CIPEA
CERN Innovation Programme on Environmental Applications

CERN for Climate Action Day

CIPEA 2025 Event

October 28 @CERN

HTS Applications for Power Distribution in Aviation and Data Centers and Energy Storage for Ships

CERN

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Outline

RENEWABLE AND LOW-CARBON ENERGY

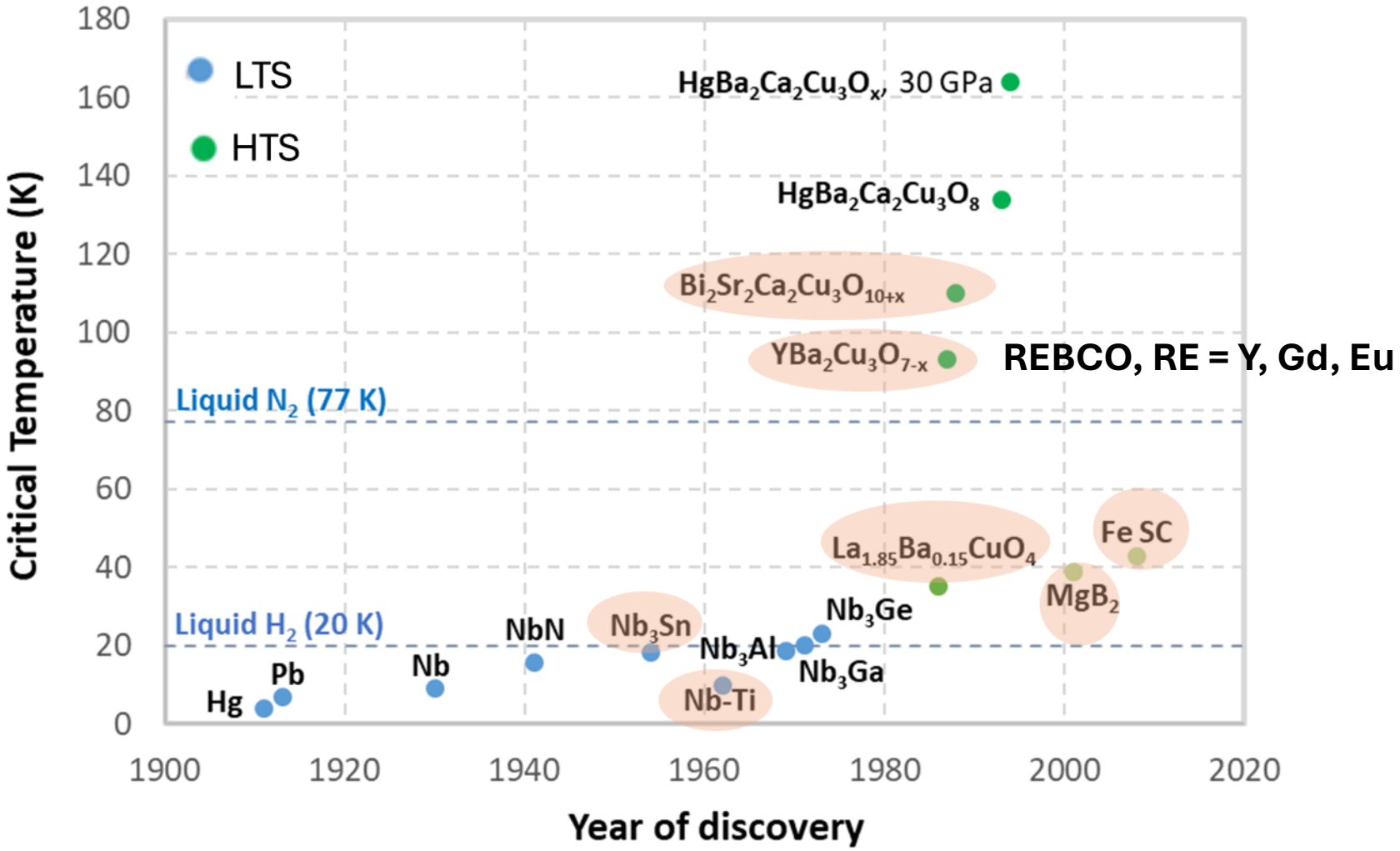
CLEAN TRANSPORTATION AND FUTURE MOBILITY

SUSTAINABILITY AND GREEN SCIENCE

CLIMATE CHANGE AND POLLUTION CONTROL

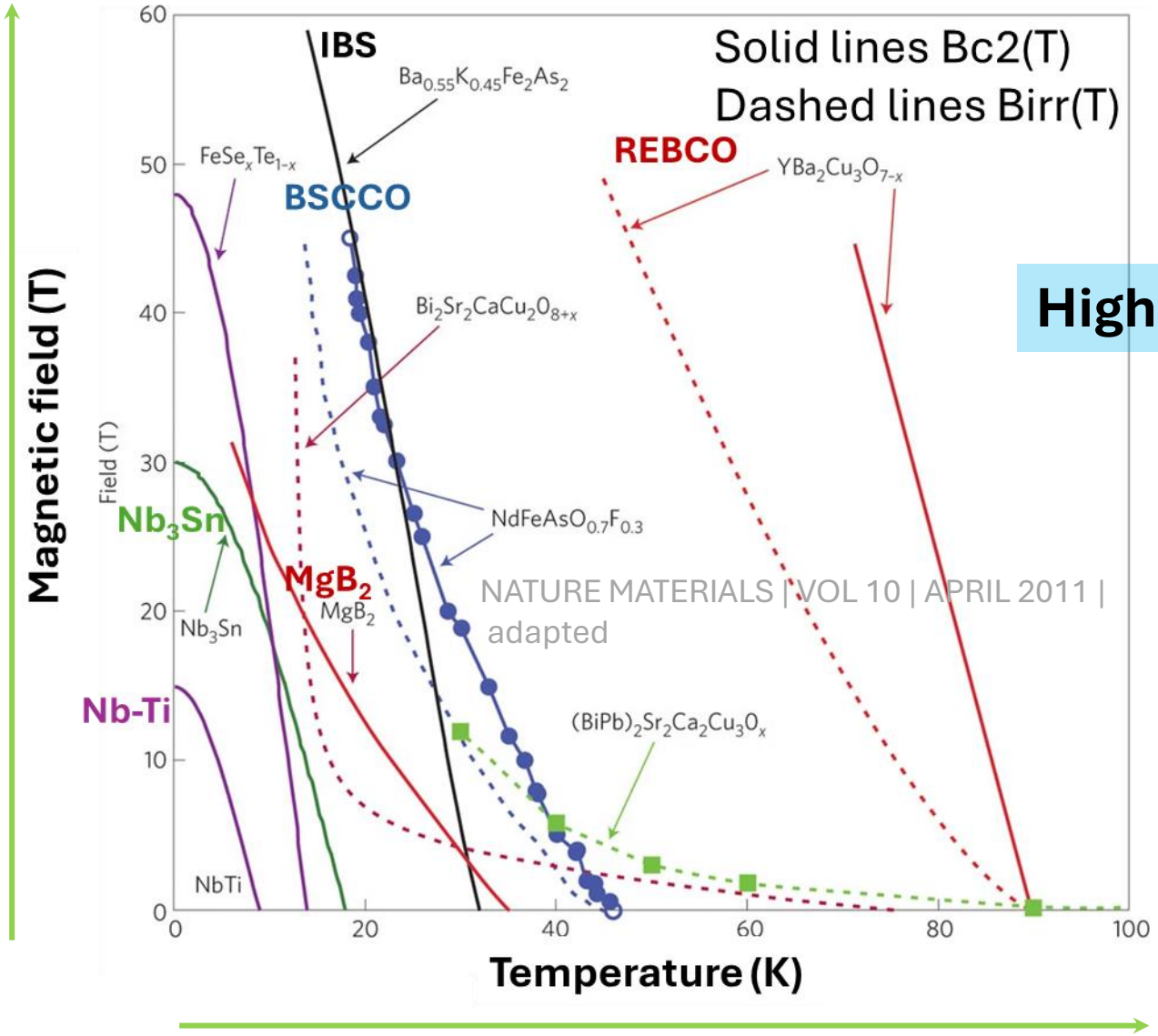
CERN Knowledge Transfer
Accelerating Innovation

High Temperature Superconductors



Potentials of HTS

Enabling high fields

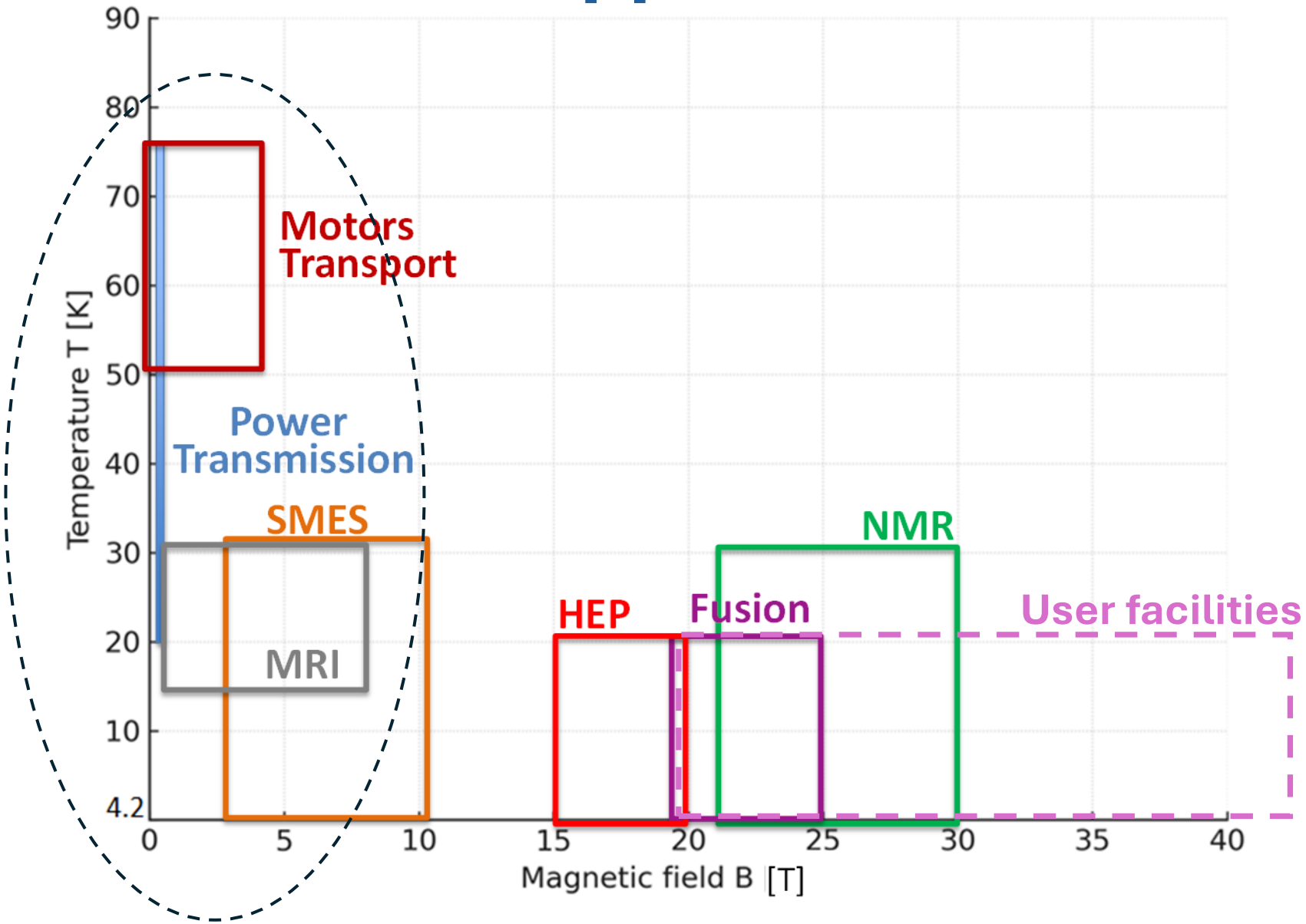


NATURE MATERIALS | VOL 10 | APRIL 2011 | adapted

High Tc and high Bc2

Energy-efficient and cryogenically sustainable at higher temperatures

HTS Applications

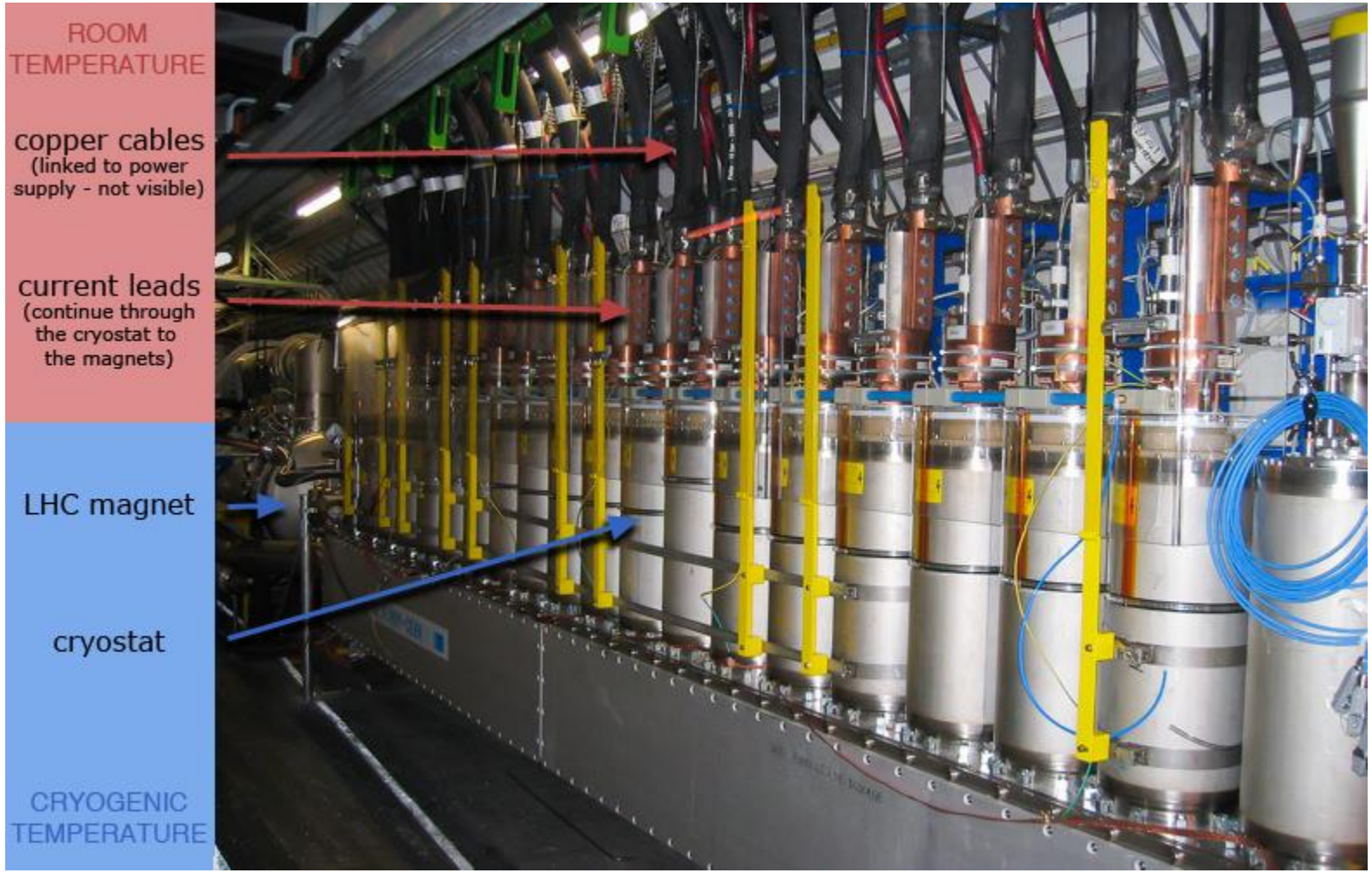


HTS and Sustainability

- The **global drive for electrification**—one of the key pathways toward **achieving zero emissions**—is fostering the development and demonstration of **superconducting technologies** for **societal applications**, particularly in the **marine**, **aviation**, and **power-grid sectors**
- **Superconducting systems** that **make electrification lighter, more efficient, and more sustainable** include:
  - **Motors** and **generators** for propulsion and energy conversion
  - **SMES** systems for high-speed energy buffering
  - **Cables**, **transformers**, and fault **current limiters** for efficient, resilient power grids
  - **Electrical transmission,** e.g. for industry and data centers
- **HTS** combines the benefits of superconductivity with **simplified and cost-effective cryogenics**

HTS for Electrical Transmission

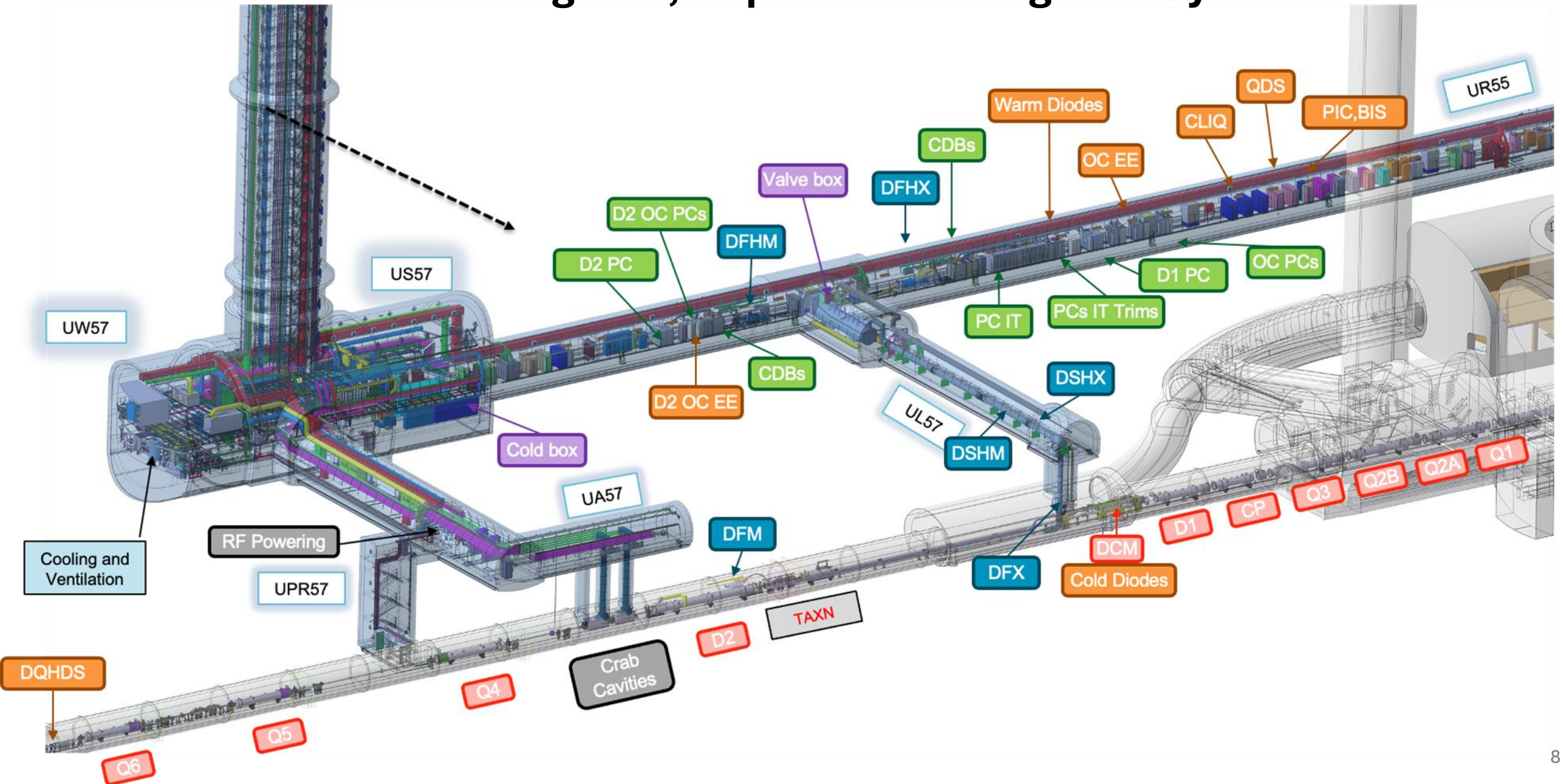
LHC magnets, total transfer of ~ 3.4 MA of current



BSCCO 2223 HTS (50 K → 4.5 K) ~10× reduction in cryogenic power at 4.5 K

HTS for Electrical Transmission

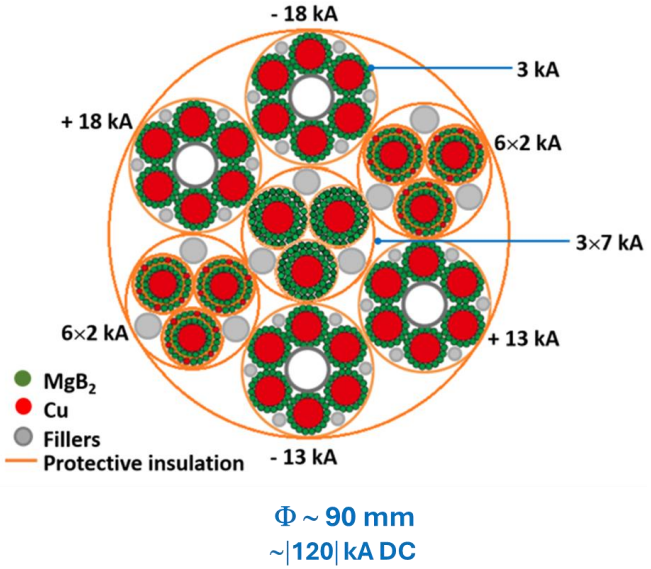
HL-LHC magnets, Superconducting Link Systems



HTS for Electrical Transmission

HL-LHC magnets, Superconducting Link Systems

~120 kA



Φ ~ 90 mm
~|120| kA DC

MgB_2 (20 K → 4.5 K)
~ 80 m

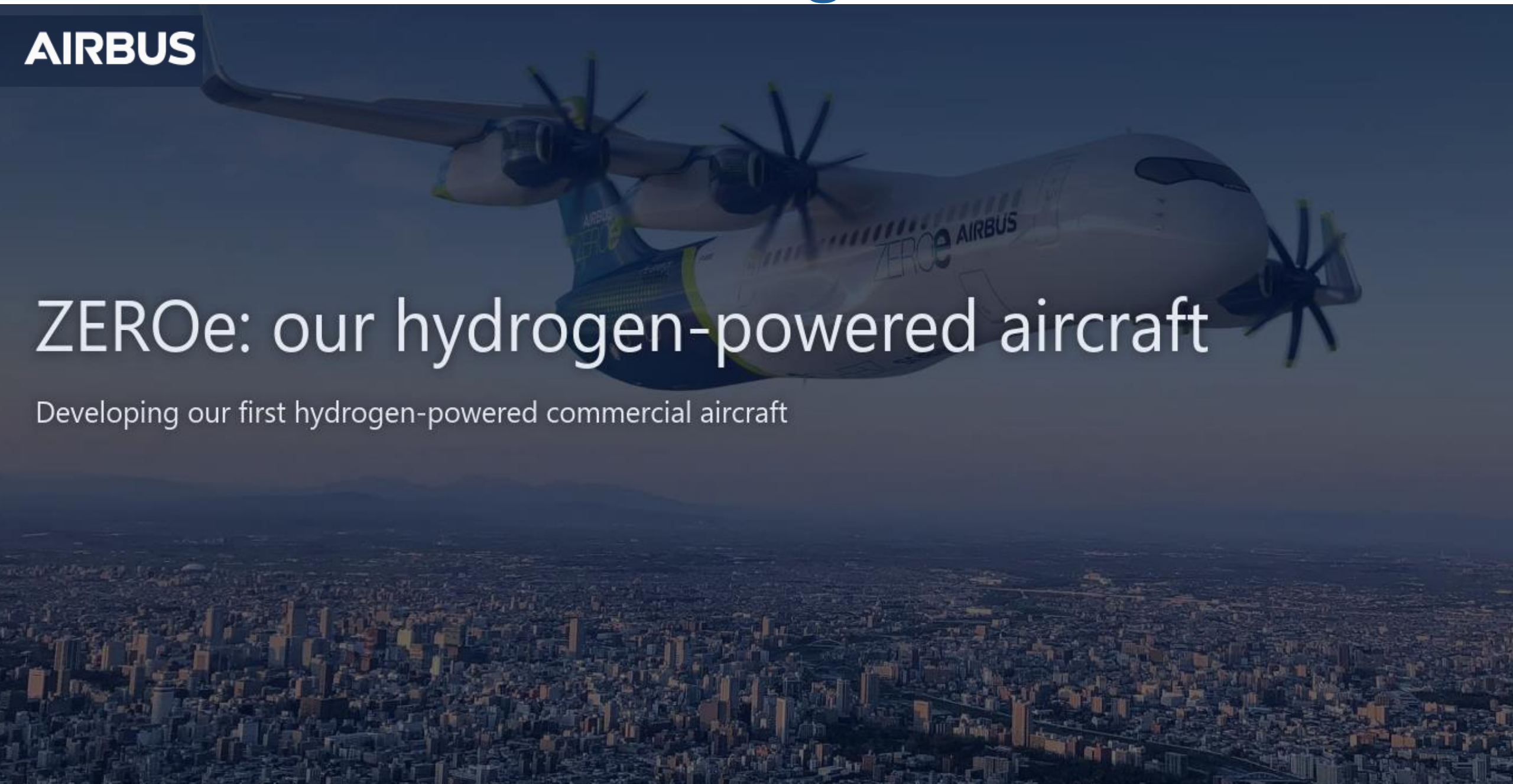
REBCO HTS (60 K → 20 K)
~ 5 m

Helium Gas Cooling

HTS for Aviation

- The **EU target** aims at reaching **zero emissions by 2050**
- **Electric and hybrid-electric** aircraft are a key pathway to achieve this zero-emission goal
- **HTS systems** are investigated **together with fuel cells** (as power sources) for **zero-emission, hydrogen-based propulsion**
  - **Liquid hydrogen**, stored on board as fuel for the fuel cells, also serves as the cryogenic source for the superconducting systems
  - **Fuel cells** generate electricity through an **electrochemical process**, producing **zero CO_2 emissions**
  - **HTS transmission lines** deliver current to the motor, offering **compactness and low weight**
  - A **superconducting motor** drives the propulsor with **high efficiency and power density**
- HTS can **also** enhance **battery- and turbine-electric aircraft** by reducing system weight and losses, provided that dedicated cryocoolers supply the necessary cooling

Airbus Programme

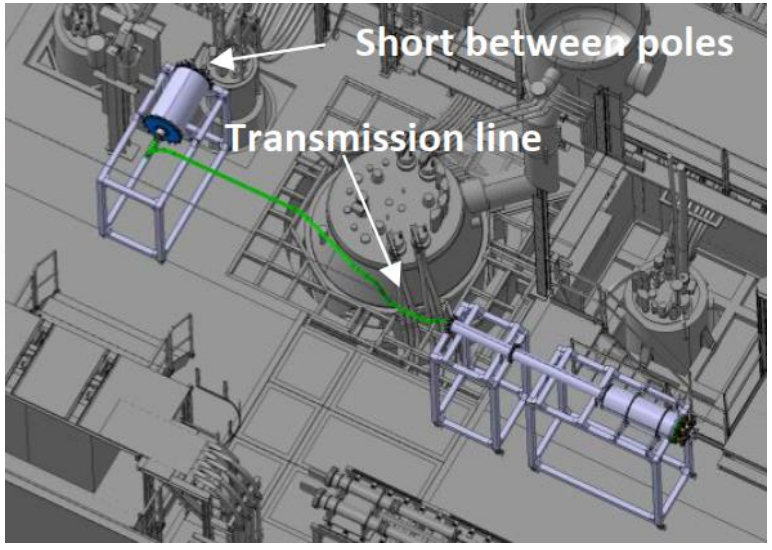


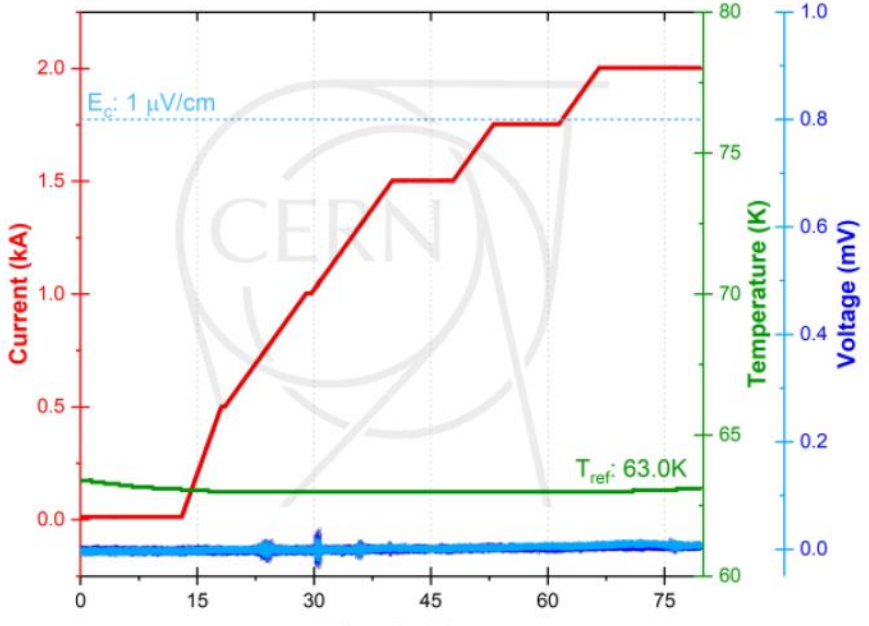
Collaboration Agreements with Airbus - SCALE

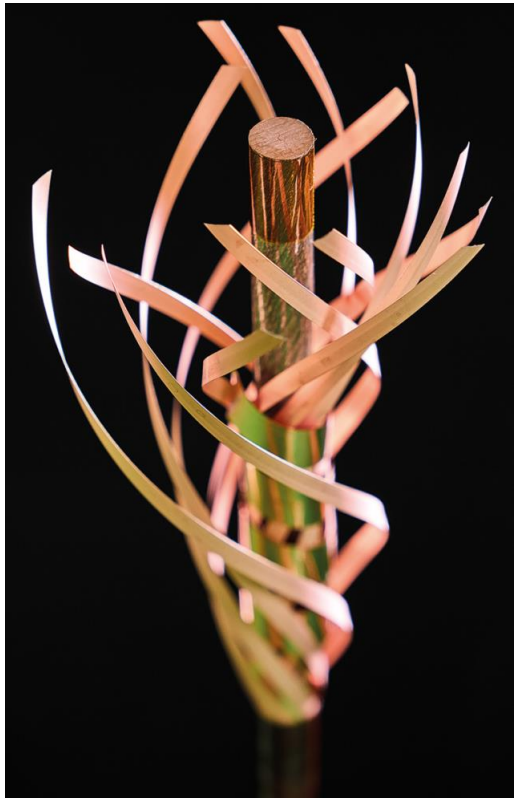
- **SCALE** (Super-Conductors for Aviation with Low Emissions) **demonstrator** developed and built at CERN (2022-2023). Successfully completed in 2023
- **Activities at CERN included**:
  - Development of high-current **lightweight HTS REBCO cables**
    - **A coaxial REBCO cable,** operated **2 kA in DC** mode at **60 K,** with a weight of **290 g/m**
  - Development, construction and test at CERN of a specific, one-off, superconducting **powertrain transmission line** incorporating the lightweight REBCO cables

Collaboration Agreements with Airbus - SCALE

CERN EDMS Nr: 3075001







REBCO Co-axial

± 2 kA DC

290 g/m

Collaboration Agreements with Airbus - SAMBA

- **SAMBA** (Superconducting Applied Materials for Broadband Aircraft Vibrations), 2025-2026
- Development and production of **REBCO cables** that will be **used in CRYOPROP**, the Airbus demonstrator that will integrate a two megawatt-class superconducting electric propulsion system cooled by liquid hydrogen via a helium recirculation loop and developed by Airbus. CRYOPROP will be tested in Ottobrunn, Germany. Airbus demonstrators:
  - **ASCEND** (Advanced Superconducting and Cryogenic Experimental powertraiN Demonstrator): electrical system demonstrator. Concluded in November 2023 with the test of a 500 kW prototype. Together with SCALE at CERN, it reached **TRL 5** by end 2023
  - **CRYOPROP** (Cryogenic Propulsion): hydrogen propulsion demonstrator. Launched in May 2024, it aims at demonstrating a subsystem at **TRL 4** by 2026
- Qualification of **transmission lines operated in a vibration environment** representative of a commercial aircraft. Construction of a dedicated test bench

HTS for Maritime Applications (1/2)

- In 2019, **marine transportation produced about 4% of total greenhouse gas (GHG) emissions** in the European Union
- **The International Maritime Organization** (IMO) has introduced **guidelines to reduce emissions** of carbon dioxide (CO_2), sulfur oxides (SOx), and nitrogen oxides (NOx)
- **Electrifying propulsion** and onboard systems helps meet the IMO guidelines
- **Energy storage systems** are vital to replace combustion engines and stabilize power
- **SMES** ensures **fast response and high power density,** outperforming batteries and fuel cells

HTS for Maritime Applications (2/2)

- **Significant electrical power on ships** (multi-megawatt electrical power continuously, often exceeding 50 MW total on large vessels) **for propulsion**, **maneuvering**, and **onboard system**
- **Power densities** are rising fast with **electrification**
- **HTS cables** (high-voltage DC (HVDC) distribution on ships), **motors**, and **generators**: more power, smaller, lighter, and more compact, quieter operation, and greener shipping
- **HTS SMES** can absorb or deliver megawatts of power in milliseconds, stabilizing the onboard grid. Could support load levelling or power stabilization during propulsion changes

HTS technology can be an enabler to manage high power densities efficiently

On-Going Collaboration Agreements for Maritime Applications

- **POSEIDON** (POwer StoragE In D OceaN). EU Reseach Project coordinated by Asociación Centro Tecnológico Naval y del Mar (CTN), Spain (2023 – 2026)

  Goal: demonstrate the applicability of three innovative fast-response energy storage systems (ESS) — supercapacitors, flywheels and **superconducting magnetic energy storage (SMES)** — in the marine transport sector, addressing on-board integration, cost, competitiveness, efficiency and safety

- **MARES** (MArine REciprocating Superconducting generator). EU Research Project coordinated by CIEMAT, Spain (2024-2028)

  Goal: develop a **superconducting** direct-drive **generator** that can efficiently convert wave motion into electrical power

POSEIDON (SMES for buffering) and **MARES (wave-energy conversion)**

POSEIDON SMES

IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 35, NO. 5, AUGUST 2025

	Parameter	Value
SC material	Material	2G HTS Tape
	Supplier	Shanghai Superconductors
	Dimensions	4.8 mm width & 0.34 mm (Cu lamination & Kapton insulation, see TABLE IV)
SC coil	Internal radius	86 mm
	Cross section	49x10 mm^2
	Turns	144 per coil (200 m. of tape)
Magnet	N° of Double pancakes	12
	Topology	Solenoidal
	Inductance	1.68 H
	Nominal current	457A @4.2K (220A @20K) (80% of critical current)
Cooling system	Operating temperature	4.2K@LHe bath (20K in operation)
Power and control system	Topology	Voltage Source Converter
	Voltage	500-600 V
SMES	Energy	275 kJ (@ 4.2K)

Main parameters of the **POSEIDON SMES**

Electric ship where the POSEIDON SMES system will be tested. Qualification the laboratory in liquid helium (4.5 K). Final operation at 4.2 K to 77 K

Superconducting SMES: ultra-fast response (μs), high power and high efficiency

Data Centers

- **Long-distance, high-voltage transmission**
  - Grid interface/sub station, 10-35 kV AC, Incoming utility power to the data center
- **Main distribution**
  - Within building, to data hall PDUs, 3–10 kV
- **Local, low/medium-voltage distribution** (power delivery to the IT racks)
  - Internal distribution local within data hall, ~1 kV AC or DC
- **Rack-level Supply**
  - Direct power to IT equipment, 400 V AC or 48 V DC

HTS in Data Centers

- Data centers face **escalating power demand**
  - Explosion of **Digital Services**, which has led to exponential growth in global data traffic
  - **Rise of AI** and **High-Performance Computing**
  - Massive **Cloud Expansion**
  - Increased **Redundancy and Reliability Requirements**
- **Sustainability** challenges. **HTS reduces energy losses** in power distribution, **minimizes cooling needs**, and enables compact, material-efficient design (**reduced footprint**). It also **supports renewable integration** through low-loss DC/AC links, enabling on-site solar, batteries, and sustainable microgrids

HTS Transmission **addresses the rapid escalation of facility power demand** (multi-100 MW class sites, >100 kW/rack). It allows delivery of **higher total current and power within existing spatial and thermal constraints**

On-Going Collaboration Agreement for Data Centers

- There are **different implementation pathways**, classified by how much of the existing electrical and cooling infrastructure needs to be modified — aiming to **minimize changes to existing building blocks**
- A **collaboration agreement with META** has enabled us to study various approaches for implementing **HTS transmission in data centers** and to identify the most promising configuration
- The **next step** will focus on **defining proof-of-concept demonstrations** and proposing prototype and pilot-scale initiatives.

Conclusions: HTS from Research to Sustainability

- HTS electrical transmission **proven** at CERN in demanding environments (**LHC** and **HL-LHC**)
- **Enables efficient electrification across sectors** — from aviation and maritime transport to data centers
- **Supports the energy transition** with lighter, denser, and cryogenically sustainable power systems
- As we move toward sustainability, technologies like **superconductivity find new purpose** — from enabling science to advancing **sustainable technologies and systems**