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PIANO NAZIONALE DI RIPRESA E RESILIENZA

MUR
Ministero dell'Università e della Ricerca

# Cryogenic systems for superconducting lines and magnetic energy storage


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# Outline

- Context
- The IRIS project:
    - 20 K Green Superconducting Line
    - Test station
- Hybrid lines for the transmission of electric and chemical power
- Superconducting Magnetic Energy Storage (SMES) devices
- Challenges

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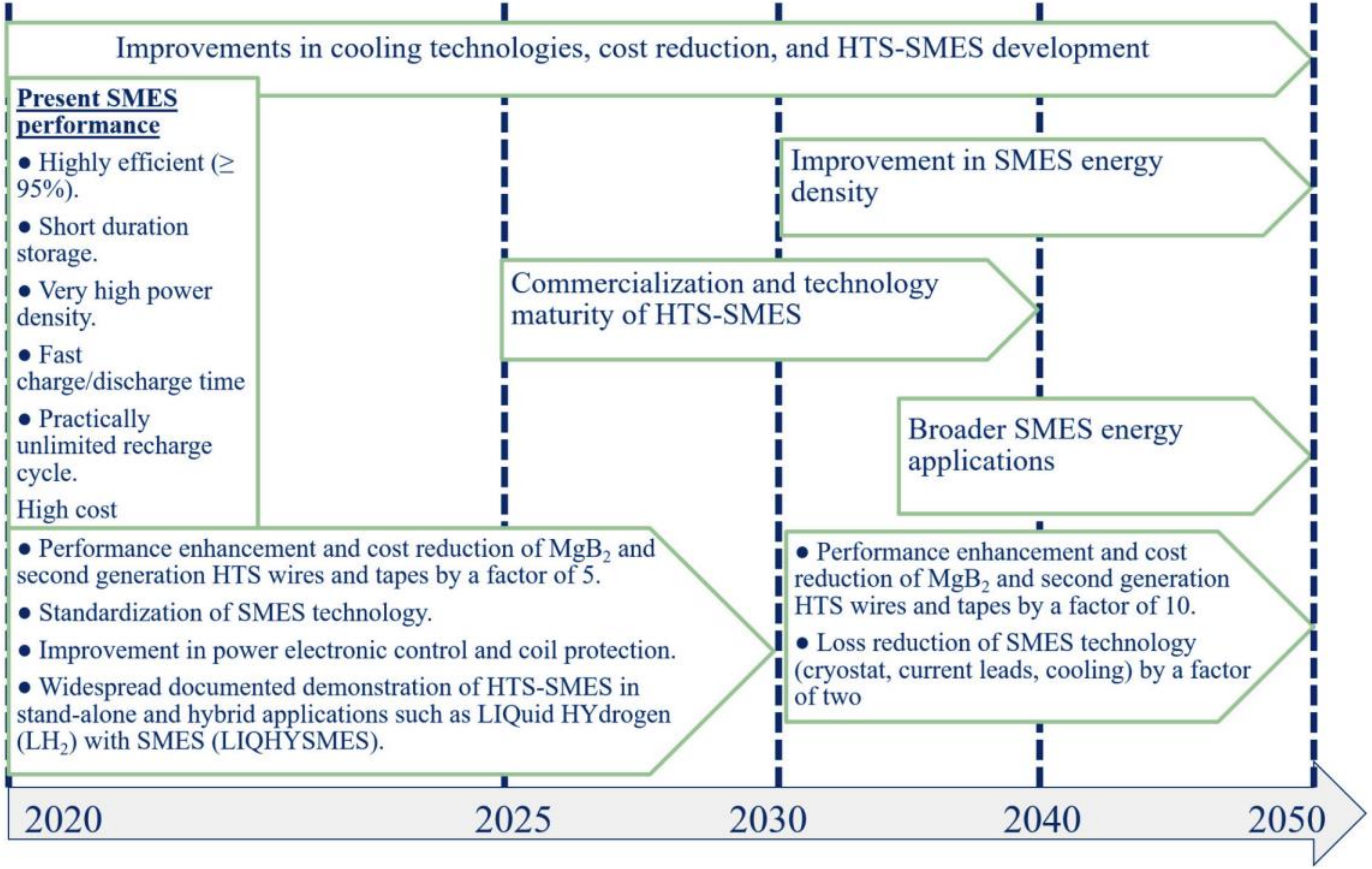
# Context – SC lines

| LOW TRL | MED. TRL | HIGH TRL |
| --- | --- | --- |

| Energy Delivery System | 2021 | 2025 | 2030 | 2035 |
| --- | --- | --- | --- | --- |
| Transmission (HV > 66kV)<br>Increase capacity for HV AC and DC circuits | HV AC Cable | - - - → | HV AC Cable | |
| | HV DC Cable | - - - - | - - - → | HV DC Cable |
| Limits faults on HV system | HV SFCL | | | |
| Substation<br>Interconnect substations on secondary side | MV AC Cable | | | |
| Limits faults on MV system | MV SFCL | | | |
| Replace conventional transformer | Transformer | - - - - | - - → Transformer | Transformer |
| Distribution (MV < 66kV)<br>Provide HV AC power to cities | MV AC Cable | | | |
| Retrofit existing ducted cables | MV AC Cable | - - → MV AC Cable | MV AC Cable - - → | MV AC Cable |

[B. Marchiolini et al, IEEE TAS 2023]

# Context - SMES




[B. B. Adetokun et al, J. Energy Storage, 2022]

# Innovative Research Infrastructure on applied Superconductivity: the IRIS Project

- Focus on developing high temperature and high magnetic field superconducting technologies both for civil applications
- Among the Societal Applications (WP8)

Goal: Green Energy transport at $0^3$ (zero cube) emission.

- **Zero (almost) $CO_2$ emission:**
- **Zero emission of e.m. radiation (DC)**
- **Zero (almost) ground occupation: 0.5 m underground piping may be rated up to 5 GW, the rating of a overhead line (30 m high and 50 m wide area required).**
- **Energy loss about 1% (average about 6 % for TERNA)**

**Important for society but also for the sustainability of big research infrastructure**

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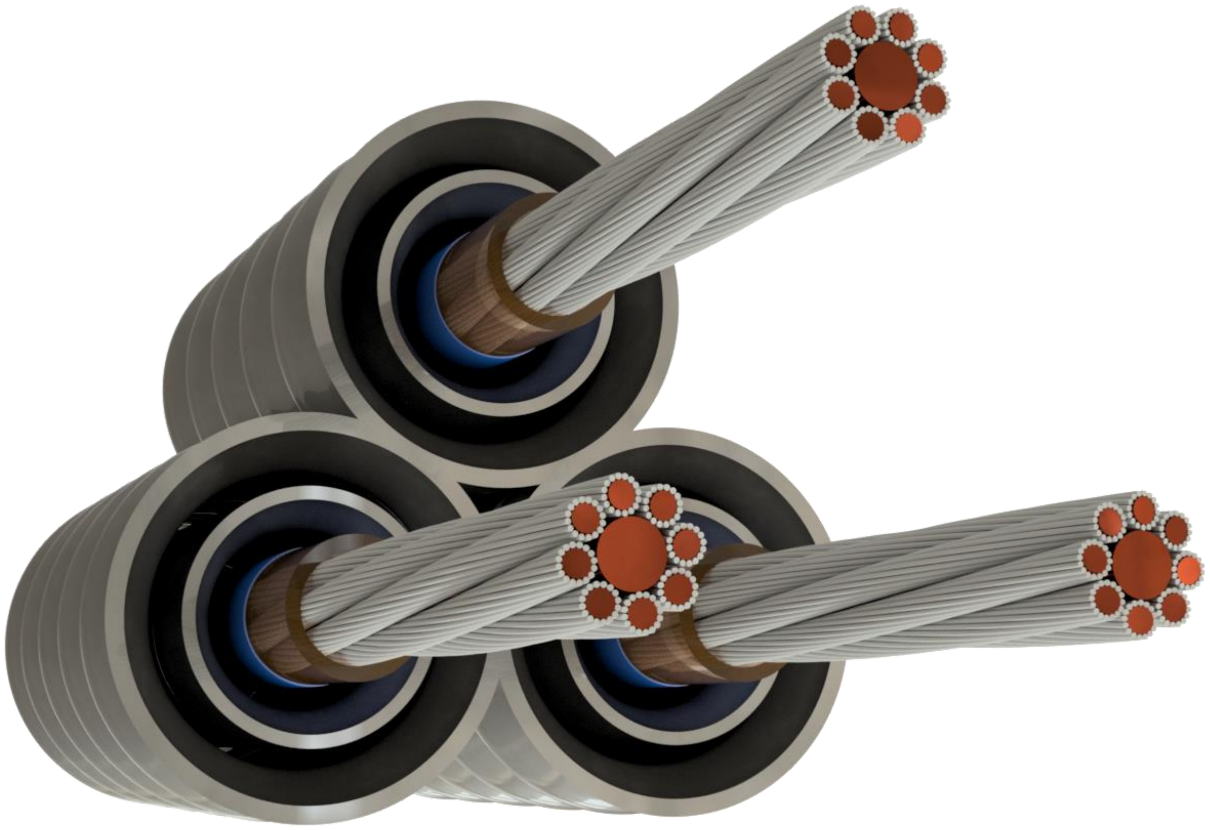
# Design of a 20 K Green Superconducting Line (GSL)

- 40kA – 25 kV rating (1GW)
- 130 m
- 4 x MgB2 conductors
- Full redundancy
  (1 spare conductor-cryostat
  and emergency ground return)
- He cooled (20 K, 10 bar)
- Total heat load $\leq 3\ W/m$
- In line joint (plus!)



Overall cable diameter $\sim 100\ mm$,
Cryostat diameter $\sim 250\ mm$

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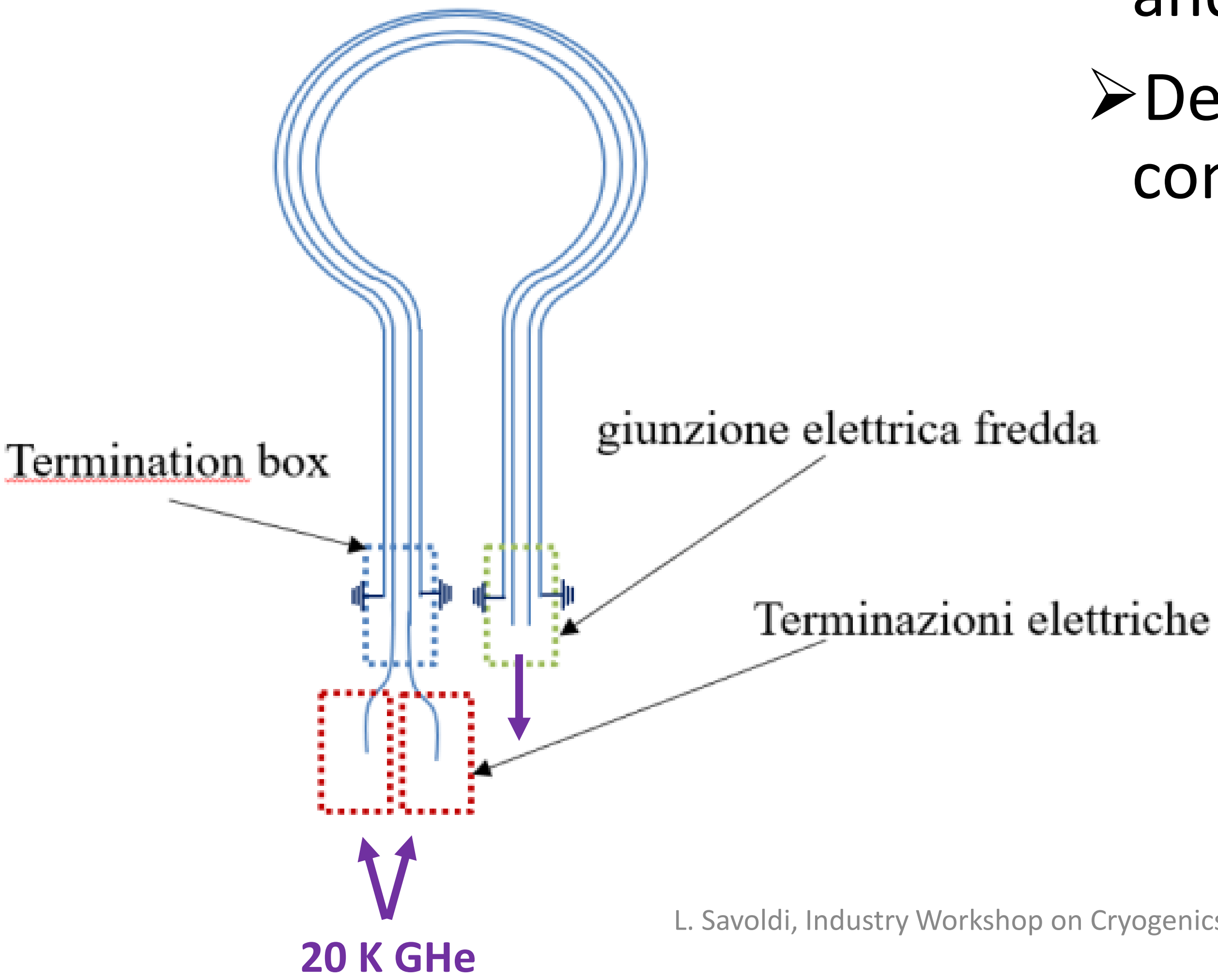
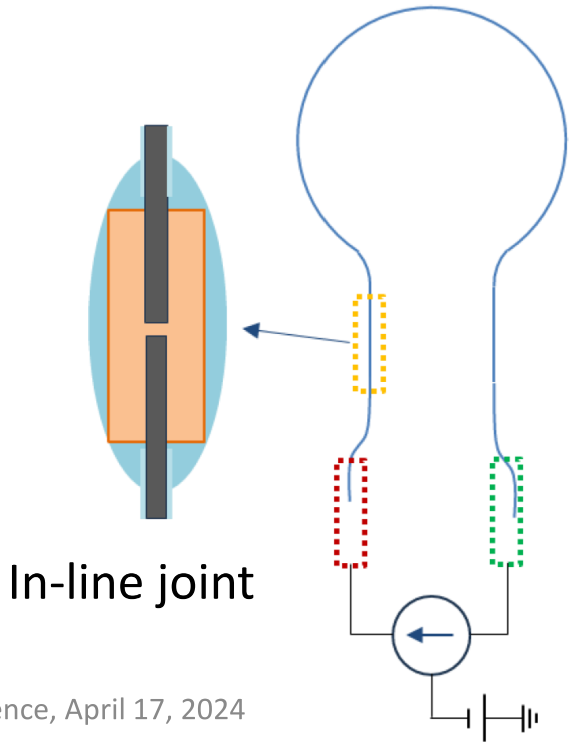
IRIS

# Installation of the 20 K GSL

Bending radius $\sim 2\ m$




- Supply of the 1GW GSL, the cryostat and the power leads
- Delivery and installation to Salerno to commission the Test Station



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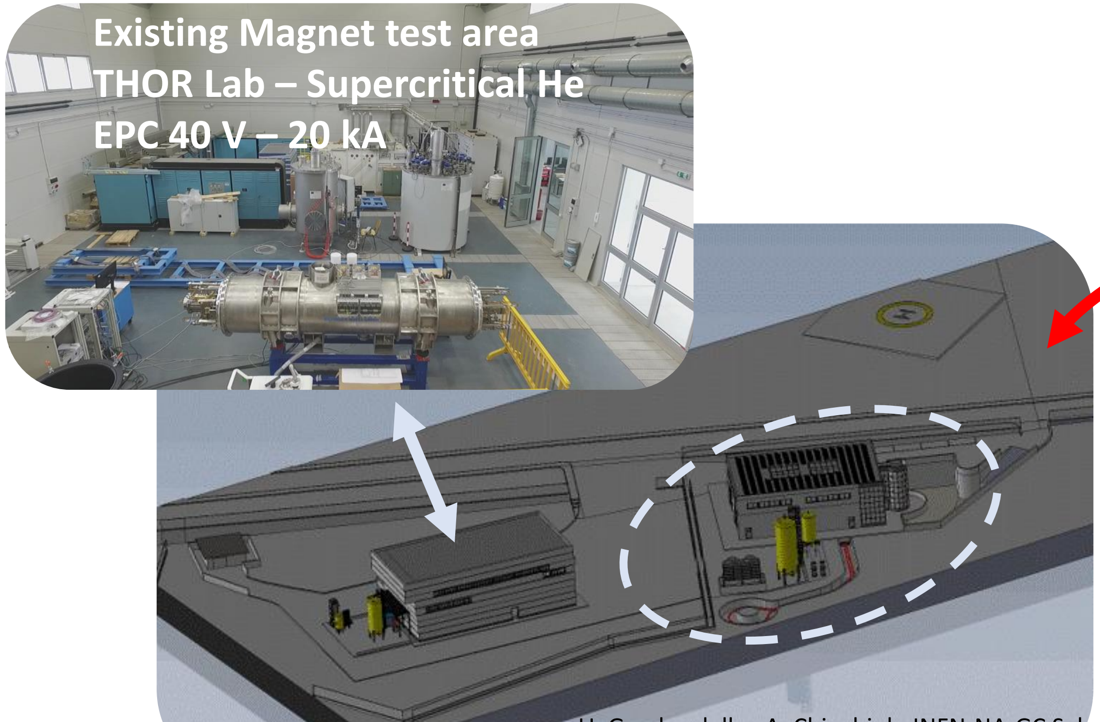
IRIS

# The Test Station - I

A full test station is also being constructed in the framework of the IRIS project in the Salerno premise. The test station will be open access for research institutes and industry and is intended to become a benchmark for standardization.



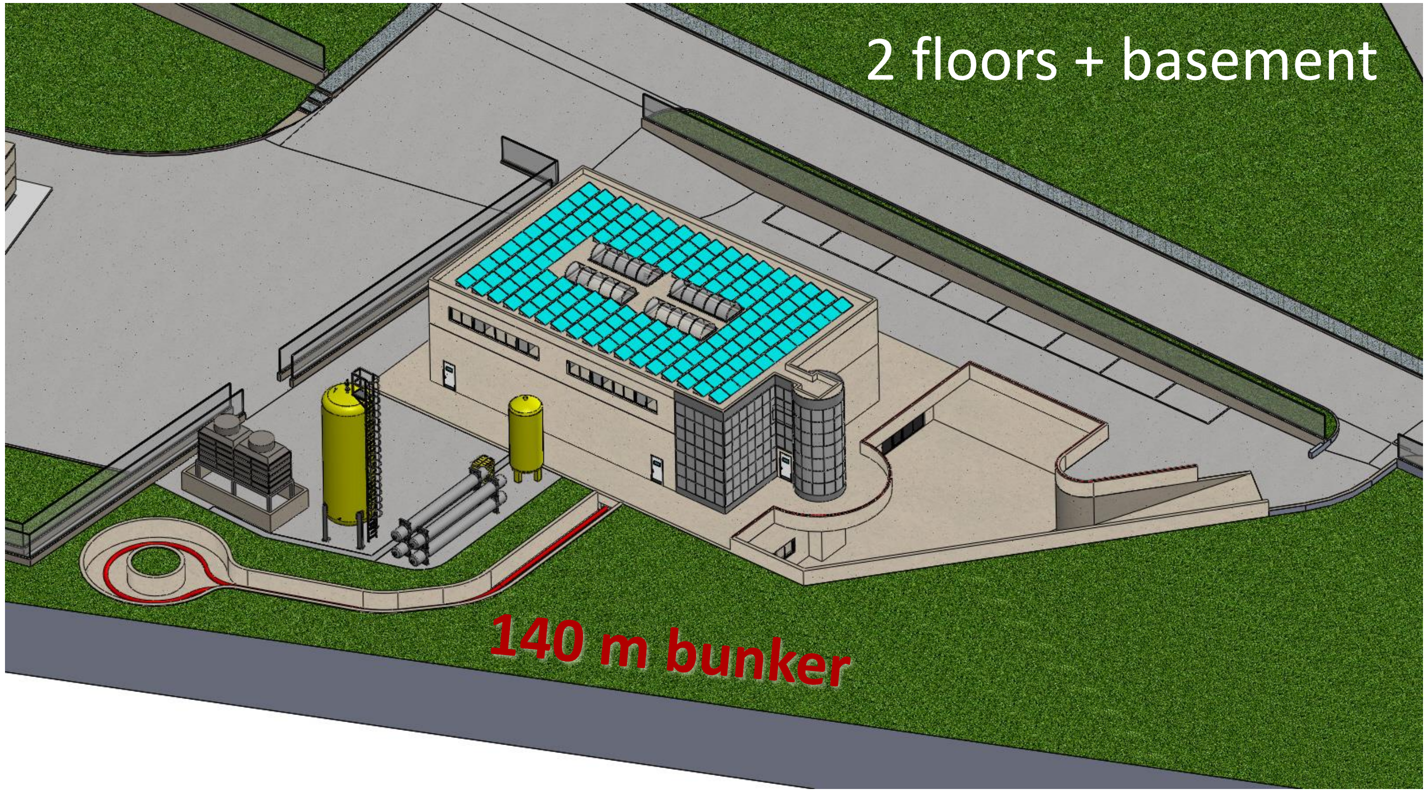

U. Gambardella , A. Chiuchiolo INFN-NA-GC Salerno and S. De Pasquale, Univ. of Salerno


*Figura 1 – Vista aerea del Campus ed individuazione del lotto su cui sarà realizzato l'edificio*

# The Test Station - II

The facility is planned to be operational in 2025 IV Q

Open access (RI and industry) rules to be defined




Test facility in Salerno

- Voltage up to 50 kV
- Power supply 40 kA (at 50 kV)
- Cooling power 500 W @ 20 K G-He gas
- 140 m long covered bunker for cable
- DAQ and integration by UniNa (Prof P. Arpaia)

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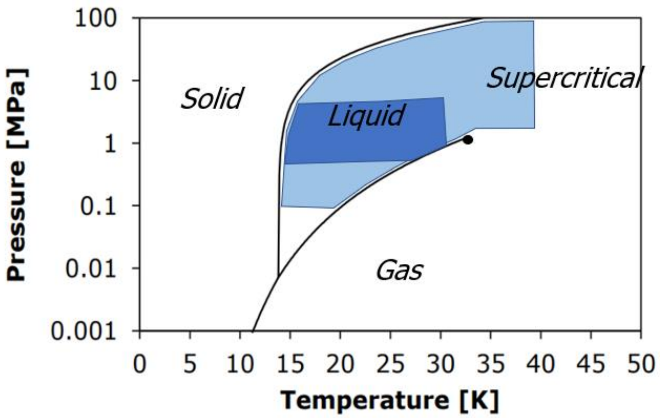
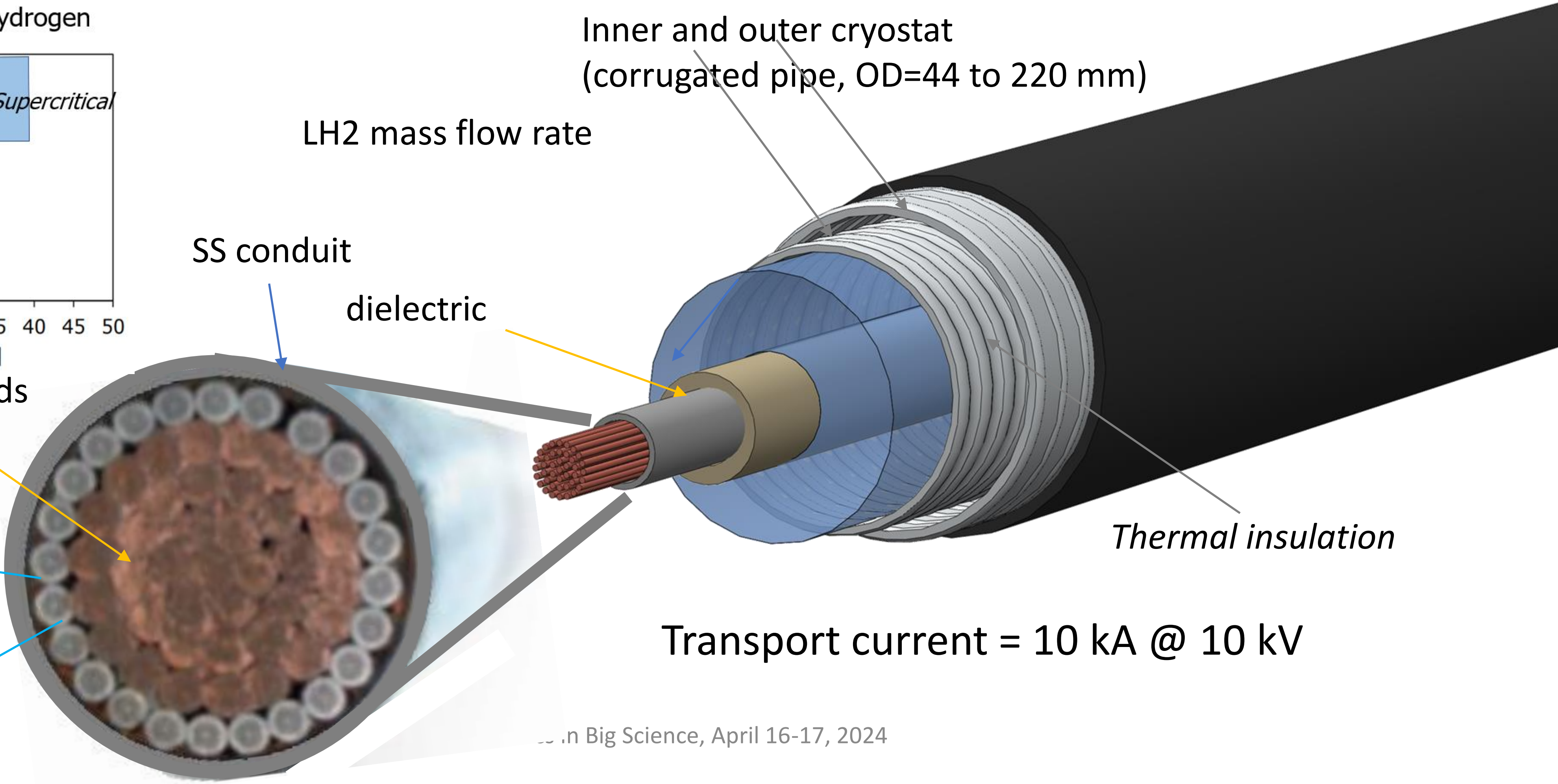
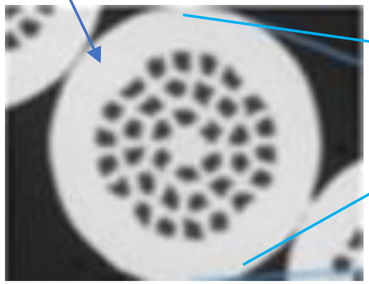
# Design of an hybrid line for the transmission of electric and chemical power: the SCEP - I

## e.g., DC single-pole single-coolant (0.1-GW$_e$ ,0.1 GW$_t$) hybrid lines

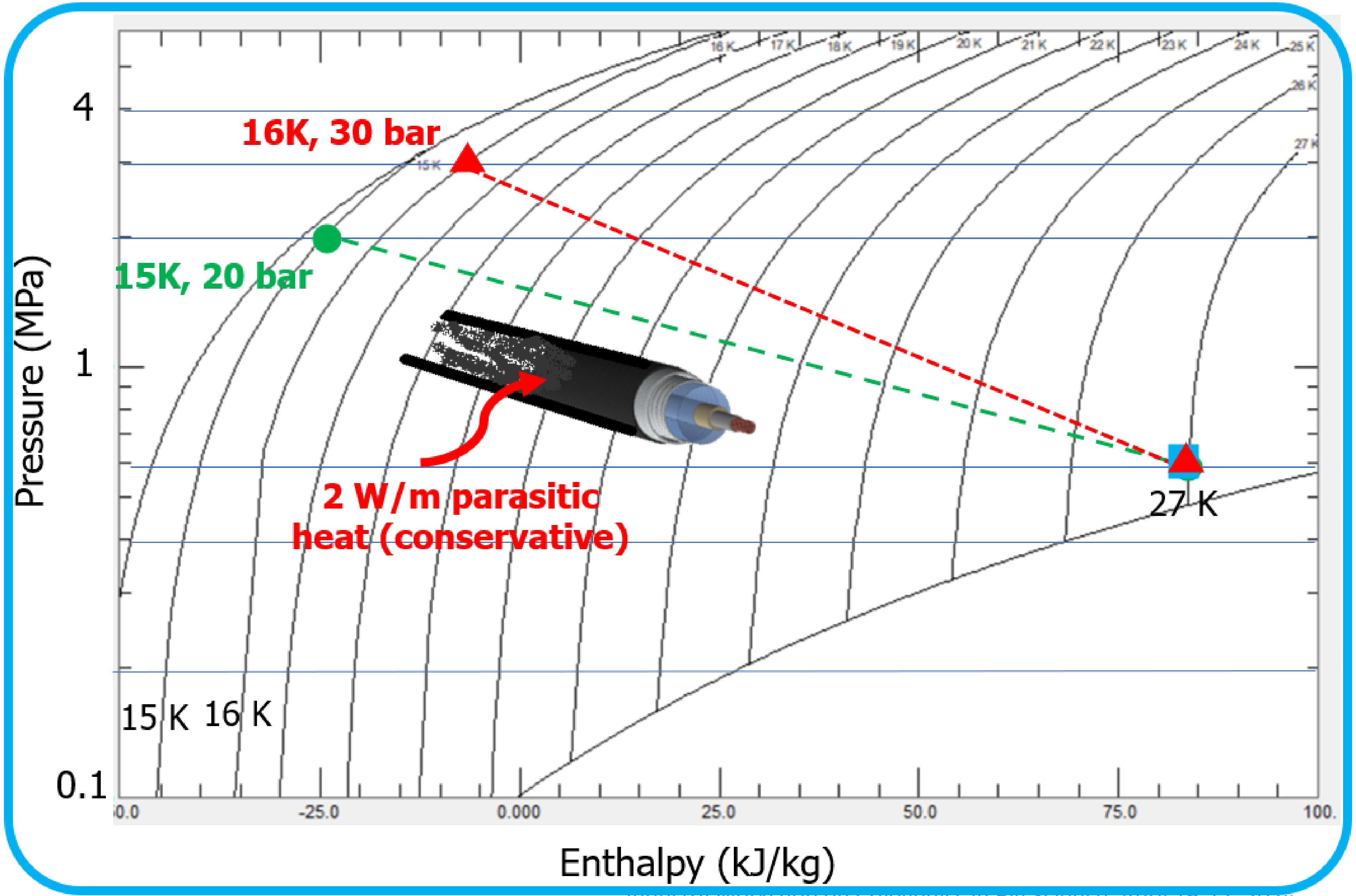
p-T diagram of para-hydrogen



# Design of an hybrid line – II




- 10 kA, 10 kV cables can reach 60-70 km transferring ~1-1.5 kg/s of $LH_2$, also contributing to hydrogen storage
- Test facility to assess friction factors and parasitic load under design

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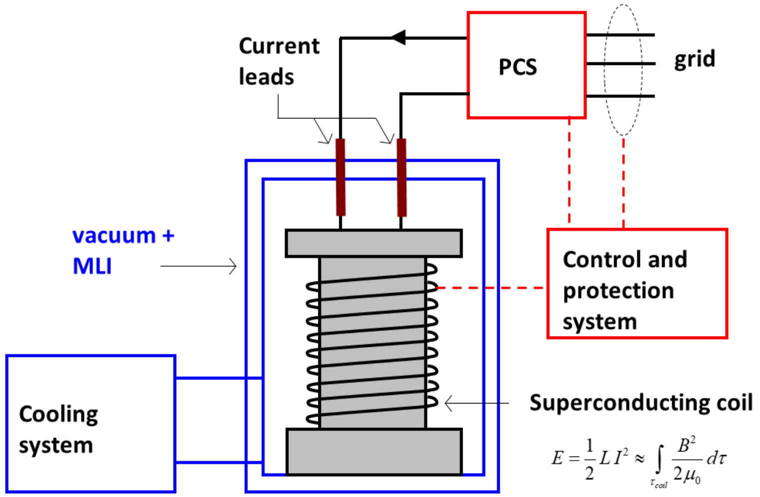
# Hybrid lines for the transmission of electric and chemical power

Relevant Interest National Project (**PRIN**) awarded to PoliTo and UniBo, in collaboration with INFN:

- Design of a $MgB_2/LH_2$ hybrid line with detailed electro-magnetic, thermal-hydraulic, thermo-mechanic analysis in normal and off-normal conditions, tailored for an Italian test-case
- Techno-economic performance to be considered to start introducing hybrid lines in dispatchment models

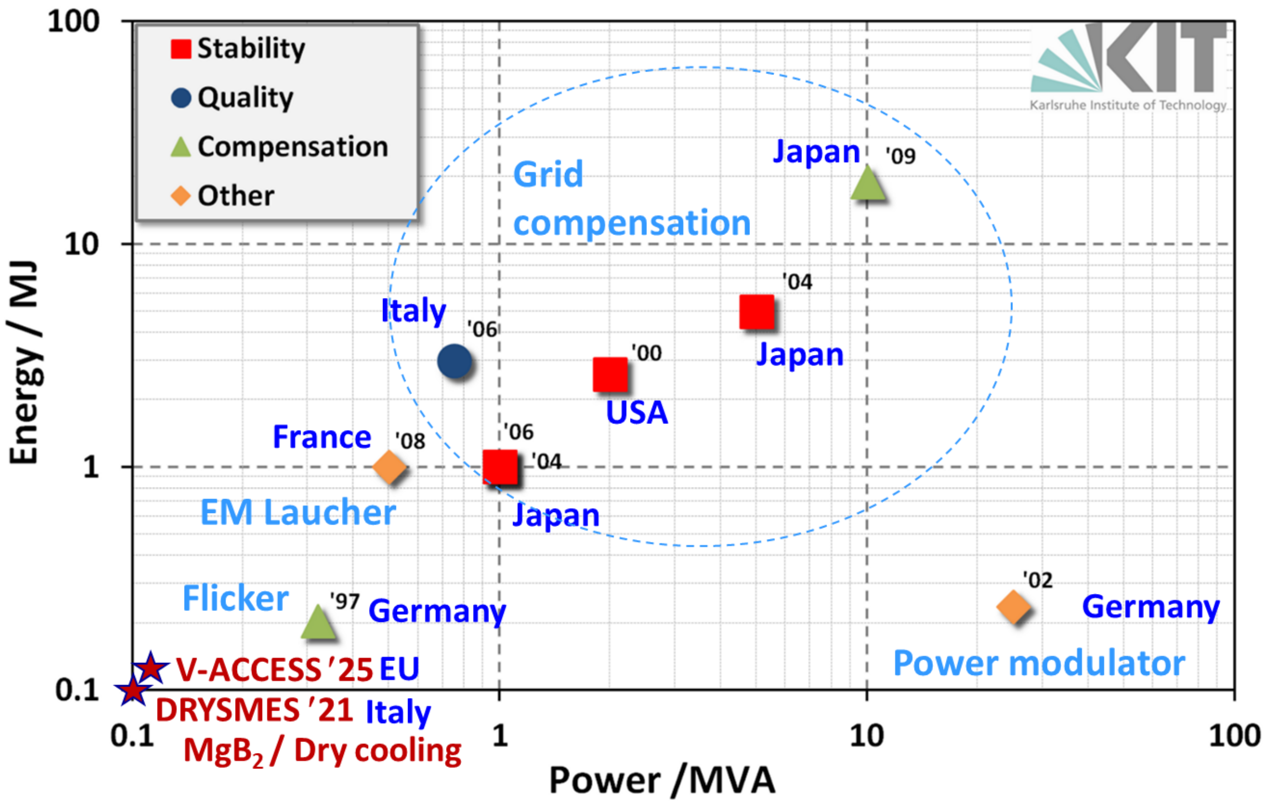
This study was carried out within a project –funded by the Ministero dell'Università e della Ricerca –within the PRIN 2022 program (D.D.104 -02/02/2022). This manuscript reflects only the authors' views and opinions and the Ministry cannot be considered responsible for them

# Superconducting Magnetic Energy Storage devices (SMES) - I




- High deliverable power
- Virtually infinite cycling capability
- Limited energy density

Suitable for
- high-power stand-alone systems
- Combined use with batteries in optimized hybrid ESS




- LTS SMES systems with up to 10 MW power developed and operated in field
- Advanced cryogenic is the enabler for modern and cost effective HTS SMES

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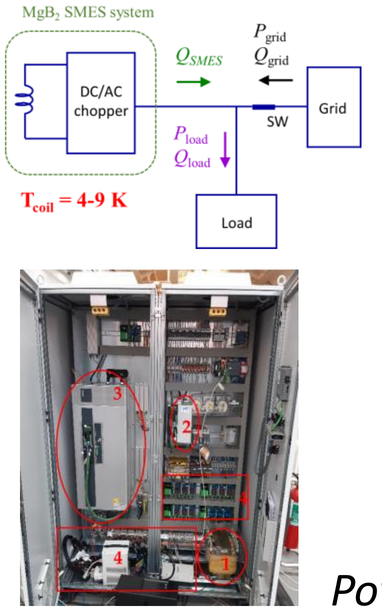
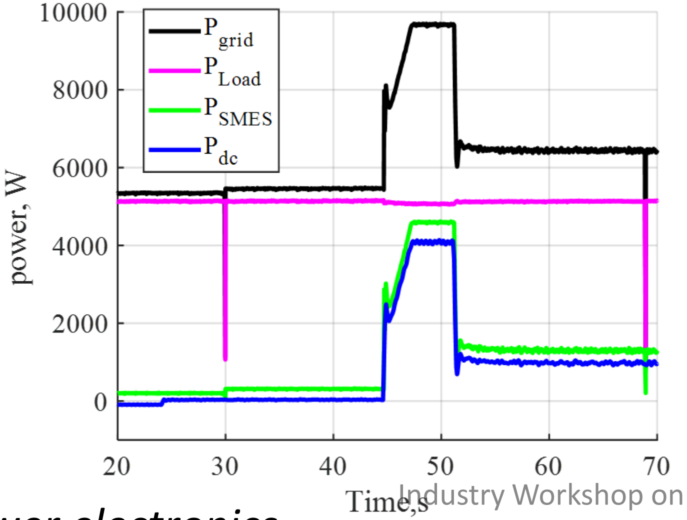
# Superconducting Magnetic Energy Storage devices (SMES) - II

DRYSMES4GRID

Superconducting Energy Storage for Smart Electrical Grid


*MgB2 SMES coil and cooling system*




*Power electronics*

**New approach to SMES technology with HTS material and advanced cooling recently started**

**A 21 kJ / 7 kW dry-cooled SMES system was developed based on a state-of-the-art $MgB_2$ wire confirming:**

- Ability of the coil to undergo extremely fast charging at increased temperature up to 9 K
- Ability of the system to exchange controlled power and to operate in a grid

**Next steps in SMES research:**

- **Material optimization – develop high current conductors with reduced AC loss**
- **Cryogenics - develop innovative cooling approach allowing continuous charge/discharge at high power**

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# Challenges

Make SC lines and SMES attractive for stakeholders

→ Increase the number of in-field installations to improve confidence of final users and to assess reliability

→ Decrease capital cost - demonstrate feasibility of cheaper solutions

→ Improve global efficiency and availability, and reduce operational costs

→ If LH2 is used, demonstrate safety

→ Investigate impact on the grid and explore novel technical transmission solution enabled in the long term

→ Communicate technical potential and impact to a wider audience