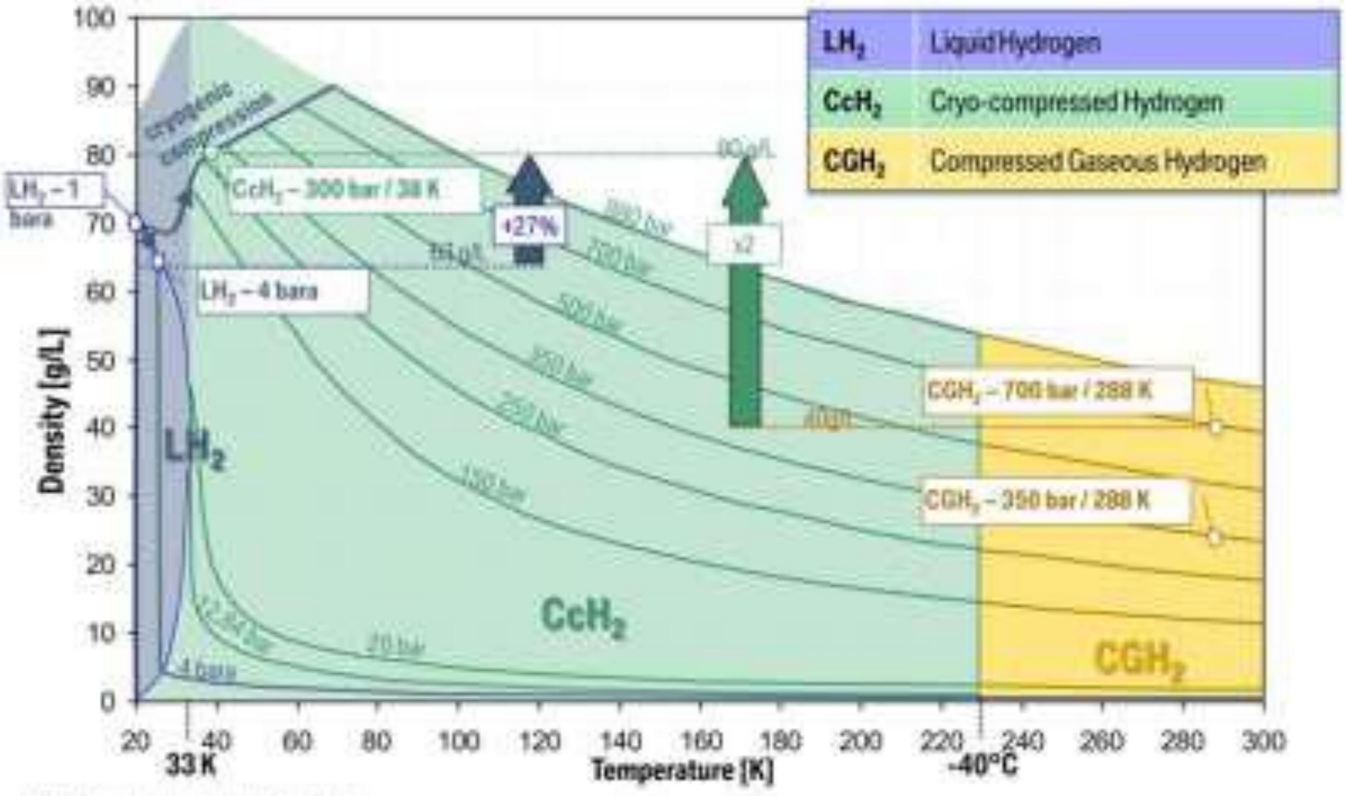


HYDROGEN STORAGE: Phase		
Compressed	Cryo-compressed	Liquid Hydrogen
• At 700 bar is stored at 288K, Pressures the volume requires is very high. • At 700 bar has almost 40% less density than liquid hydrogen.	• Cryo-compressed hydrogen is stored at cryogenic temperatures (20 K - 230K) • Storage at higher pressures than liquid hydrogen, ranging from 250 to 350 bar.	• Liquid hydrogen is stored at extremely low temperatures (below 20 K) and near atmospheric pressure. • Stored in a liquid state, which significantly increases its density



Liquid hydrogen has the highest density among the three storage methods, making it ideal for applications where high-density storage is essential, such as aerospace applications.

- **Hydrogen** is only can be obtained in **liquid form at cryogenic temperatures (20K).** With these methods we obtain densities of hydrogen, about 40 Kg/m3 for compressed Hydrogen and 78 Kg/m3 for liquid Hydrogen



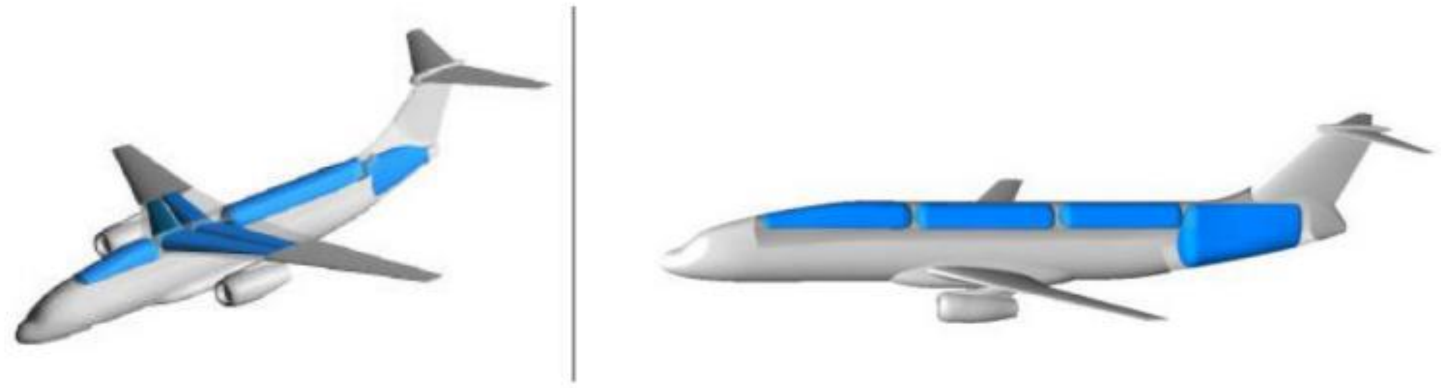
- Therefore, storage at these temperatures is also a great challenge, since hydrogen has a very low enthalpy, so with little energy absorbed it is converted again into gas, so these storage systems must prevent heat inputs from from the outside.

In conclusion, hydrogen is difficult to store, it must be insulated very well thermally, and it requires large
volumes.

It is important to note that, there are to type of hydrogen isomers. Ortho and para hydrogen refer to different spin isomers of the hydrogen molecule (H2) based on the alignment of the nuclear spins of the hydrogen nuclei, or protons.

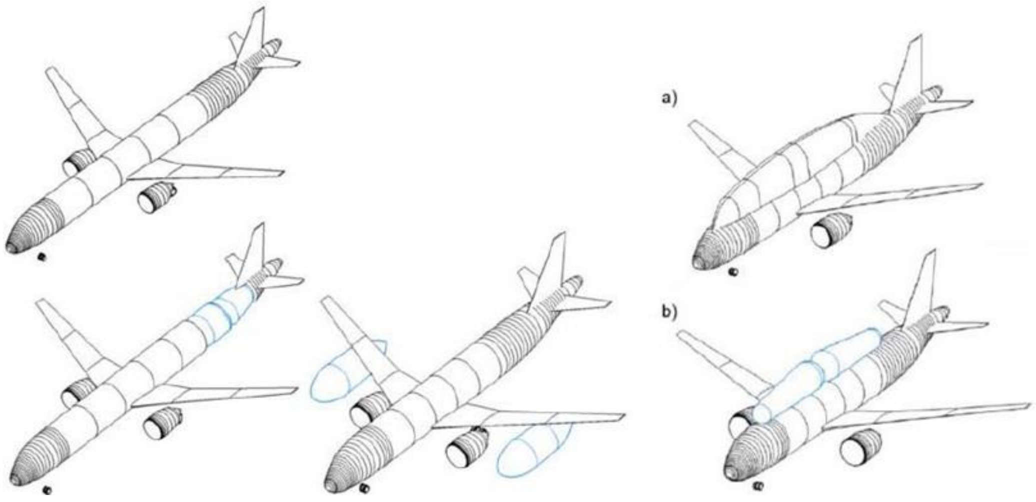
- **Ortho-Hydrogen (o-H2):**
  - Ortho-hydrogen is characterized by a **higher energy state** compared to para-hydrogen.
  - Under normal conditions, hydrogen gas contains a mixture of ortho and para isomers, with ortho-hydrogen being the **dominant** form at **higher temperatures.**
- **Para-Hydrogen (p-H2):**
  - Para-hydrogen is characterized by a **lower energy state** compared to ortho-hydrogen.
  - At very **low temperatures**, typically below around 20 Kelvin, the conversion of ortho-hydrogen to para-hydrogen becomes kinetically favored, leading to the **enrichment of para-hydrogen** in the hydrogen gas mixture.

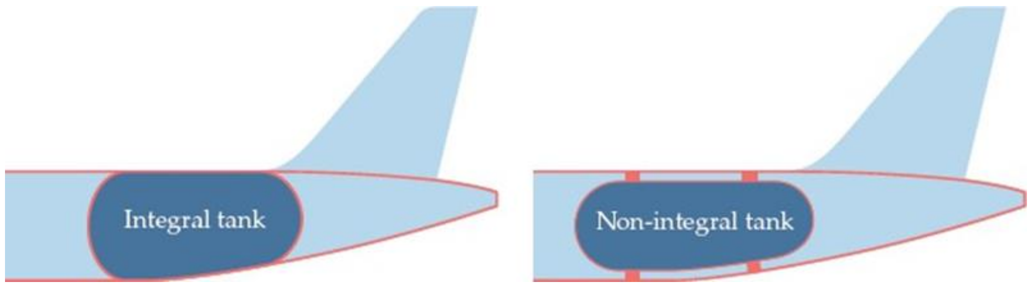
- **Para Hydrogen** is generally considered **better for cryogenic storage** due to its higher stability and energy density.



S/M Range A/C First proposal

Revised configuration





- The main objective of the **TANK2ZERO** project (Hydrogen Storage Technologies to Boost the operation of zero-emission aircraft) is to raise the level of maturity of the Cryogenic hydrogen tank concept made by composite material reinforced with carbon fiber for commercial aviation.

- The novelty of these systems is that due to the weight requirements of the aircraft, a novel double-jacket cryogenic system in composite material is proposed reinforced by carbon fiber (CFRP).

Financiado por la Unión Europea NextGenerationEU
Plan de Recuperación, Transformación y Resiliencia
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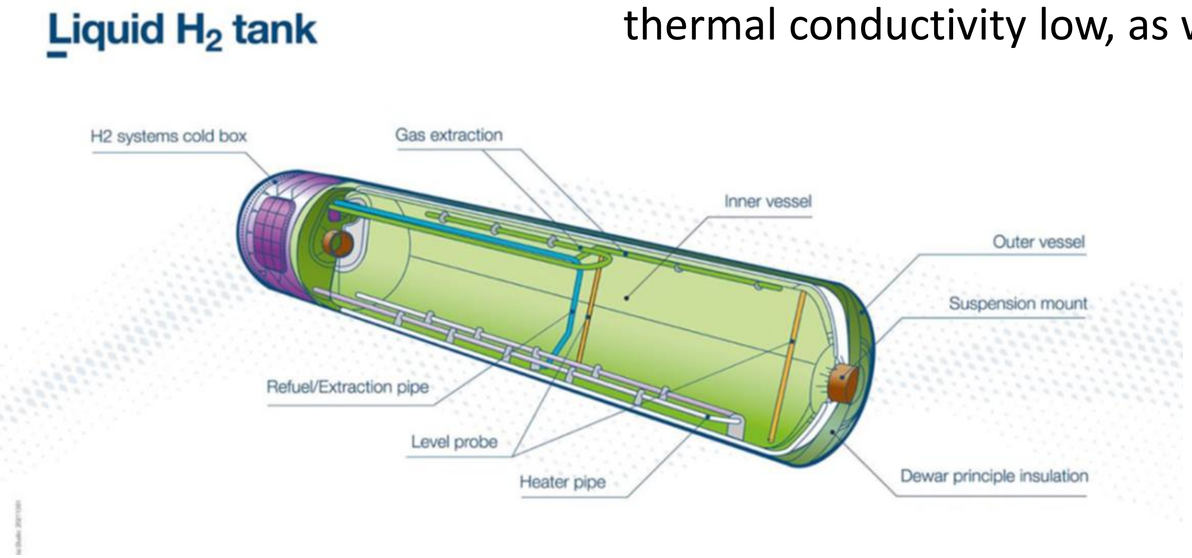
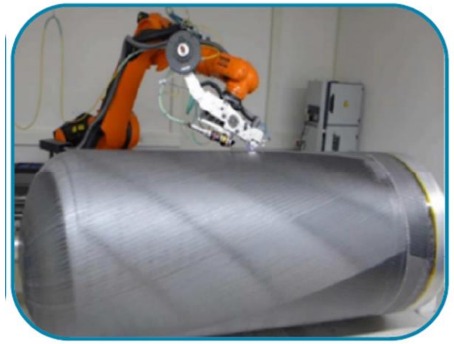
Objectives

- OB1: Search for new materials with better characteristics for Cryogenics.
  - Investigate new materials that reduce microcracks at cryogenic temperatures.
- OB2: Advance high vacuum systems in CFRP tanks Cryogenics
  - Search for solutions that guarantee vacuum between the carbon fiber tank jackets
- OB3: Advance in the concepts of joining between tank jackets at cryogenic temperatures
  - Investigate how to limit heat inputs through joining, piping, flanges and so on.
- OB4: Advance the integration methods of all the main parts of the tank.
  - Investigation of the integration of systems (pipes) guaranteeing vacuum and thermal conductivity low, as well as integration between tank liners.





CFRP tank prototype production - CASA Espacio (2014)

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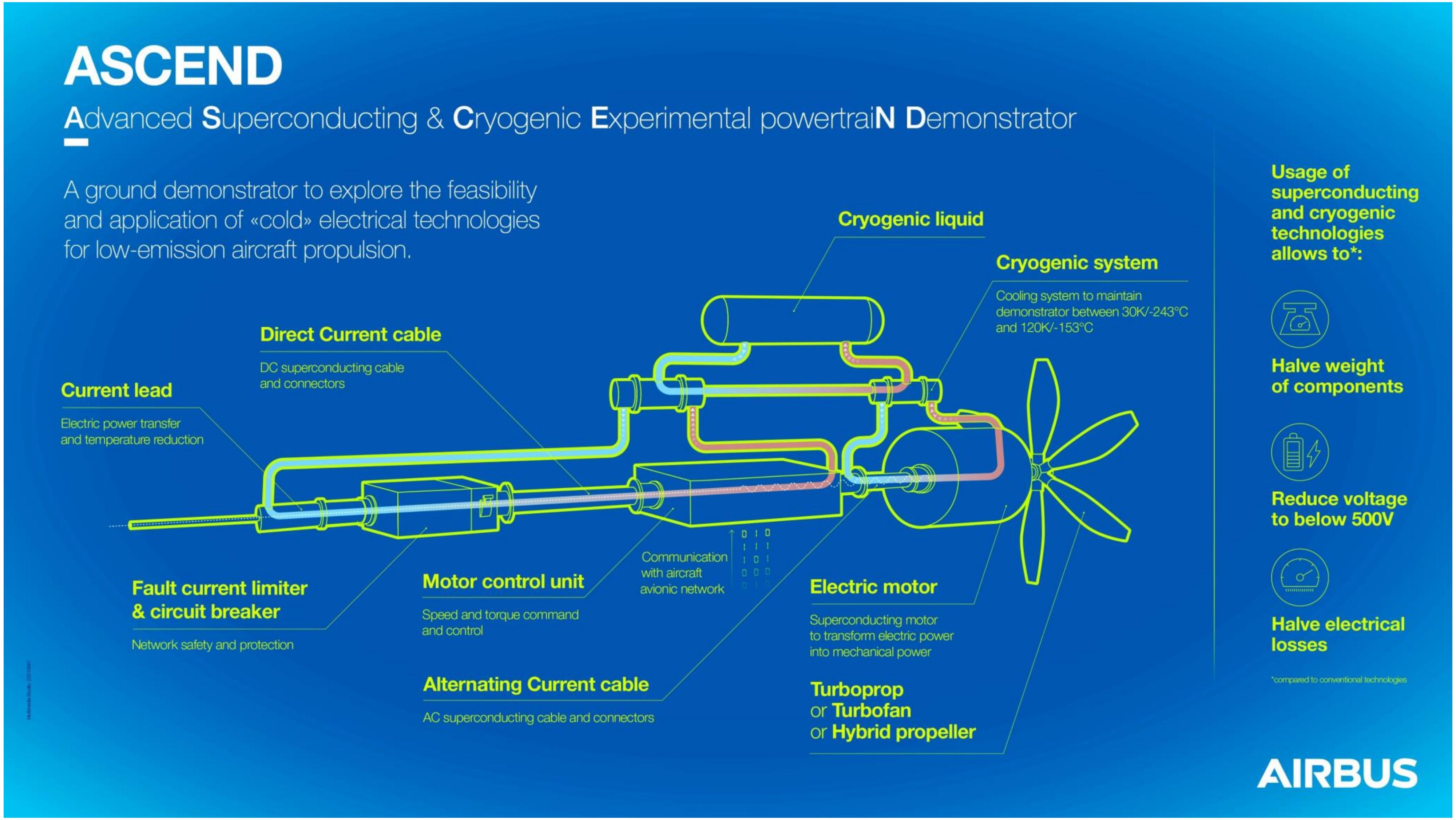
- Cryogenics also plays a key role in a powertrain.
- Electric motors are going to SC technology due to their compacity and the power density.

Superconductivity needs cryogenics and vacuum

Aspect	Superconducting Motor	Resistive Motor
Advantages		
Low energy consumption	✓	✗
High efficiency	✓	✗
Lower energy loss due to heating	✓	✗
Higher power density	✓	✗
Higher current density	✓	✗
Absence of electrical resistance	✓	✗
Disadvantages		
Higher initial cost	✗	✓
Requires cryogenic cooling	✗	✓
Complexity in design and manufacturing	✗	✓
Lower overload capacity	✗	✓
Sensitive to temperature variations	✗	✓



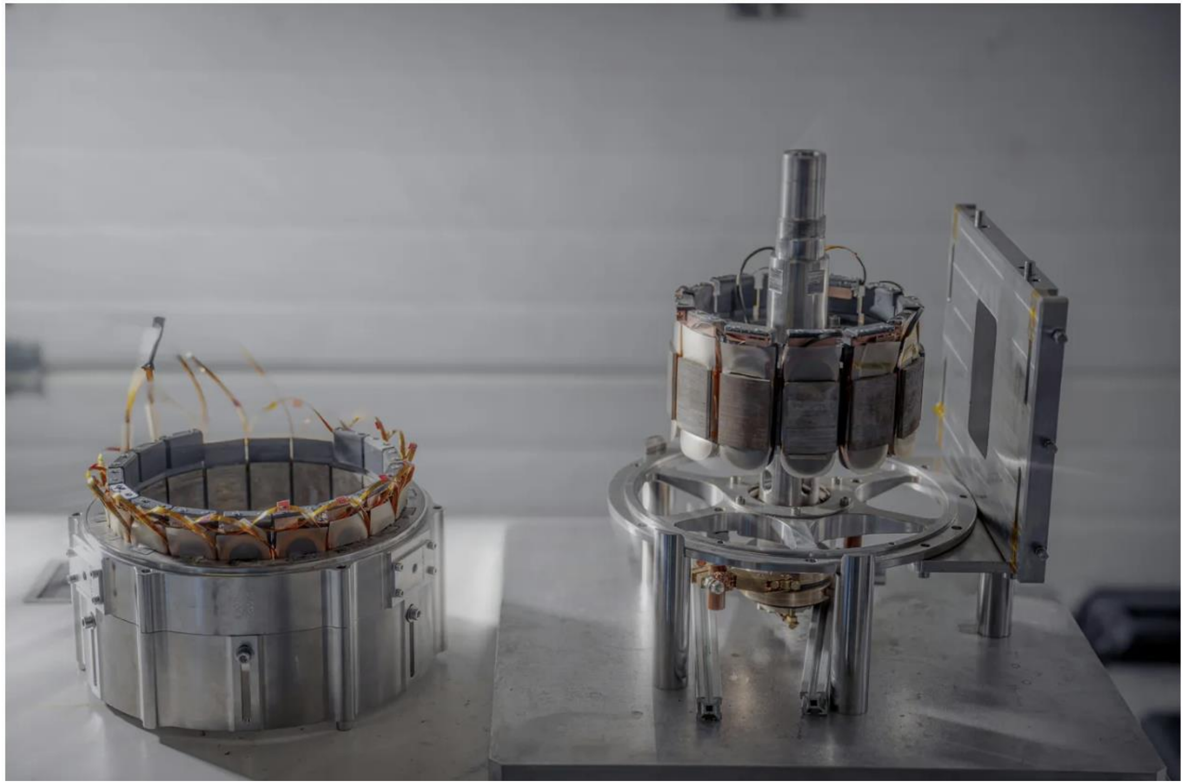
Pioneer demonstrator based in a superconducting motor

- The Airbus UpNext team built their own electric demonstrator motor. ASCEND has shown it is possible for a superconducting powertrain to create a major power shift in electric propulsion, from several hundred kilowatts to multi-megawatts.

- On board an electric aircraft, a superconductive powertrain could reduce voltage and practically eliminate losses, while keeping the weight and size of the overall system in check.

- The conditions for superconductivity would be created by the same cryogenic process used to maintain liquid hydrogen on board the aircraft at -20 K, where the hydrogen is used to generate power through electrolysis inside a fuel cell.

- **ASCEND concluded in November 2023** with the **successful** powering-on of a 500 kilowatt powertrain, consisting of superconducting tape, a cryogenic motor control unit and cooling system, and a superconducting motor.

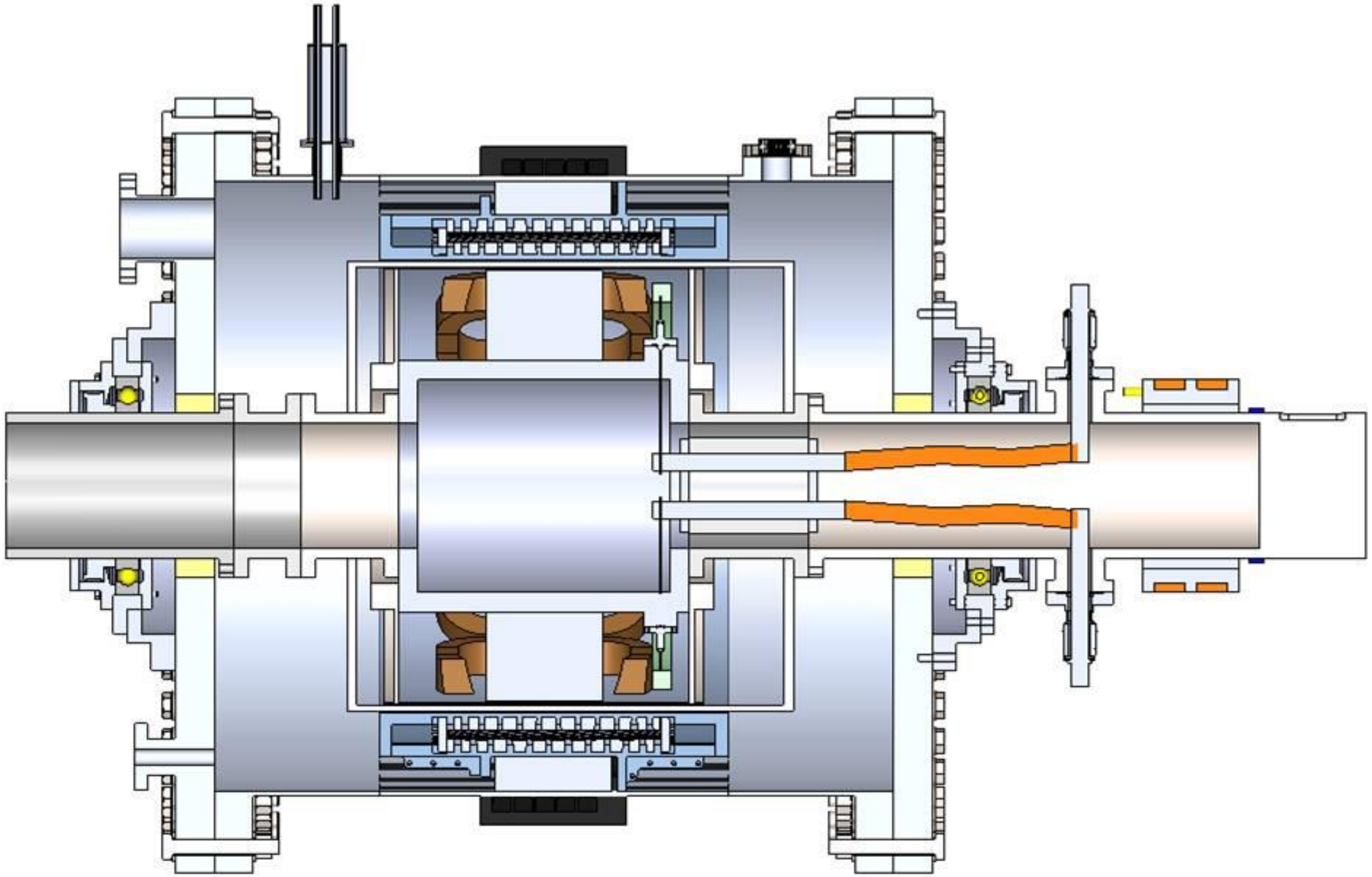


hivomot.eu

JTI-CS2-2020-CFP11-THT-12

HIgh power and VOltage operation of electric MOTors in aeronautics (HIVOMOT)

Conceptual Design



Patent numeber PCT/ES2022/070812

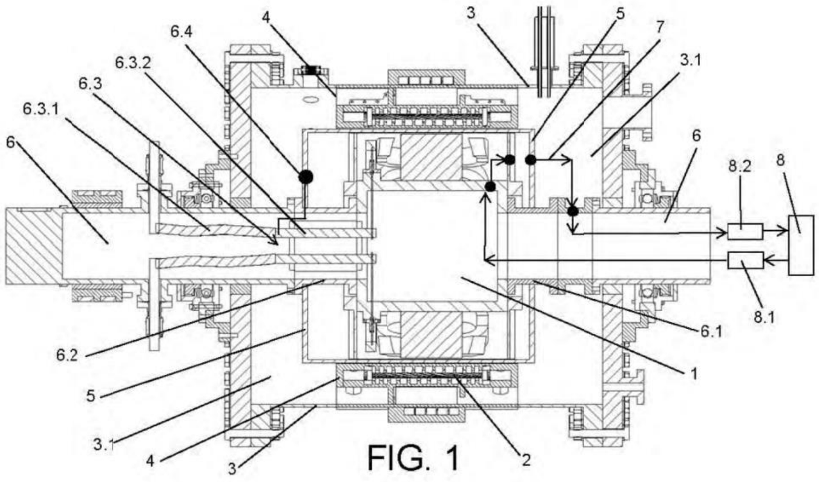
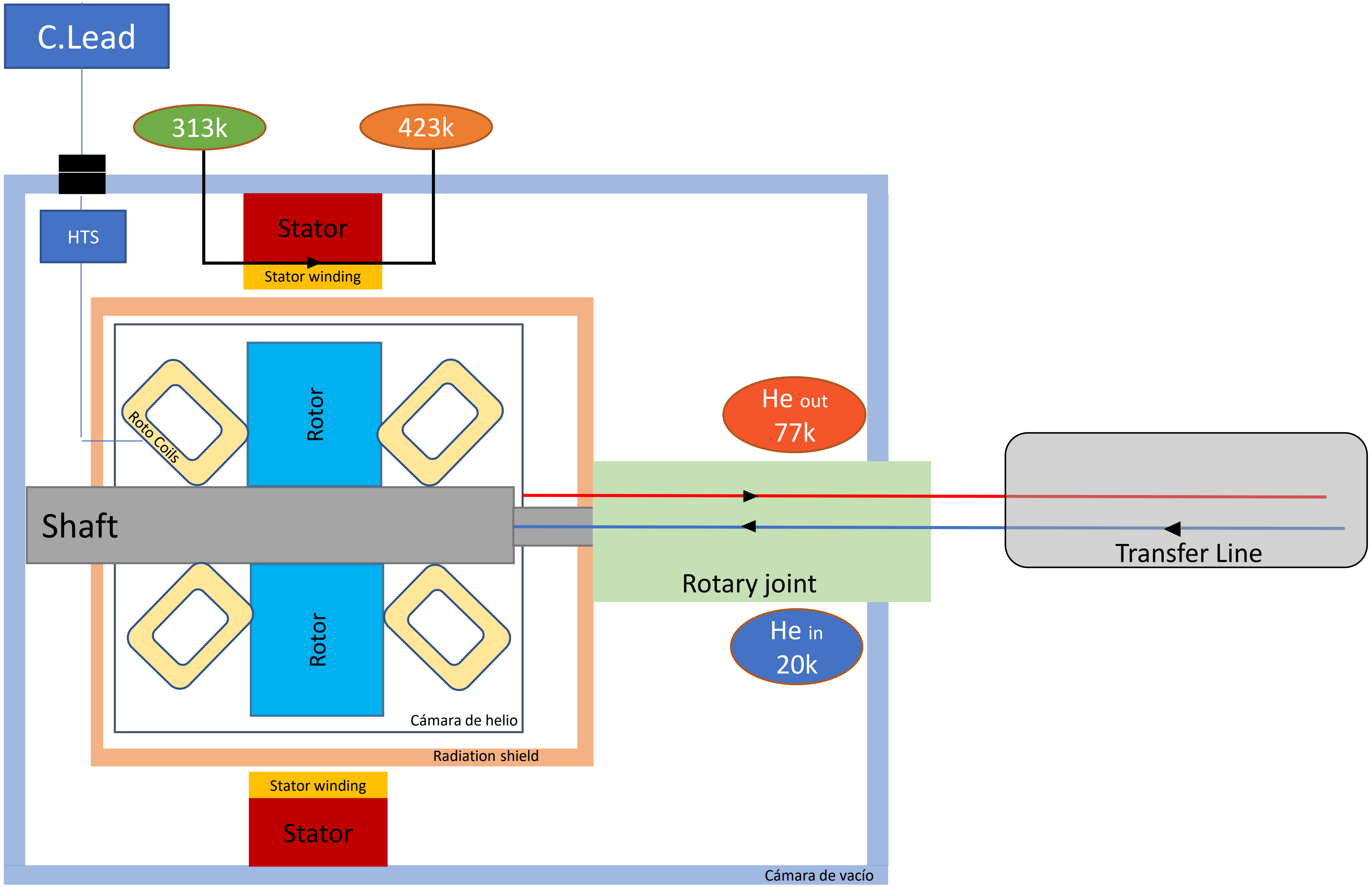


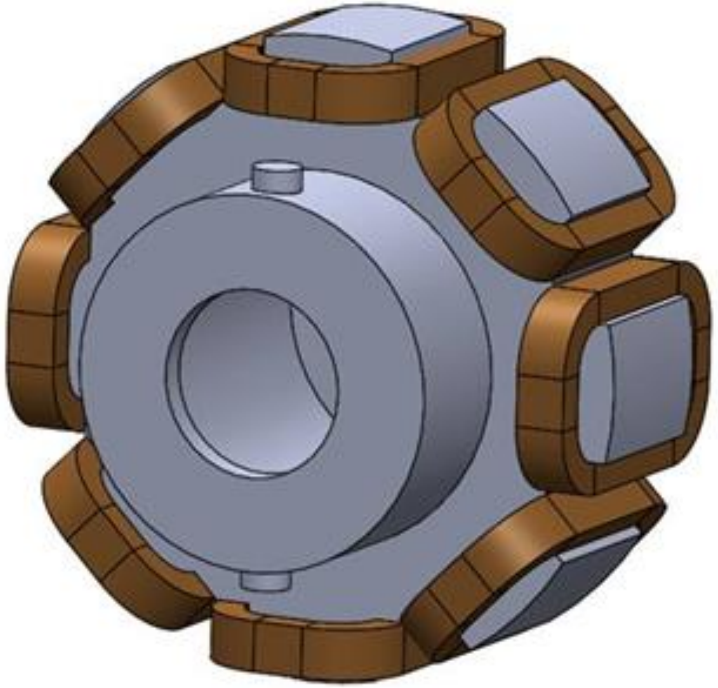
FIG. 1

Conceptual design of a 2MW synchronous motor at 2700rpm

Hivomot mock up termal diagram

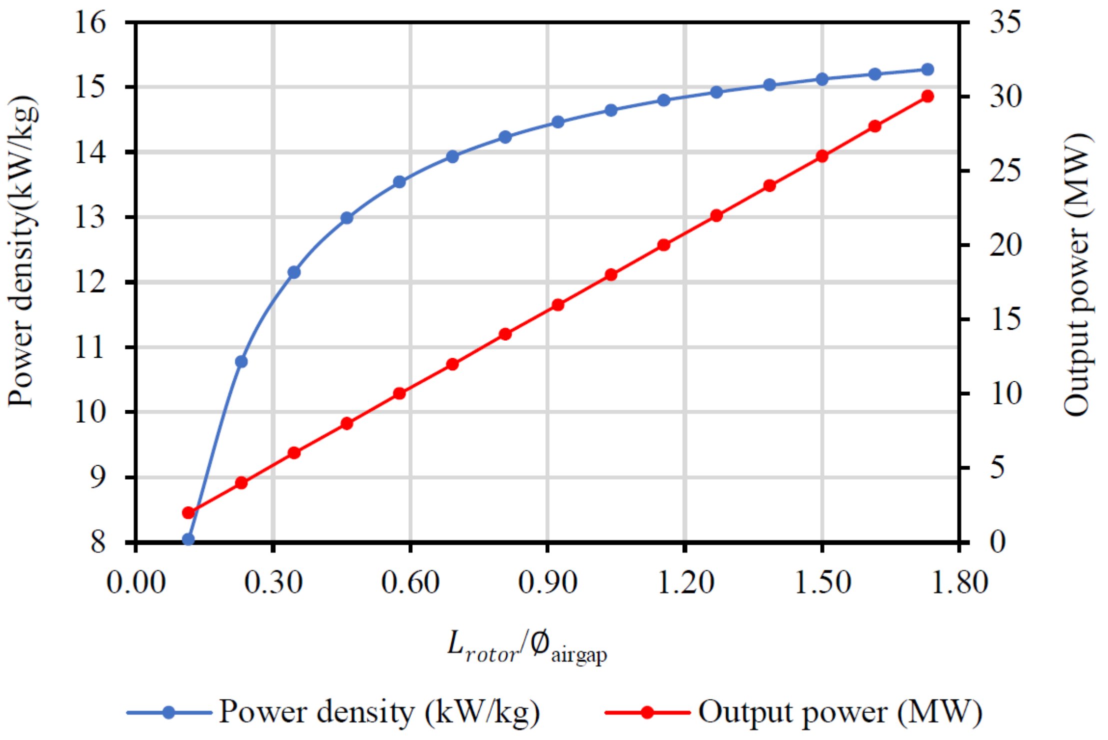


- HTS 2G superconductors

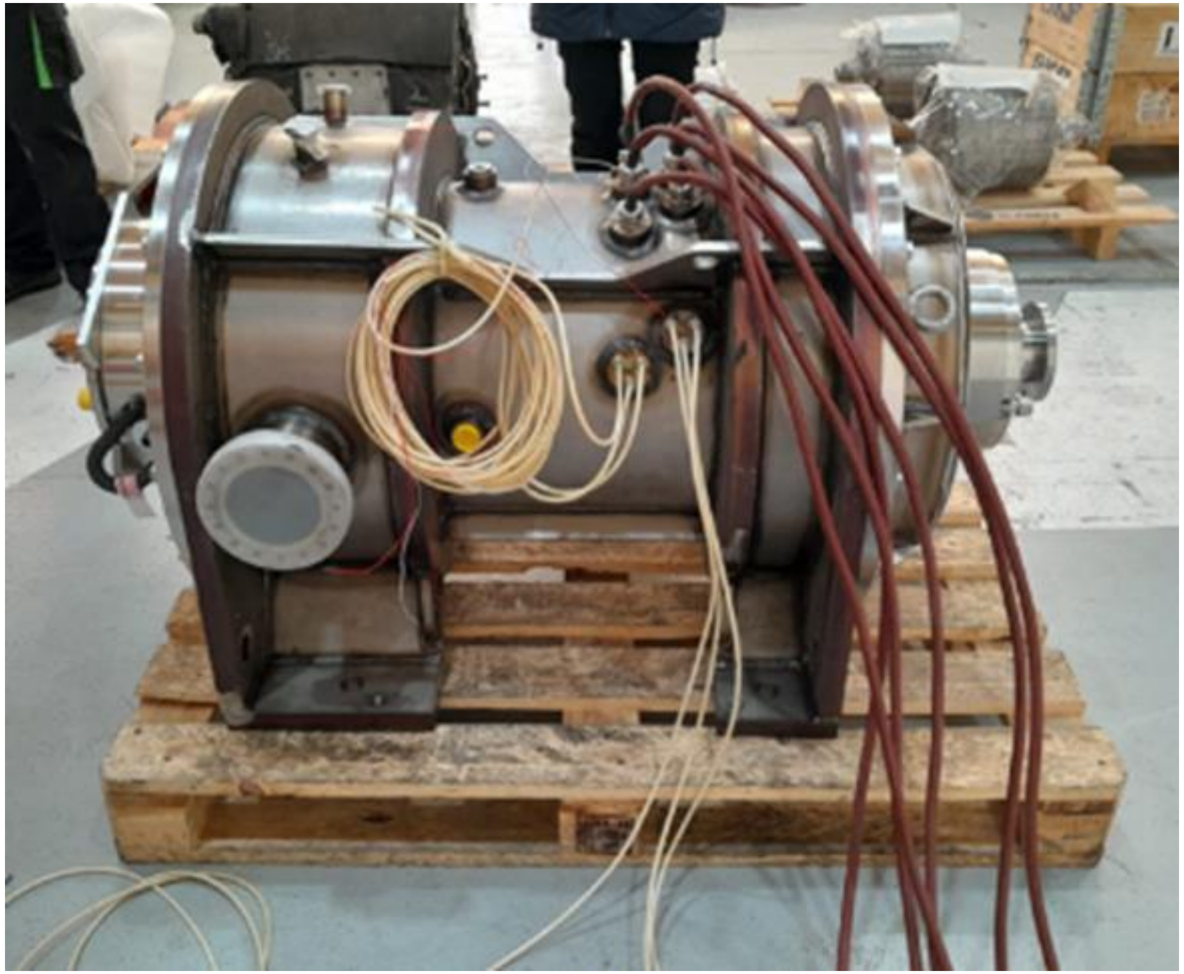


	Parameter	Value
cryogenic operational goals	Working temperature	20-25 K
	Working pressure	0.1 – 2 MPa
	Working cryogen	GHe
	Cryogenic system	Stationary cryocooler or heat exchanger with working fluid circulation.
	Thermal insulation system	Actively cooled radiation shield at around 77 K
	Cooling power	40-60 W at 20 K 200 - 300 W at 77 K
	Working fluid mass flow	TBD

Conclusiones

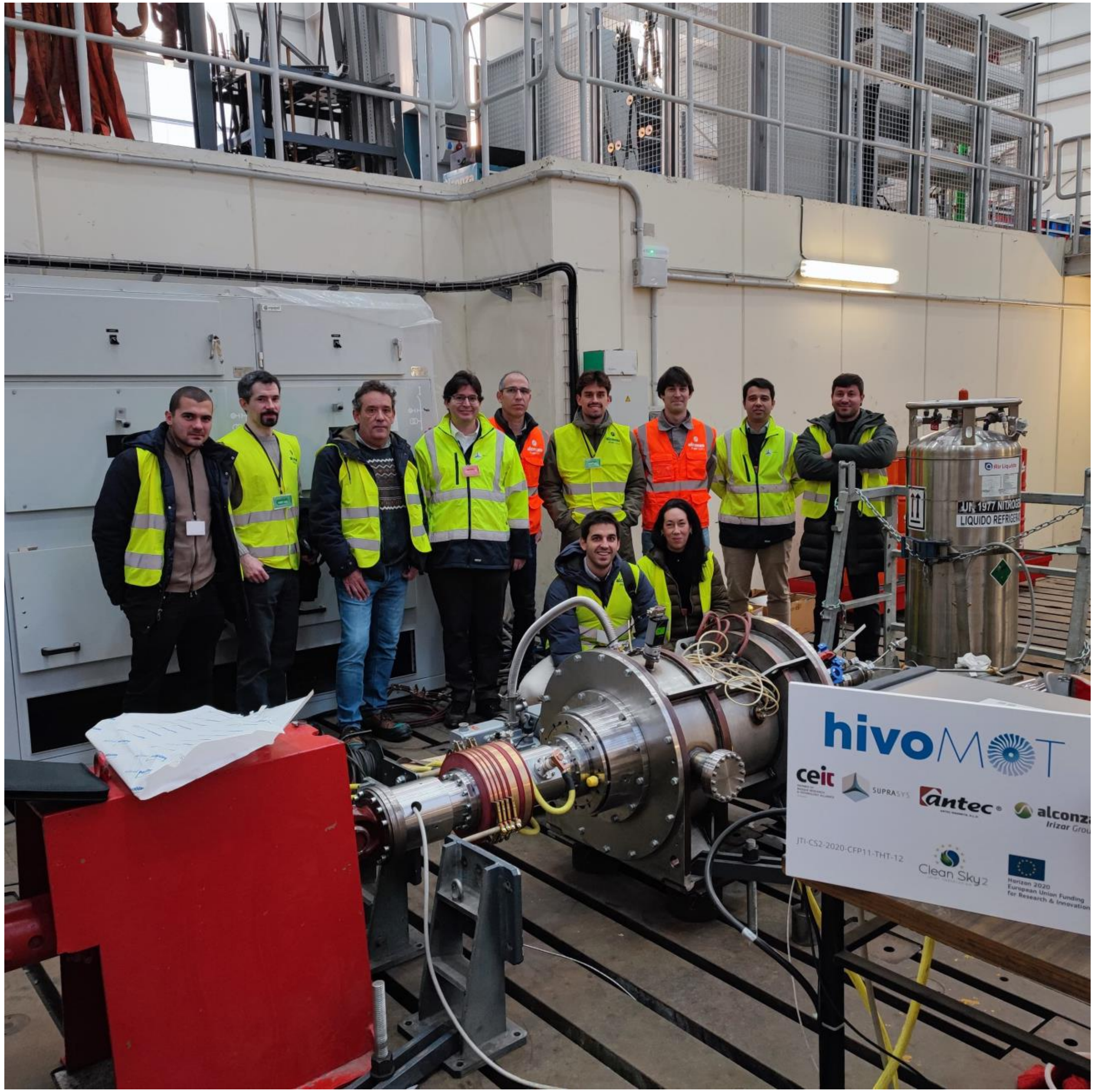


	Parameter	Value	Unit
Electromagnetics	Power frequency	180	Hz
	Rotor DC current	280	kA
	Induced phase voltage	780	Vrms
	Output power	2.023	MW
	Output torque	7.155	kNm
	Rated rotational speed	2700	rpm
	Specific power (active parts)	8.052	kW/kg
	Torque density (active parts)	28.48	Nm/kg
	Stator yoke max. flux density	2.43	T
	Airgap mean flux density	3.14	T
	Electromagnetic efficiency	98.01	%



Assembly with Rotary Joint installed

Whole Assembly with Transfer line and cooling down.



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