# $sCO_2$ webinar series

## Energy Storage & $sCO_2$

10th episode – 6 February 2026

# ETN Global

Safe, secure, affordable and dispatchable carbon-neutral energy solutions

ETN Global

## ETN Global – Key facts

- International non-profit membership association and a strategic platform
- ETN in numbers
  - **140+ member organisations**
  - **21 countries**
  - **4 continents**

# Webinar moderators

- **Jitka Špolcová** (ETN Global)

- **Amgad Khamis** (ETN Global – iSOP project)

- **Marco Ruggiero** (Baker Hughes)

# Speakers

- **Isabel González-Cuenca** (European Commission)

- **Stefano Barberis** (University of Genoa)

- **Tim Held** (Echogen)

# Why do you think energy storage should be relevant?

- Decatbonization
- Intermittency
- Energy demand satisfaction
- Economical use of renewables
- To satisfy demand response
- Flexibility
- Grid balancing
- Energy transition
- Stable grid
- Renewables integration
- Renewanles
- Stable price
- Renewables
- Volatility of renewables
- Renewable energy
- To balance renewables
- Reduce bill
- Balance
- balance renewables
- Grid stability
- Storage of green H2
- Efficiency
- Grid pricing
- Transportation
- Stability
- renewable compensation
- Continous
- To justify an increase in renewable of energy share
- Grid forming
- Demand response

# European Energy Storage Inventory

*JRC. C.3.*

*Gonzalez-Cuenca M.Isabel*

6 February 2026

European Commission

Joint Research Centre

# Content

# Science for policy

ANTICIPATE

INTEGRATE

IMPACT

## Our purpose

The Joint Research Centre provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society.

# The JRC sites

Headquarters in **Brussels** and research facilities located in **5 EU Countries:**

- Belgium (Geel)
- Germany (Karlsruhe)
- Italy (Ispra)
- The Netherlands (Petten)
- Spain (Seville)


European Commission

# Background

**Unit C3:**

Smart grids

Distribution system

Market design

Labs (Petten +Ispra)

**Cooperation:**

Administrative agreement DG ENER

JRC data team

JRC Cooperation with D3, C7 and C1

Enabling other researchers

**Storage as a crucial topic:**

Renewable deployment

Flexibility needs

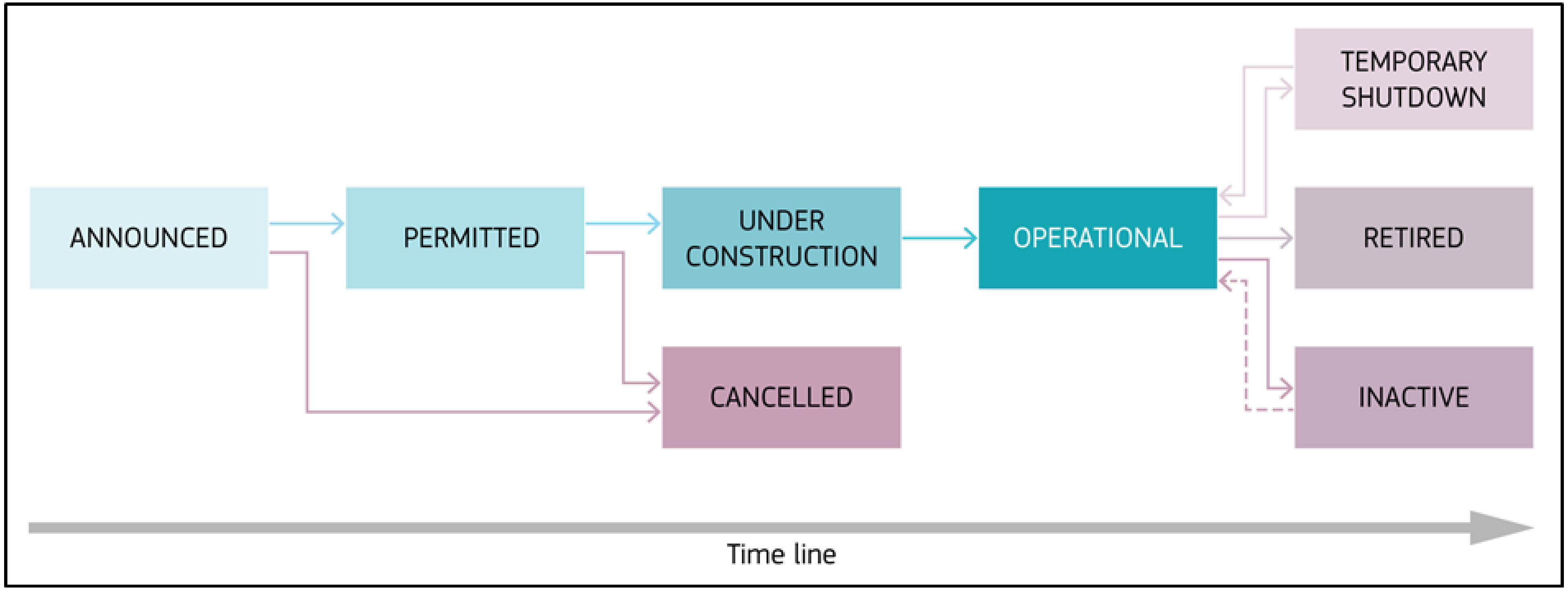
Security of supply

# 2. Description of data. Technology/Subtechnology

## Technologies in the European Energy Storage Inventory

- **Mechanical**
  - Pumped Storage hydropower (PSH)
  - Compresses Air Energy Storage (CAES)
  - Fly wheels
  - Liquid Air Energy Storage (LAES)
- **Electrochemical**
  - Iron air battery
  - Lithium iron phosphate battery (LFP)
  - Lithium manganese oxide battery (LMO)
  - Lithium nickel cobalt aluminium oxide battery (NCA)
  - Lithium nickel manganese cobalt oxide battery (NMC)
  - Unspecific Storage battery
  - Lead Acid batteries
  - Lithium-ion batteries
  - Lithium-Metal-Polymer batteries
  - Lithium-titanate battery (LTO)
  - Redow flow batteries Zn Fe
  - Redox flow batteries Vanadium
  - Sodium Nickel Chloride batteries
  - Sodium Sulphur batteries
- **Electrical***
  - Supercapacitors *
  - Superconducting Magnetic Energy Storage (SMES)*
- **Chemical**
  - Power to Ammonia – Gasoline*
  - Power to Gas (H2)
  - Power to Methanol + Gasoline*
  - Power to Methane*
- **Thermal**
  - Sensible Thermal Energy Storage (STES)
  - Latent Thermal Energy Storage (LTES)*
  - ThermoChemical Storage (TCTES)*

# Description of data. Status




Expected: announced, permitted and under construction

# Description of data. Countries

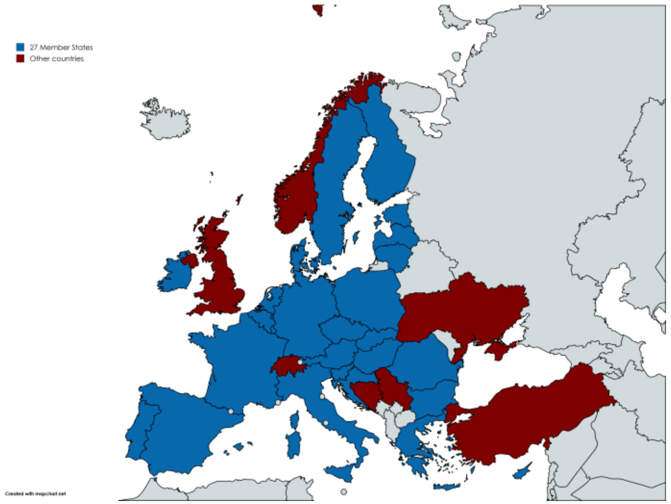
Sources: Wood Mackenzie, IEA, public sources, owners.

In house enhancement of data

Fields available:

Power and Capacity

Location



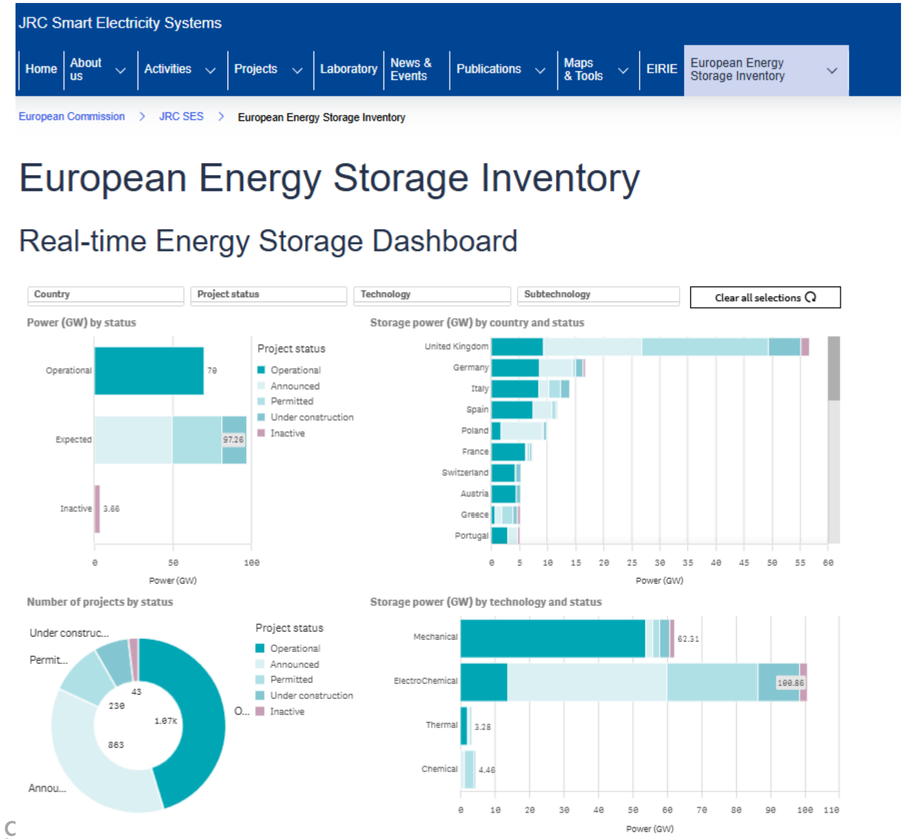

**Public data**

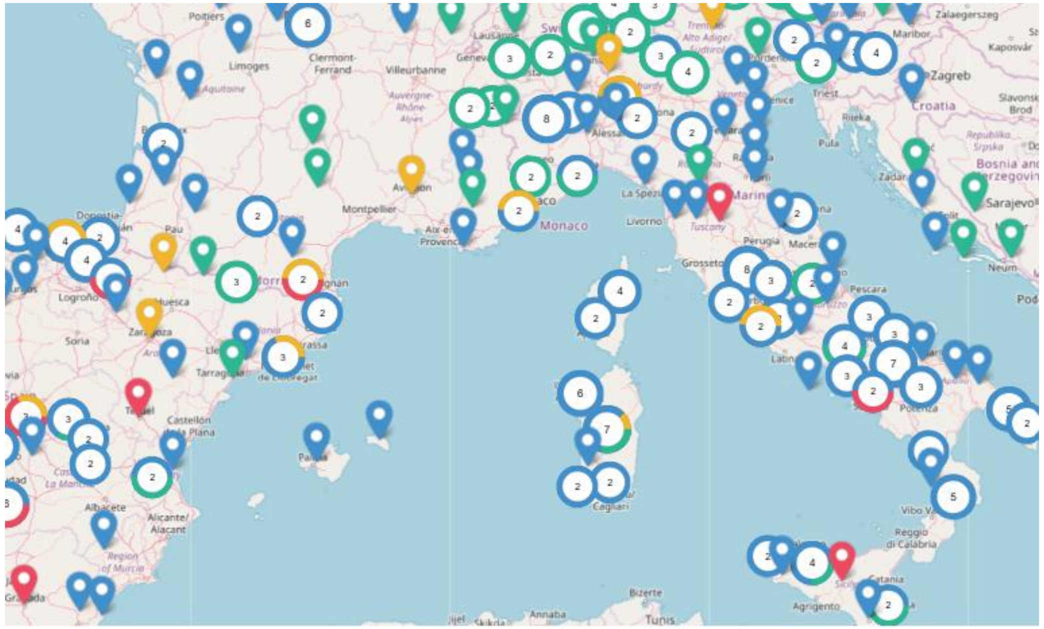
- Technology
- Status
- Power (MW)
- Capacity (MWh)
- Country
- Region

# 3. Website

**Link: https://ses.jrc.ec.europa.eu/storage-inventory**

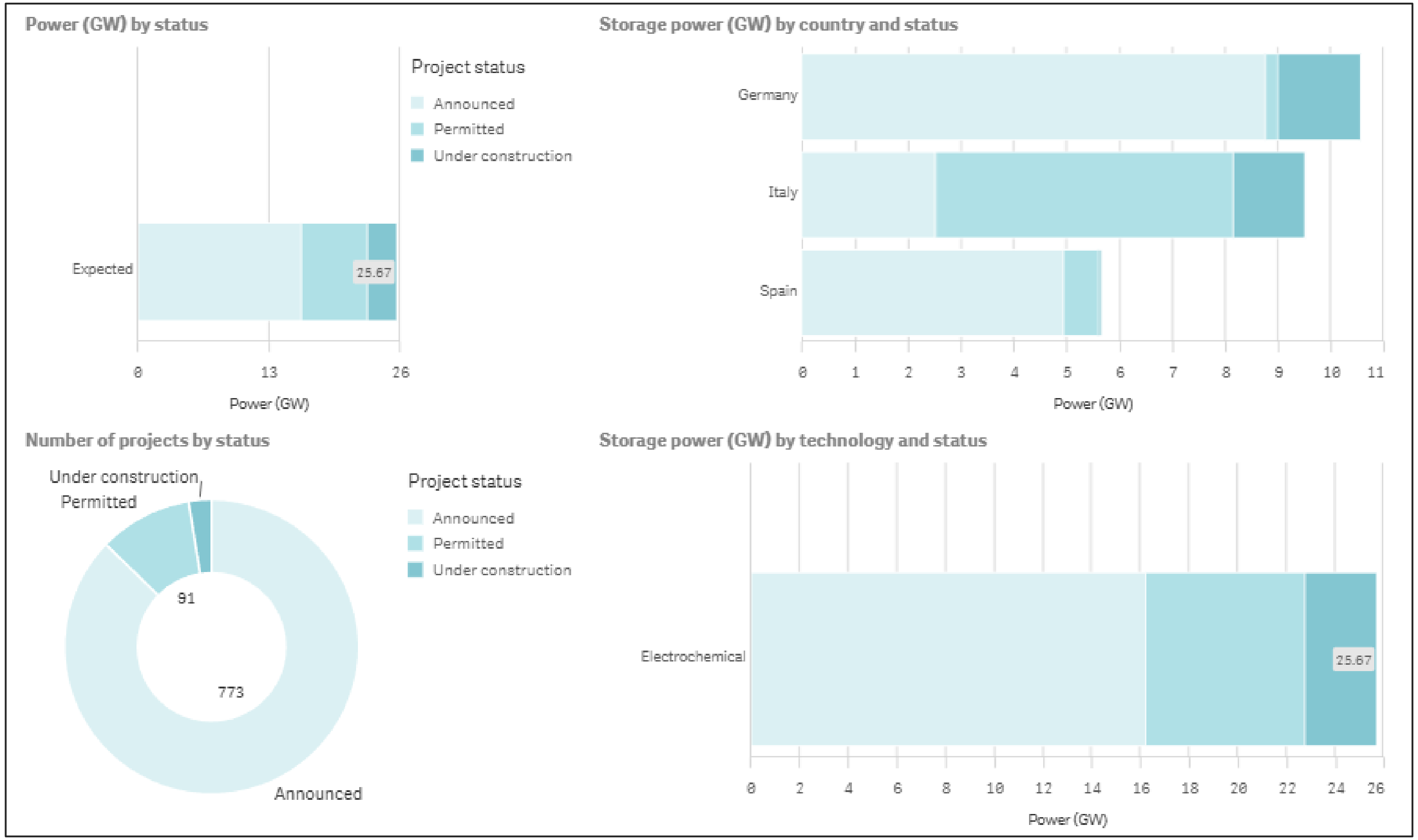
- Main sections: Dashboard and Interactive map
- Interactive, filters



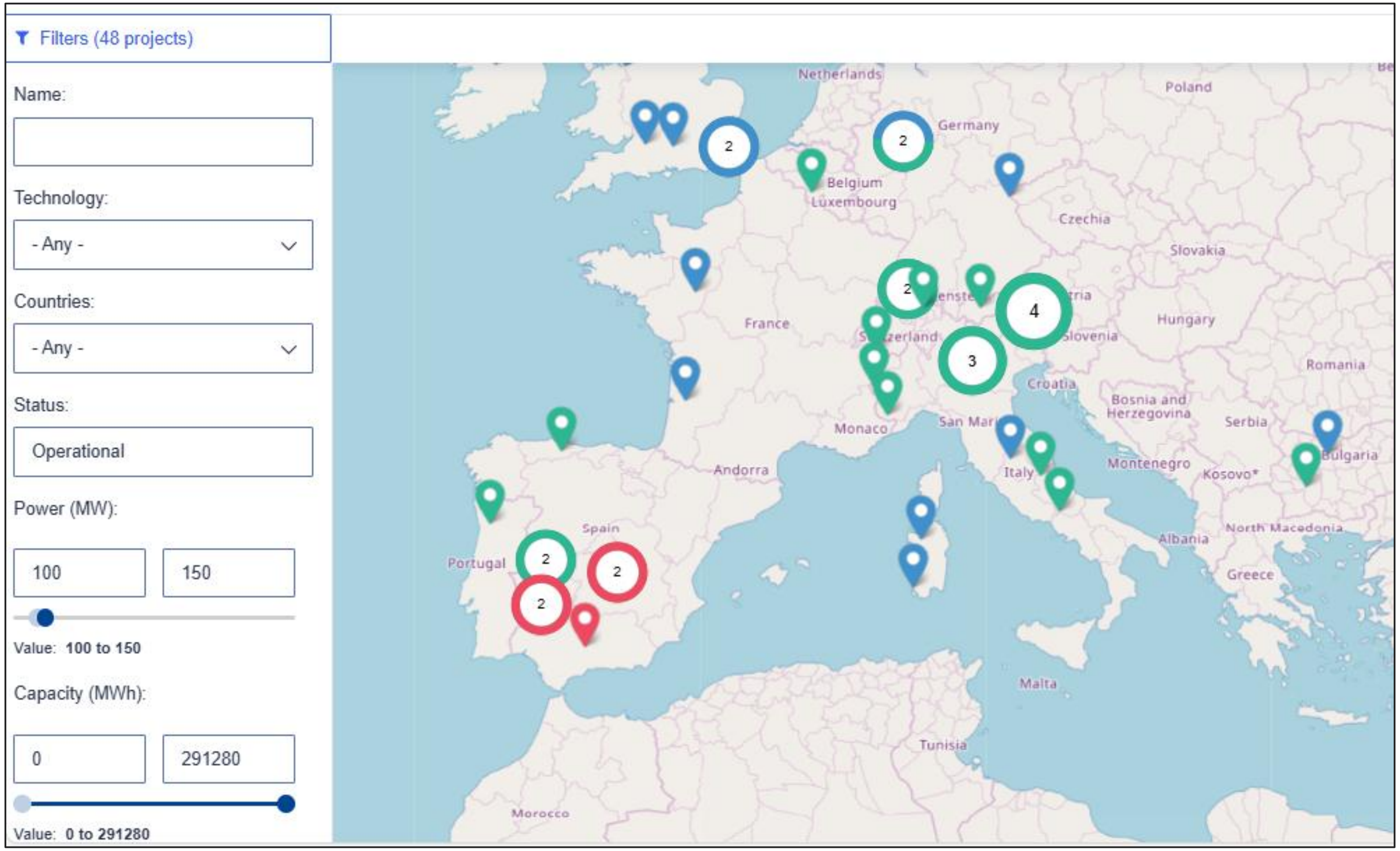
# Website. Dynamic Dashboard

➤ Let's play with the dashboard;  selecting countries, status, technologies



# Website. Filtering.

- Let's play with the map, zooming and filtering
- Example: from 100 to 150 MW, operational



# Website. Dedicated pages

- Clicking on the map

## Project: Riso Syslab Redox Flow

STATUS: Operational

- Power: 0.02 MW
- Capacity: 0.12 MWh
- Duration: 6 hours

**Technology and subtechnology**

ELECTROCHEMICAL | Redox flow batteries Vanadium

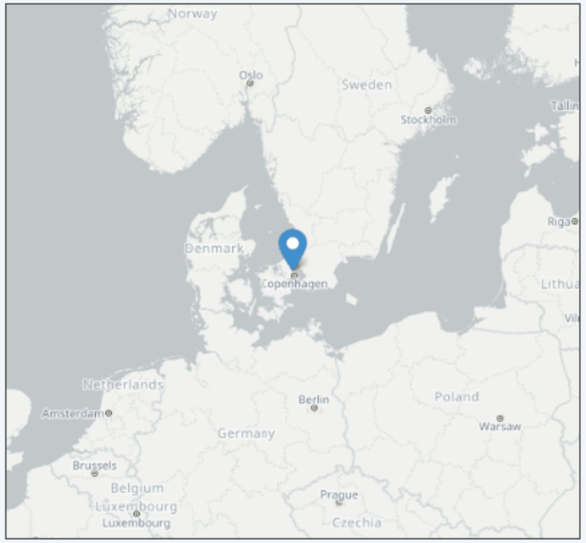
### Facility

**Country**
Denmark

**Region**
Hovedstaden

**Second Level**
Denmark

**Coordinates (lat,lon):**
55.784638 , 12.504610

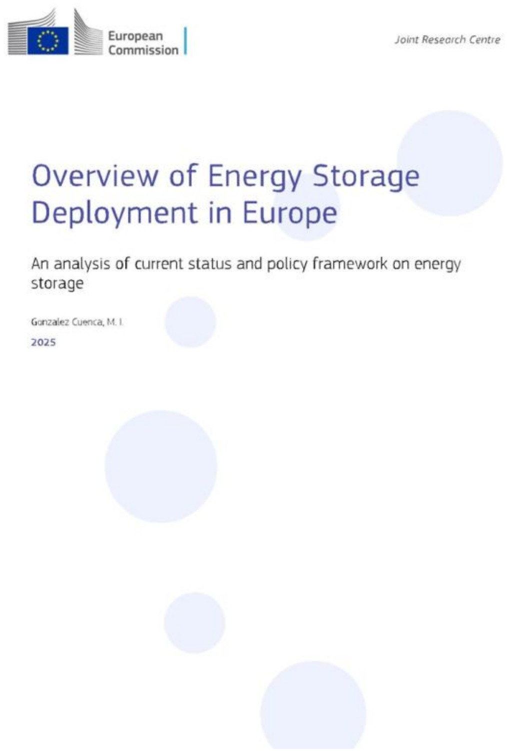



Webtools + © EC-GISCO + Leaflet | © OpenStreetMap | Disclaimer

**Disclaimer:** The information displayed about this project has been obtained from the dataset provided by Wood Mackenzie. Wood Mackenzie Limited, subject to any additional data modifications and/or input provided by the EC or any of its authorised 3rd party contributor.

# 4. Main results

- Report on deployment


European Commission

Joint Research Centre

Overview of Energy Storage Deployment in Europe

An analysis of current status and policy framework on energy storage

Gonzalez Cuenca, M. I.

2025

[JRC Publications Repository - Overview of Energy Storage Deployment in Europe]

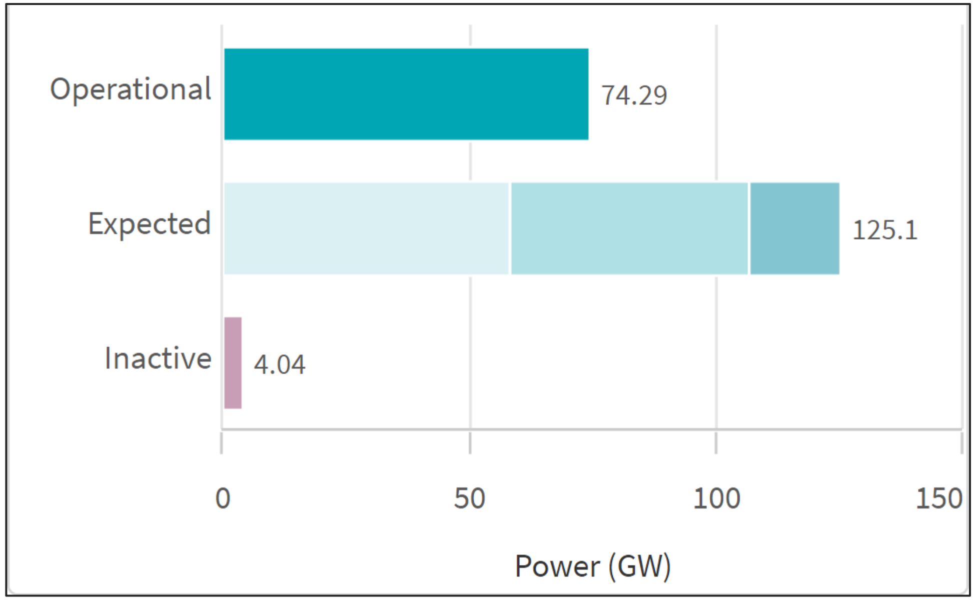
- Upcoming report on MS plans



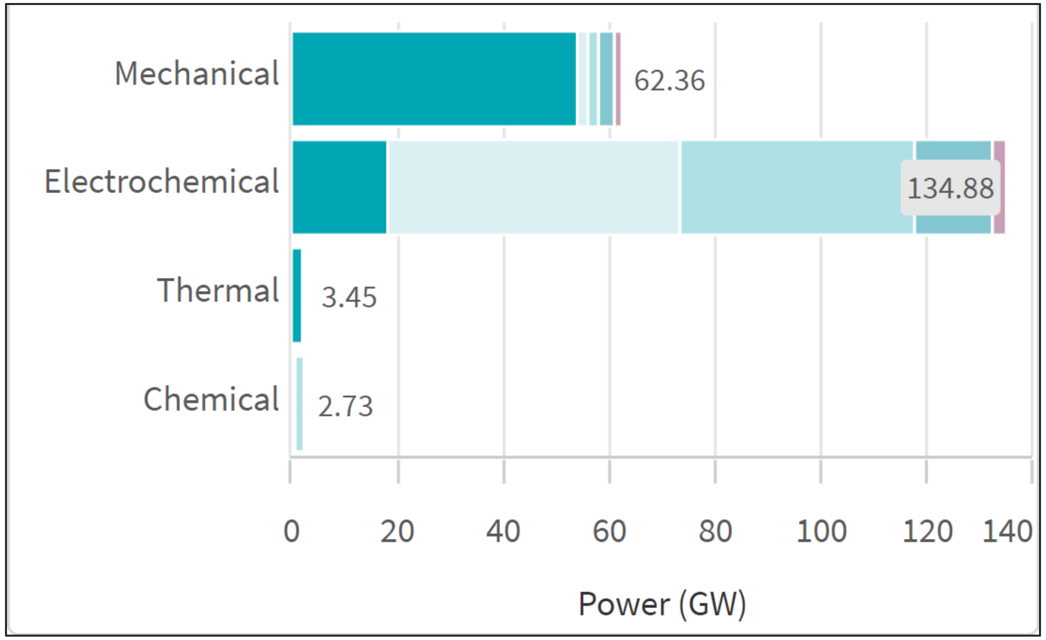
European Commission

# Main results

- Power (GW) by status

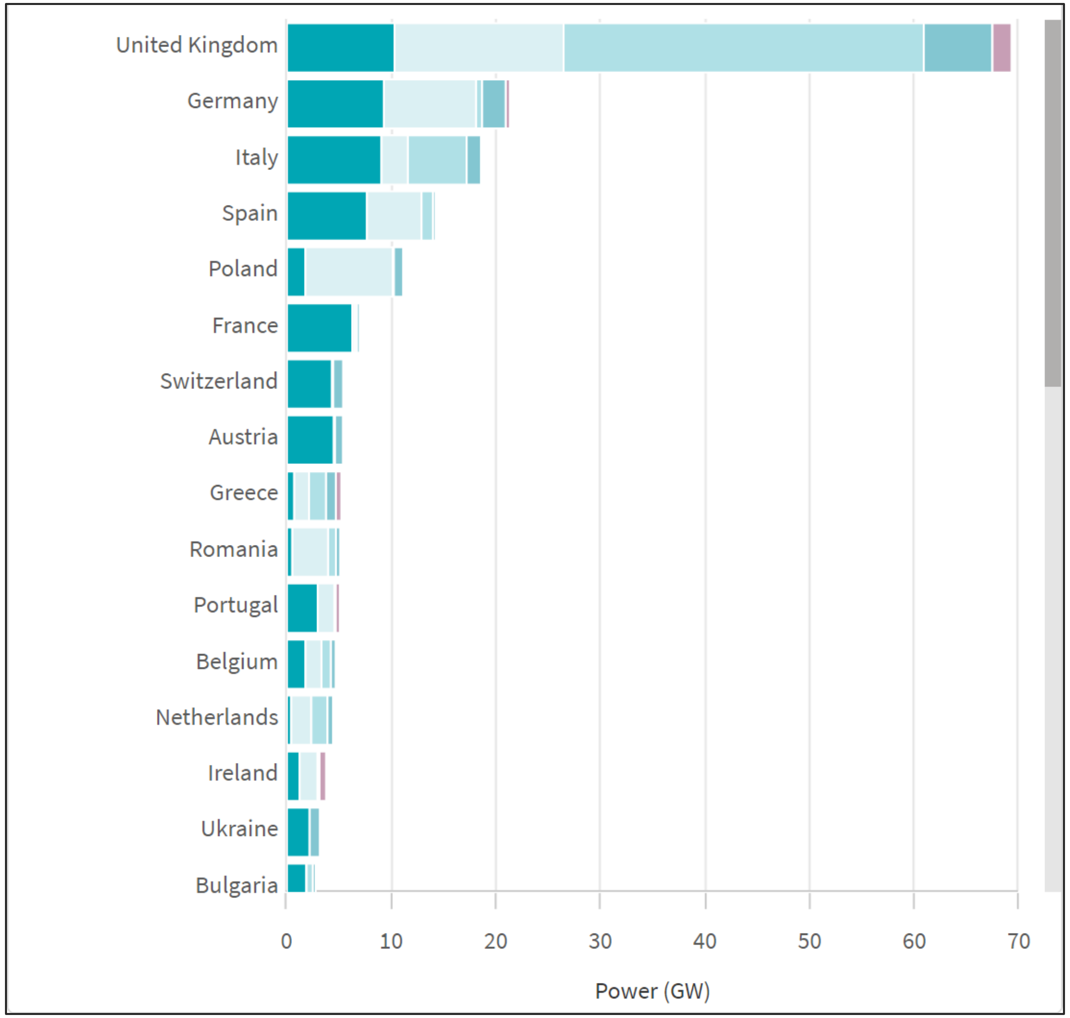



- By technology



# Main results

➤ By country



# Further information

| | |
|---|---|
| Last release January 2026 | Electrochemical increased<br>Dedicated pages for projects |
| Developing other reports and deliverables for the project | Reports on the website |
| Improvement of data | API to automate data retrieval from providers<br>AI engine to process data<br>Thermal projects<br>Some countries |
| New functionalities | Historical figures<br>Collecting data from owners/associations/public sources<br>Keeping the quality of data |

# Thank you

# Q&A

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EU Science Hub
joint-research-centre.ec.europa.eu

European Commission

# PROJECT PRESENTATION

Stefano Barberis

*PROJECT COORDINATOR*

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Università di Genova

TPG THERMOCHEMICAL POWER GROUP *since 1998*

ETN Global

ETN sCO2 webinar series

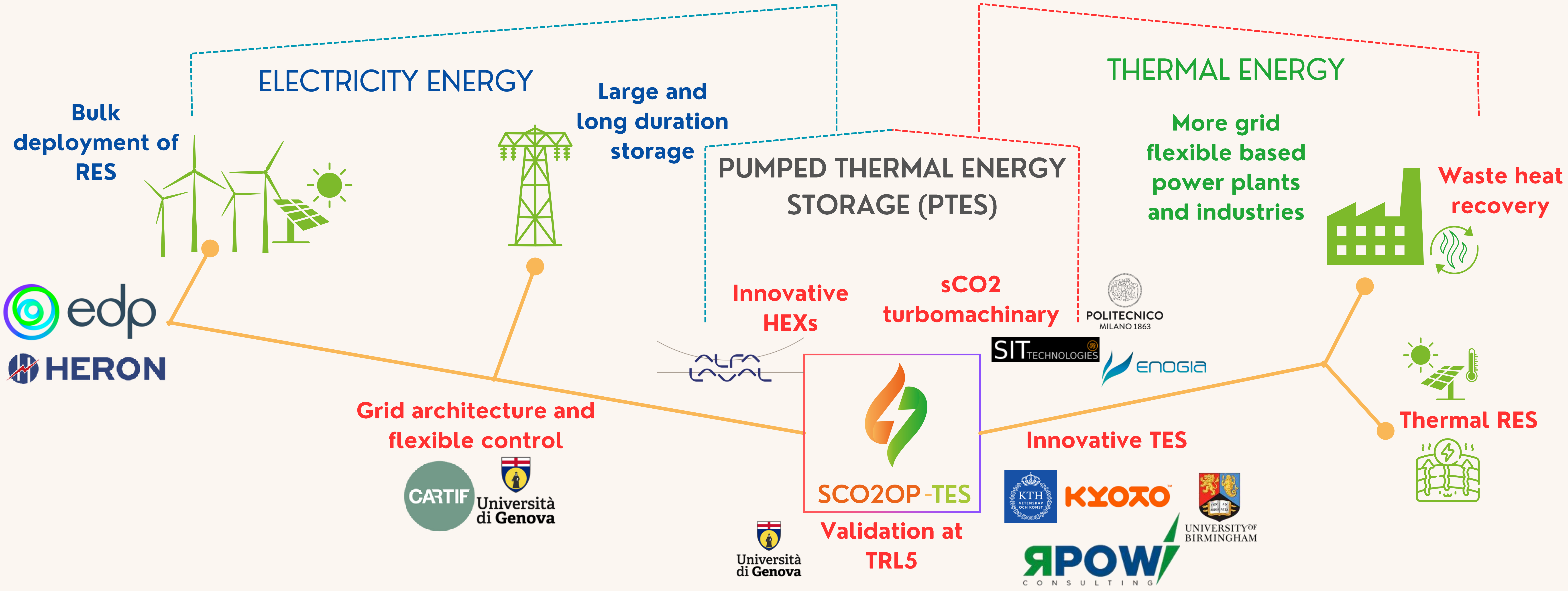
*6 February 2026*

This project is funded by the European Union Horizon Europe Grant Agreement n.101136000

# SCO2OP-TES

sCO2 Operating Pumped Thermal Energy Storage for grid/industry cooperation

# Overall Project Concept




**TRL 5 Validation of 1st of its kind sCO2 TI-PTES**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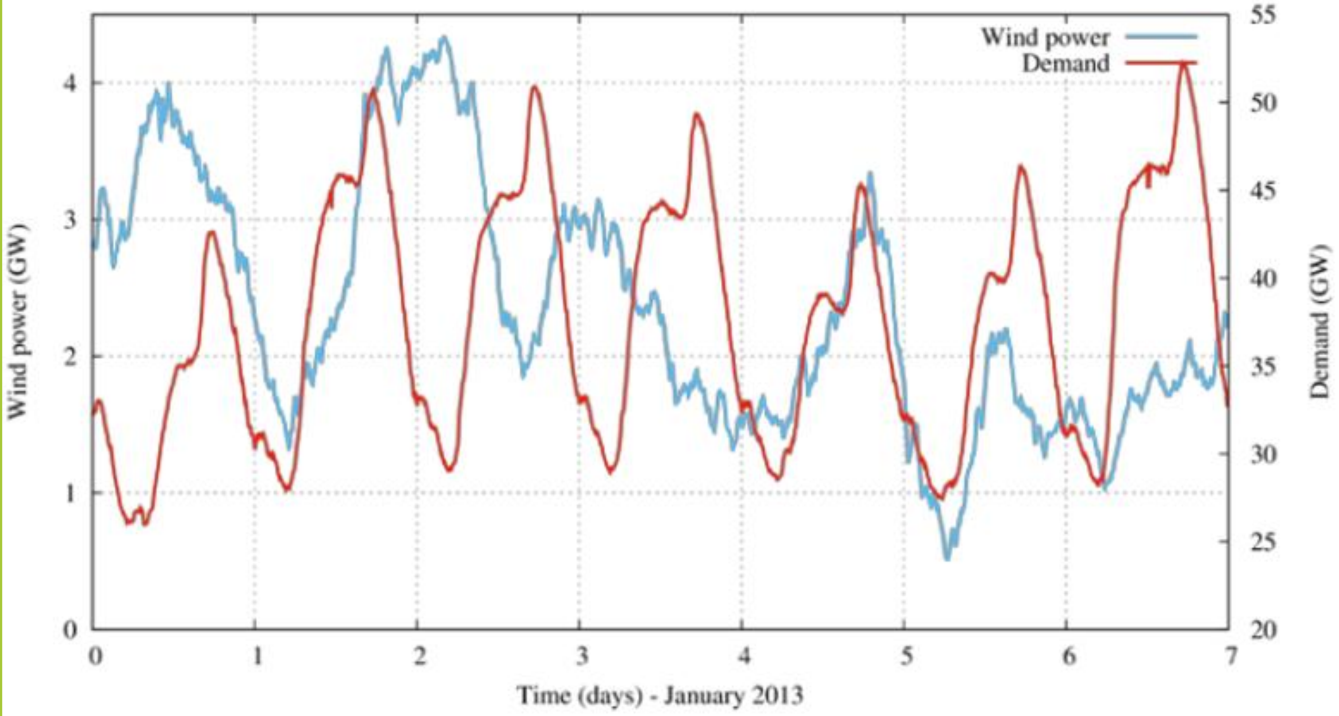
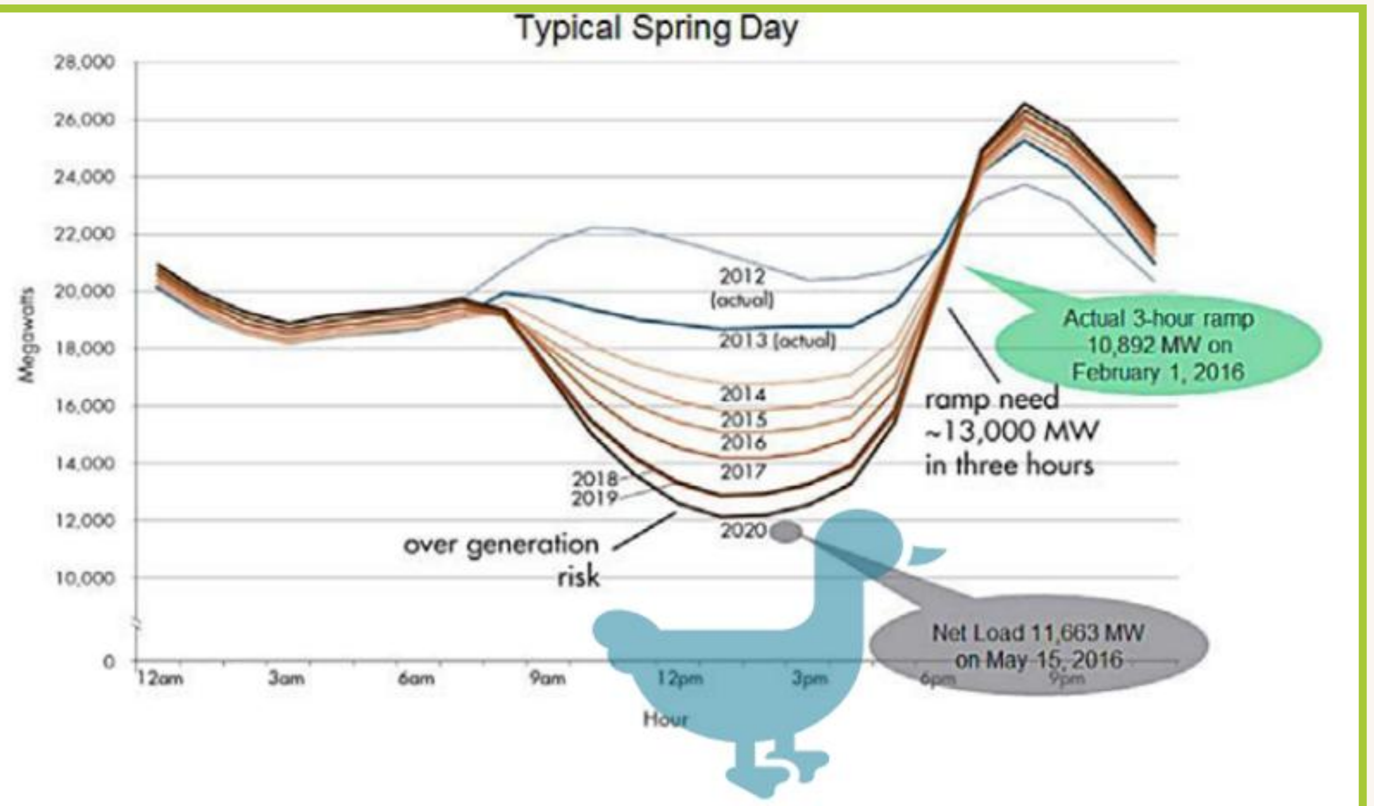
# EU Need for Energy Storage




Variable wind and demand (UK January 2013)




The Duck Curve (California)
Net load = Total demand – variable renewables

https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

Via Energy Storage, we mostly need to solve two problems:
**Lulls**: long periods with small renewable production)
**Slews:** short-term changes in either supply or demand).

As an example, we can quantify these problems looking at UK scenario and assuming that Britain had roughly 33 GW of wind power. To cope with lulls, up roughly to 1200 GWh of energy (20 kWh per person) should be stored. While the slew rate to be coped with is 6.5 GW per hour (or 0.1 kW per hour per person).

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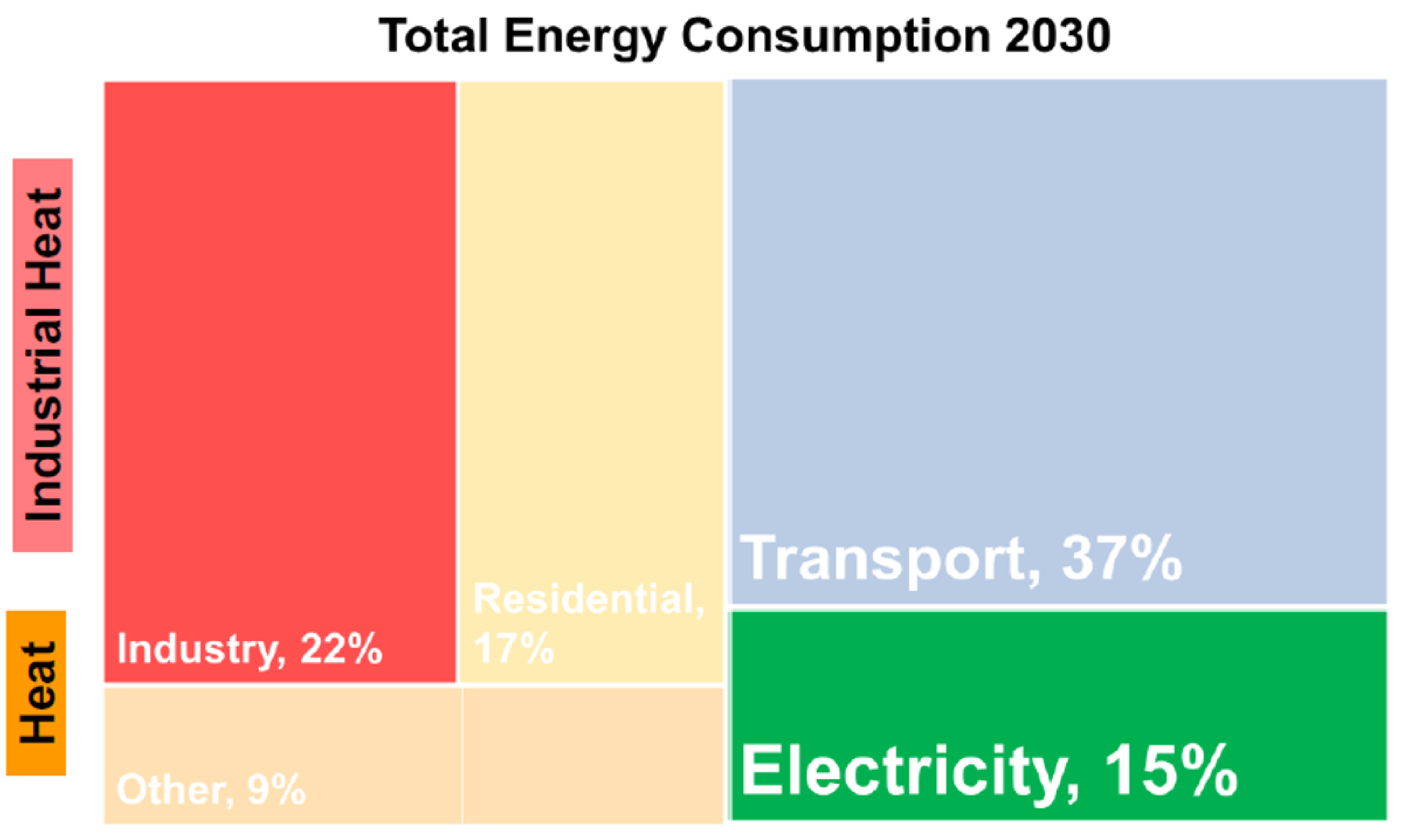
# EU Need for Energy Storage

Energy will be required in the form of **heat** as well as **electricity** for the next decades!




*IRENA, Global Energy Transformation - A Roadmap to 2050.*

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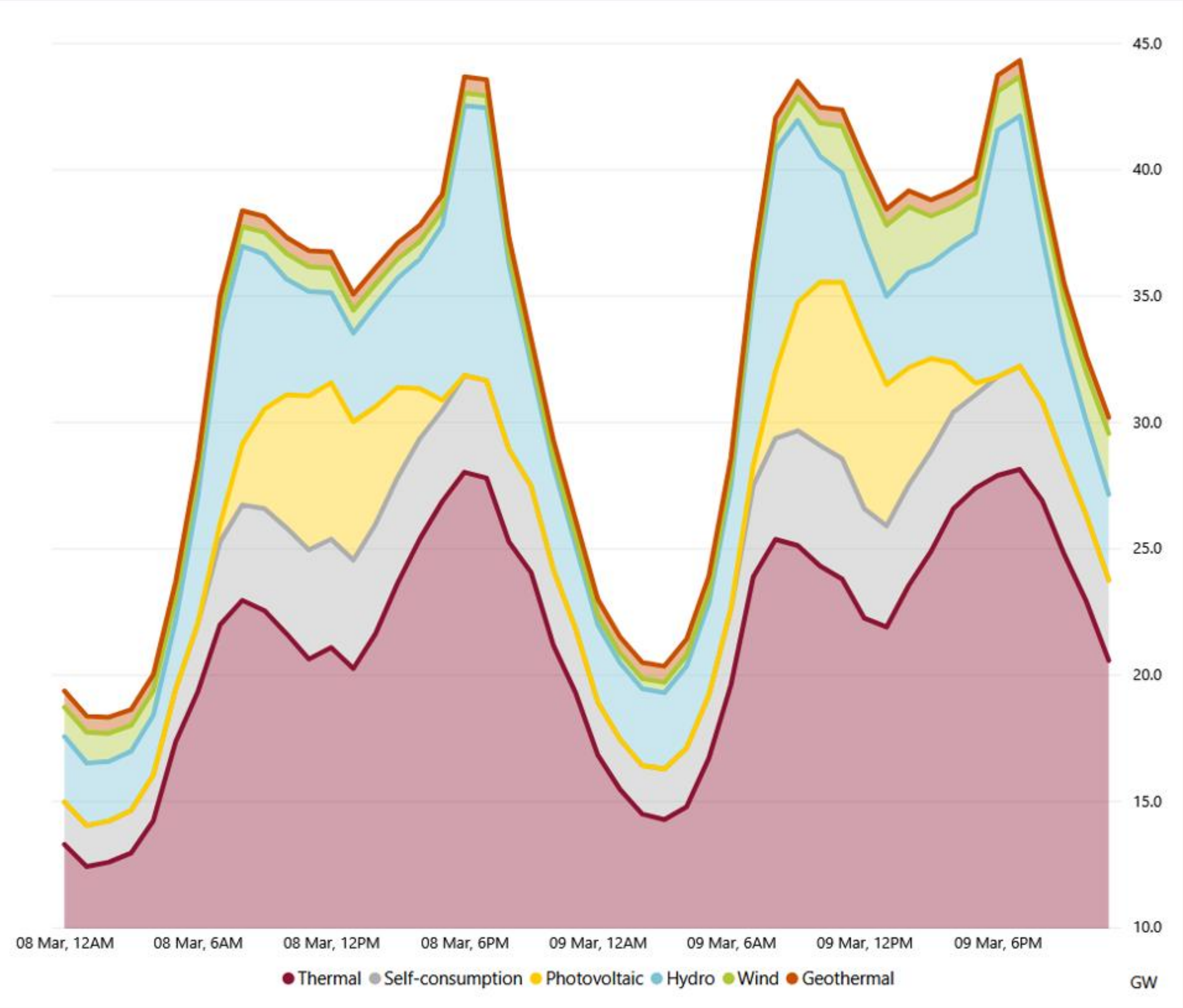
# Need for PTES

## The role of mechanical/electrical energy storages

Going towards a more sustainable future scenario the importance of Renewable Energy Sources (RES) is constantly growing while electrified processes are becoming more and more common

Since many renewable sources are non-programmable, it is important to achieve convenient ways to store energy in order to shave peaks and align production and demand




This is Italy's actual electrical generation for 8 and 9 of March 2023, taken as example

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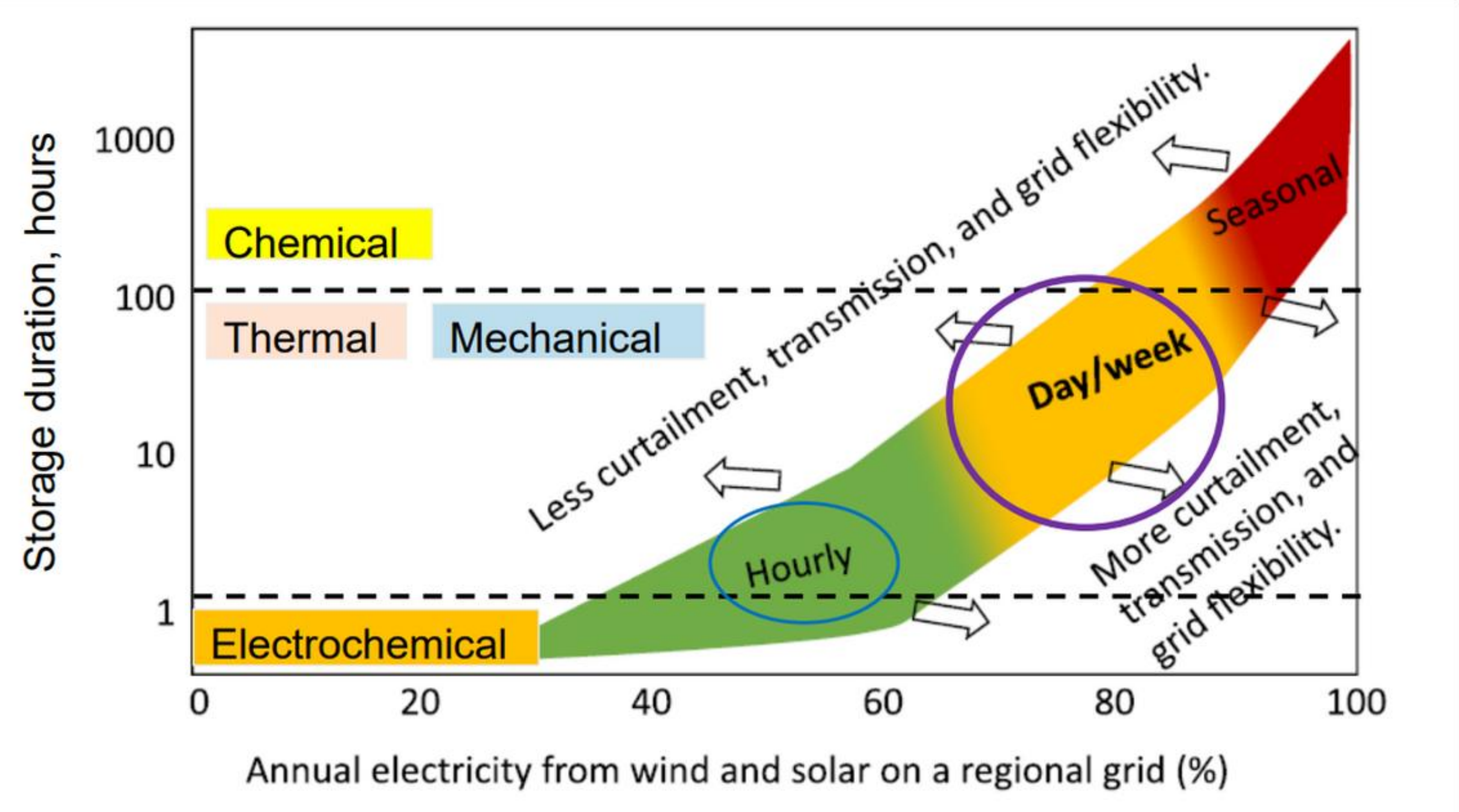
# Need for PTES

## Macro-categories of energy storage technologies

Semi-quantitative overview of maximum energy storage duration needed to ensure demand is met at all times vs fraction from RES




Ref (Annotated version of): Albertus P et al, Joule 4, 21-32,2020; https://doi.org/10.1016/j.joule.2019.11.009

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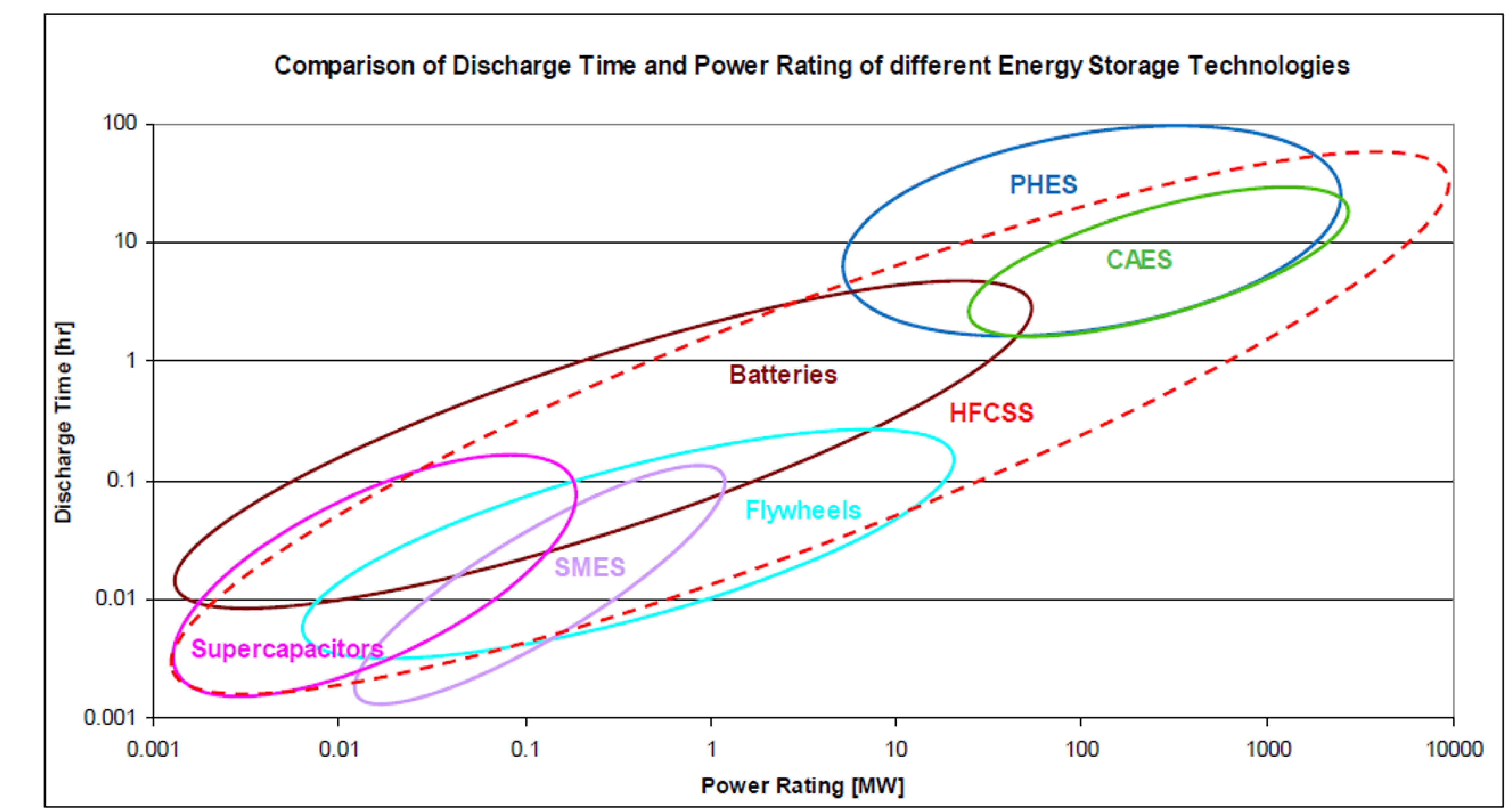
# sCO2OP-TES Potential




Services to the grid, similar to the ones provided by PHES

Further to long term energy storage, looking at grid services main potential market seems to be in this range:

- Size >10 MW
- Discharge time > 1h

DIFFERENT ENERGY STORAGE TECHNOLOGIES DEPENDING ON THE DISCHARGE TIME AND POWER RATING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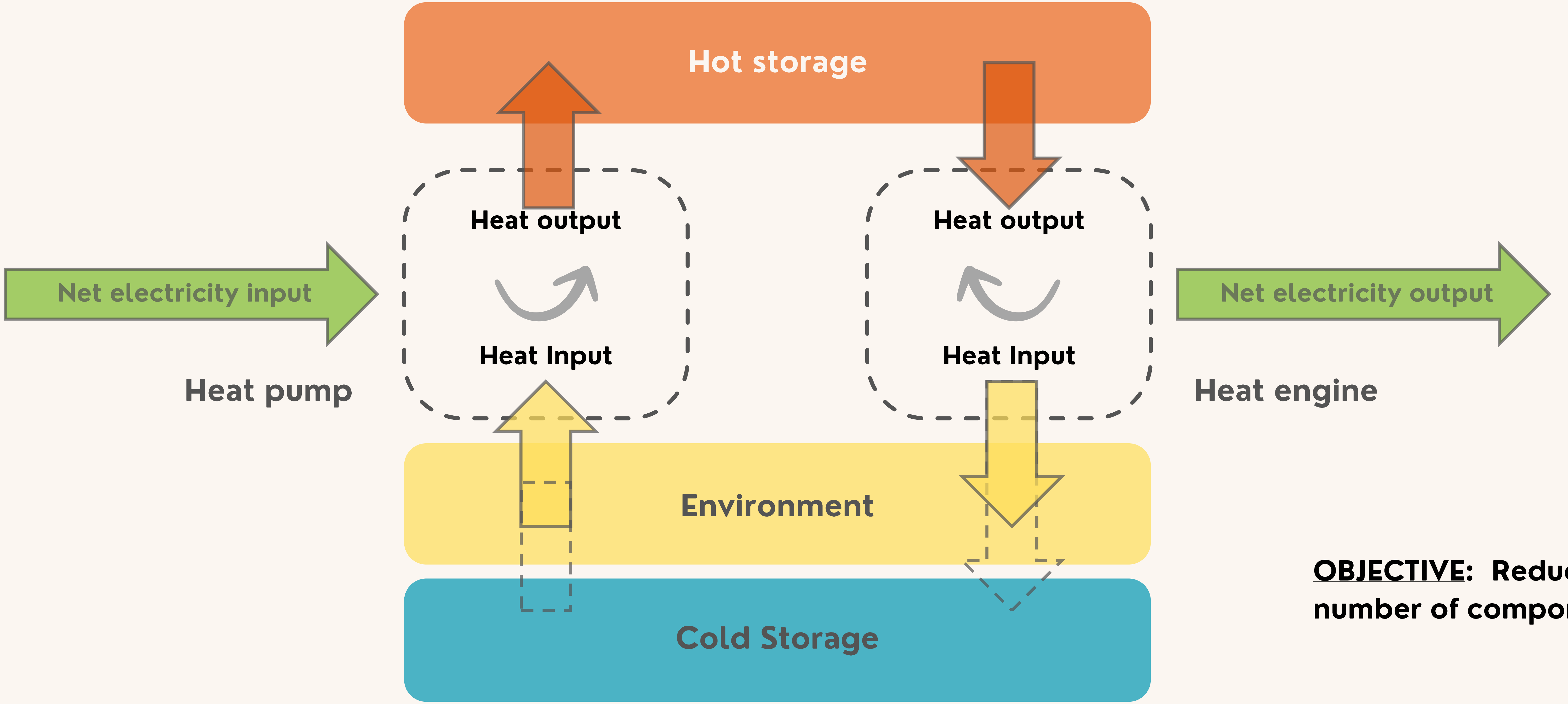
# WHY A sCO2 TI-PTES?

## TRADITIONAL CARNOT BATTERIES/PTES HAVE LIMITS ON COMPLEXITY




**OBJECTIVE**: Reduce the number of components

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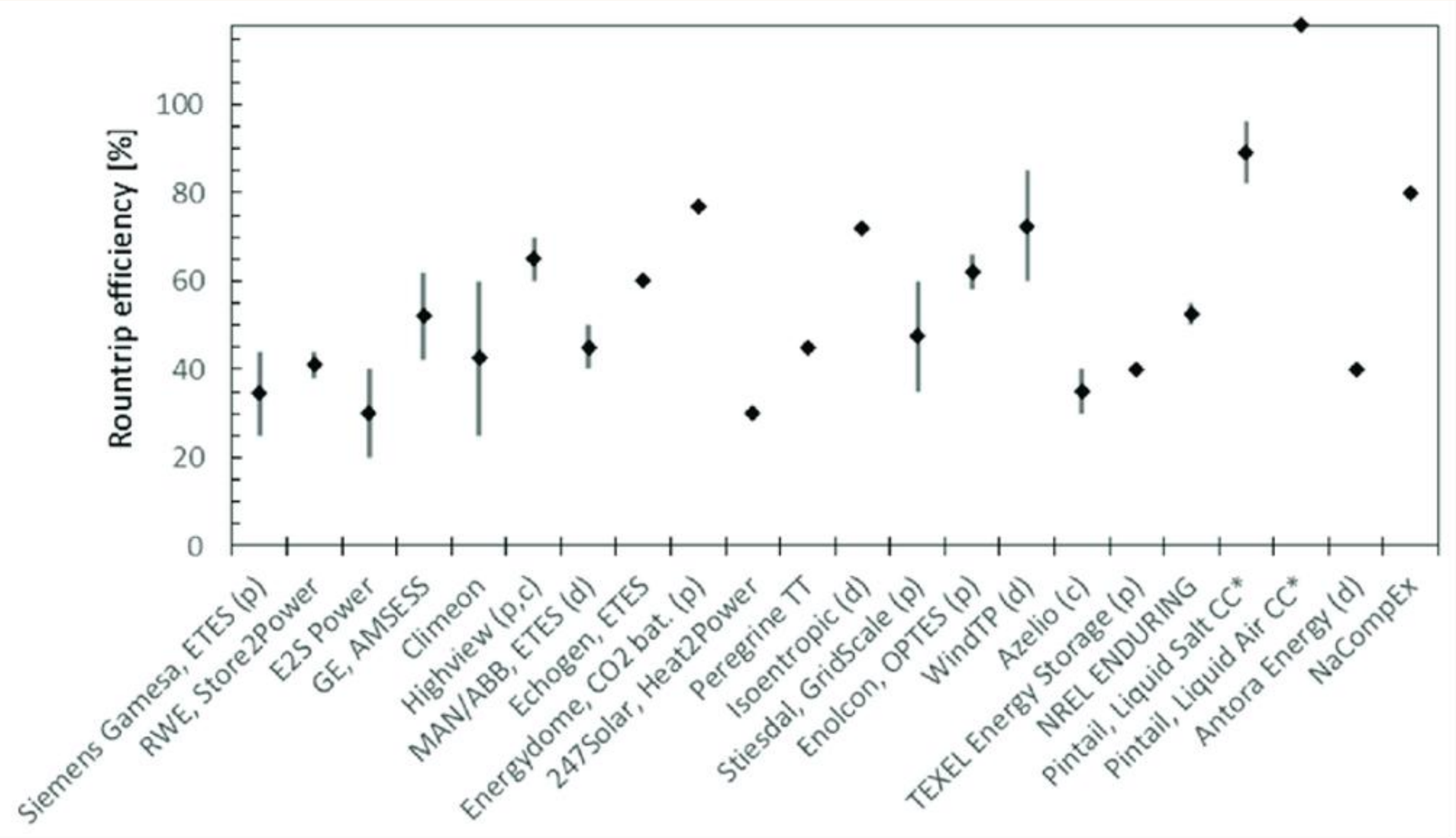
# WHY A sCO2 TI-PTES?

## CARNOT BATTERY HAVE LIMITS ON RTE

Overview of round trip efficiency in the commercially CB systems (mostly declared as experimental values are limited). In notation (d) stands for demo, (p) pilot, (c) commercial units (built or under construction).

* for systems with additional fuel firing.




Novotny, Vaclav & Bašta, Vít & Smola, Petr & Špale, Jan. (2022). Review of Carnot Battery Technology Commercial Development. Energies. 15. 10.3390/en15020647.

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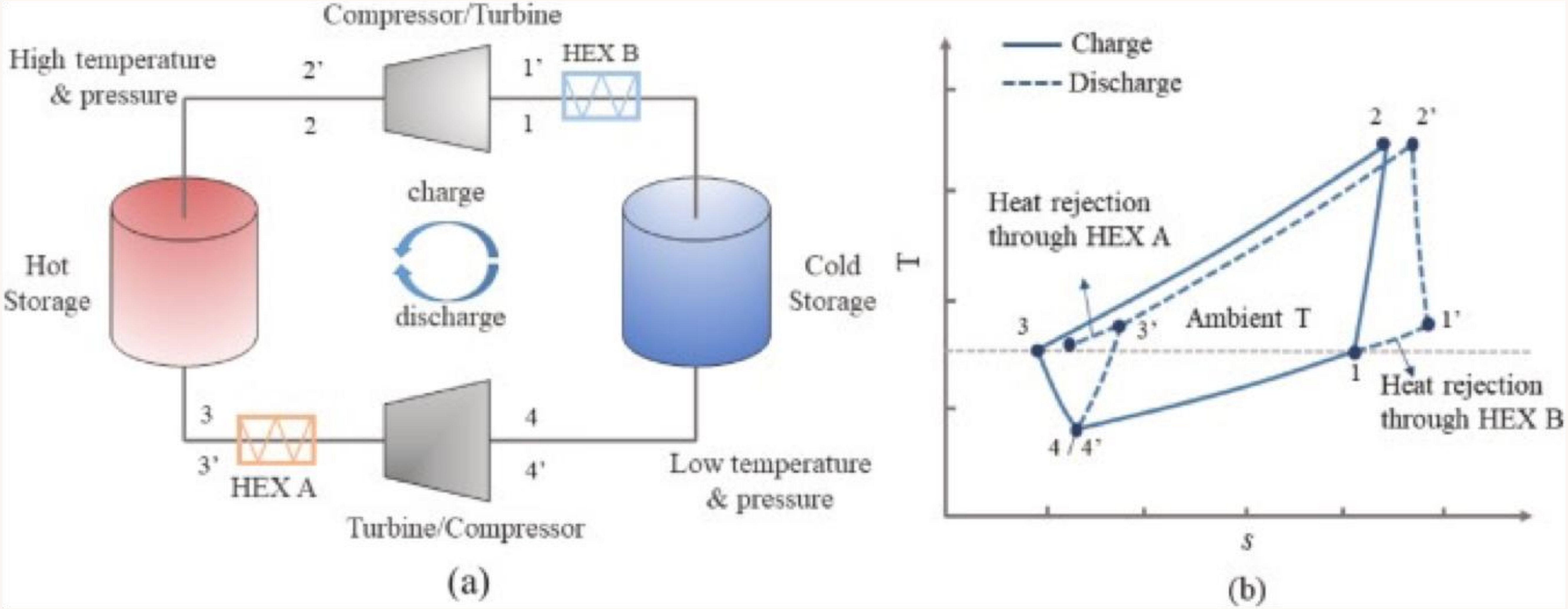
# WHY A sCO2 TI-PTES?

## TRADITIONAL CARNOT BATTERY THERMODYNAMIC LIMIT




<u>OBJECTIVE:</u> Increase RTE (discharging cycle efficiency and HP COP) and "discouple" charging and discharging cycles as much as we can thanks to an externally available heat source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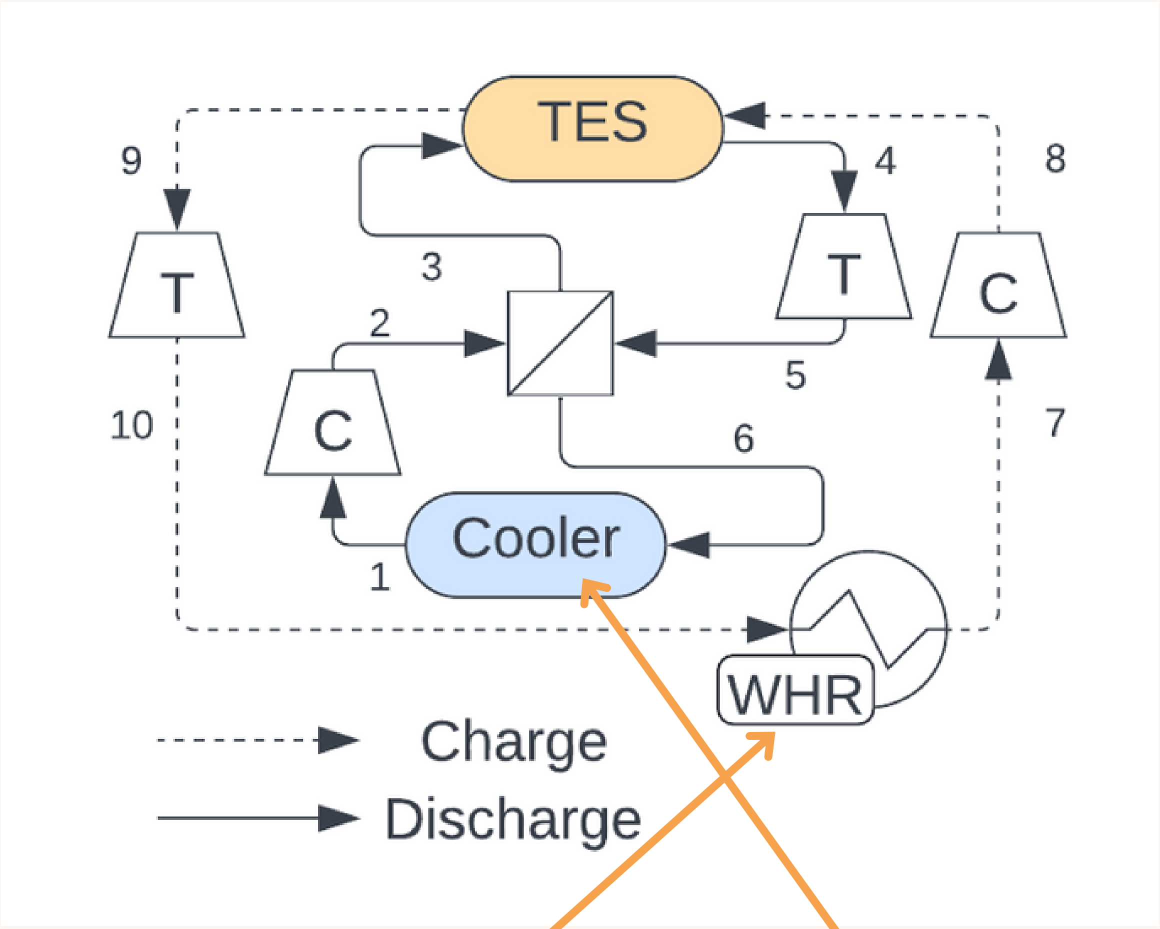
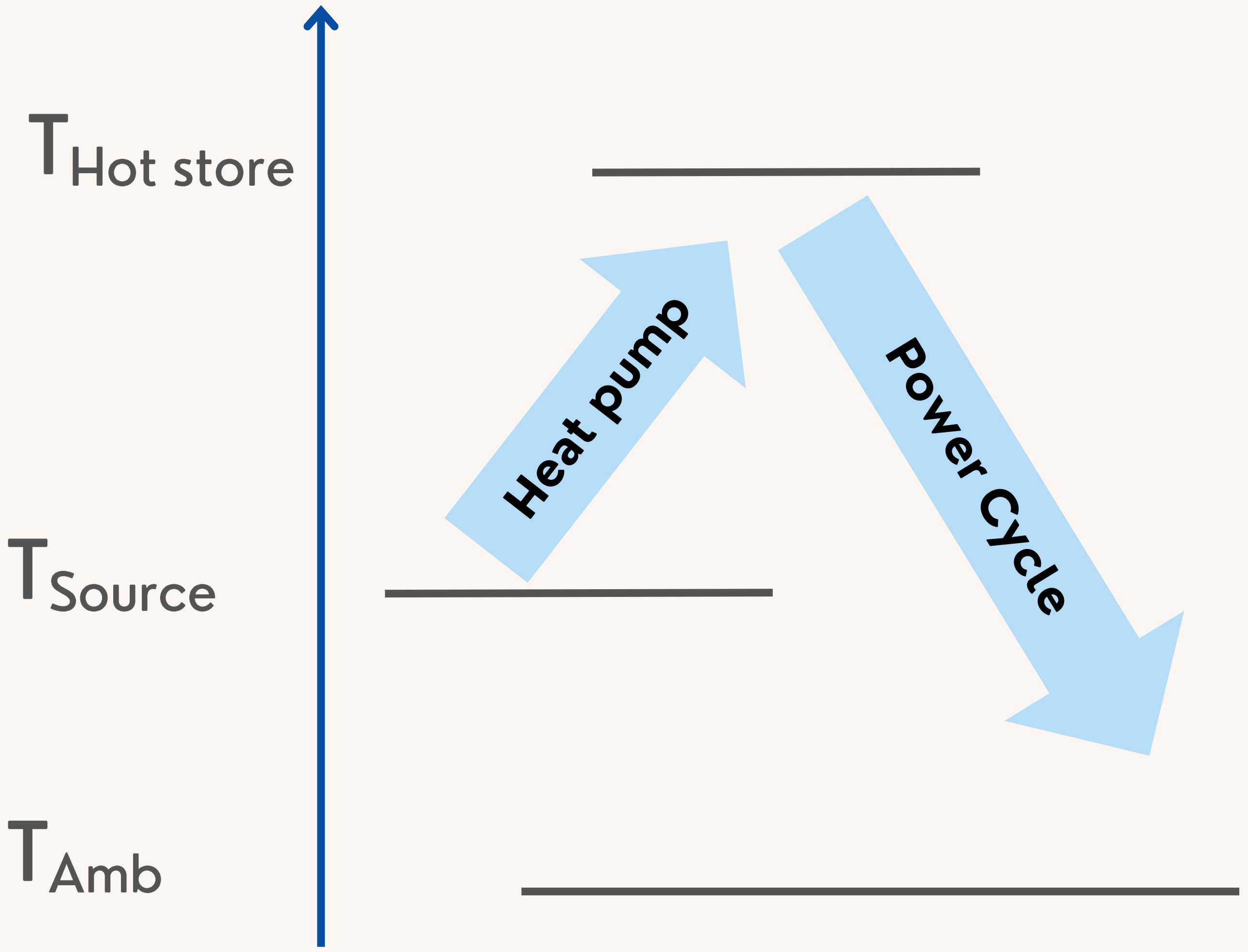
# WHY A sCO2 TI-PTES?

Project Ambition: overcome all these limits via sCO2 TI-PTES

**WH Driven PTES** to be studied in a dedicated loop to be installed in UNIGE **(~100 kWelScale)**




**INDUSTRIAL WH (250°C) FROM TIRRENO POWER SITE**

**Or potential integration of ICE TES available in Vado too with a 2 TES PTES concept**

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# Project Overall Approach

**Develop and validate cost-effective and reliable sCO2 PTES (TRL5) solutions to be integrated into industrial/power plant environments to make EU industries/fossil-based power plants more grid flexible and able to cooperate with electric grid offering different grid flexibility services, valorising WH and facilitating RES grid penetration.**

Proposed PTES solutions will be able to operate to valorise industrial/power plant WH and local industrial energy production and will have four main goals:

- Make EU fossil-based power plants and industries (which are becoming more and more electrified) more grid flexible and less grid also bothering, considering local RES production, making EU industries grid flexibility actors
- Valorise WH from fossil-based power plants for energy storage solutions (DOUBLE FLEXIBILITY)
- Using rotating machines enables faster grid services
- Enable power to heat-to-power solutions (also via aggregation) an overall grid storage to facilitate, at local and Regional/National level, higher RES penetration

Funded by the European Union

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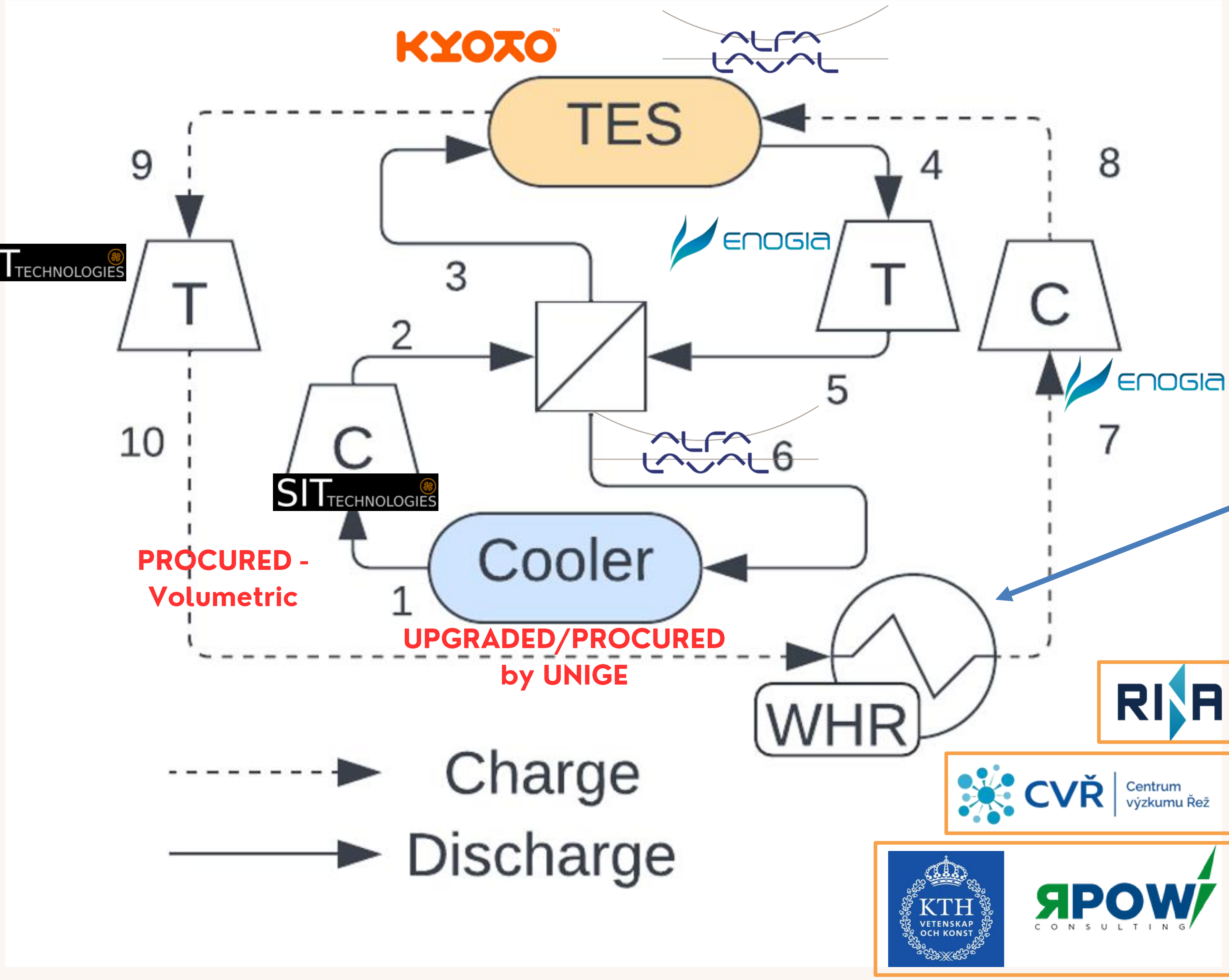
# WH Driven TI-PTES – TRL5 Goal

## LAB SCALE SYSTEM TO BE REALIZED IN UNIGE TIRRENO POWER LAB




To be emulated via an EH based on real power plant data

HEALTH AND SAFETY

SUPPORT TO sCO2 LOOP DESIGN

SUPPORT TO TES DESIGN

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# Project Objectives

**MO1: To validate sCO2 based P2H2P cycles performances in UNIGE-TP site – WP2-3-4**

- Design and Prototype TES
- Design and Prototype Innovative Machines
- Design and test the integrated cycles and all enabling components

**MO2: To validate models (dynamic, thermo-economic, grid impact) for SCO2OP-TES replication - WP1-5**

**MO3: Demonstration of economic, safety and environmental sustainability of SCO2OP-TES – WP5-WP6**

- Multi-impact assessment of the sCO2 TI-PTES concept

**MO4: Dissemination and Exploitation – WP6**

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# Project Consortium

- UNIVERSITY OF GENOVA (RTO, ITA) - Coordinator, Dynamics, thermal storage analysis, $sCO_2$ loop, system optimization, thermo-economics activity (Cold compressor purchase)
- 1b SIT TECHNOLOGIES (SME, ITA) – designer and manufacturer of the cold turbine $sCO_2$ Expanders
- RINA CONSULTING (LE, ITA) – Admin coordinator + dissemination + exploitation + safety and sustainability assessment
- KTH (RTO, SE) - Technoeconomics + $sCO_2$ expert + solid TES (KYOTO Support)
- UNIVERSITY OF BIRMINGHAM (RTO, UK) - Expert of LDES - replication assessment at EU Level (WH database from SO WHAT + benchmark with other LDES solutions)
- ENOGIA (SME, FR/GR) – $sCO_2$ hot compressor and turbine manufacturer
- POLIMI (RTO, ITA) Machine design expert (CFD/FEM Support): support to compressor design and upscale activities
- CV REZ (RTO, CZ) Support definition of $sCO_2$ Lab - eventual testing in SOFIA Loop
- CERTH (RTO, GR) smart grid management aspects and support to HERON replication
- RPOW (SME, ES) supporting KYOTO in design of MS Loop and TES
- KYOTO (SME, NO) thermocline TES for UNIGE Lab
- CARTIF (RTO, ES) grid impact aspects
- HERON (LE, GR) Replication site in a power plant to drive tests
- ALFA LAVAL (LE, FR) recuperator and primary HEX
- EDP NEW (LE, PT) Energy market and replication aspects
- 14b EDPP (LE, PT) Replication power plant


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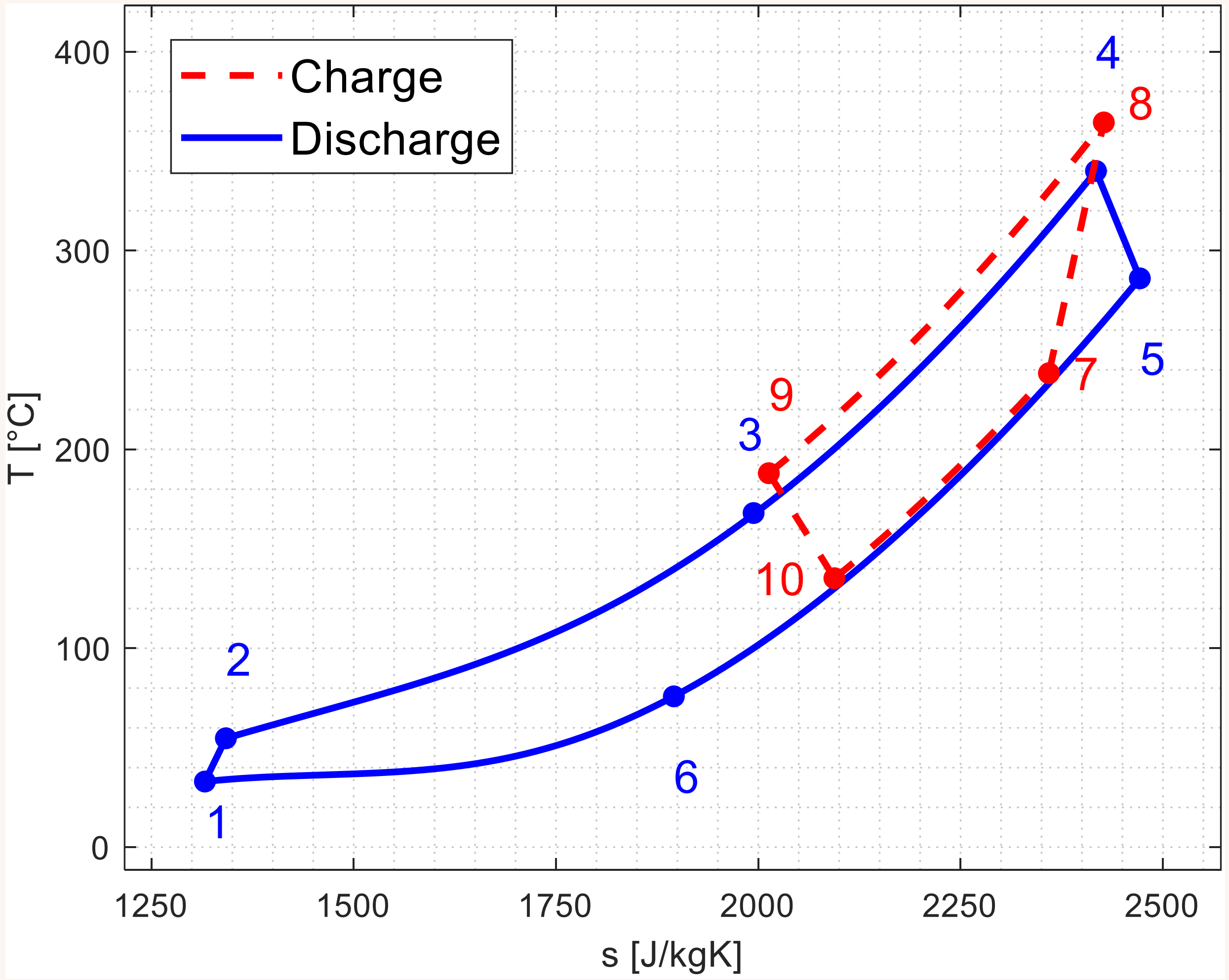
# PROJECT PRELIMINARY RESULTS

***Iterative modelling for lab scale cycle operating points definition***

| | Point | Pressure [bar] | T [°C] | Mass flow rate [kg/s] |
|---|---|---|---|---|
| Discharge | 1 | 82.98 | 33 | 0.72* |
| | 2 | 172 | 54.69 | |
| | 3 | 171.99 | 168.82 | |
| | 4 | 170.27 | 340 | |
| | 5 | 83 | 280.98 | |
| | 6 | 82.99 | 77.91 | |
| Charge | 7 | 86.8 | 240 | 0.7* |
| | 8 | 200 | 360 | |
| | 9 | 198 | 188.83 | |
| | 10 | 86.21 | 135.32 | |




| Component | Power [kW] |
|---|---|
| CC Compressor (η=68%*) | 90.74 |
| CC turbine (η=40%) | 14.94 |
| DC Compressor (η=60%*) | 15.47 |
| DC turbine (η=60%) | 32.68 |
| Hot TES Primary HEX | 157.84 |
| Cooler | 132.14 |
| WHR | 90.93 |
| Recuperator | 175.44 |
| RTE | **30.6 %** |

***FULL OFF DESIGN MODELLING ALSO TO DRIVE CONTROL STRATEGY***

***https://asmedigitalcollection.asme.org/GT/proceedings-abstract/GT2025/88810/V005T09A011/1220416***
***https://duepublico2.uni-due.de/receive/duepublico_mods_00083313***

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# PROJECT PRELIMINARY RESULTS

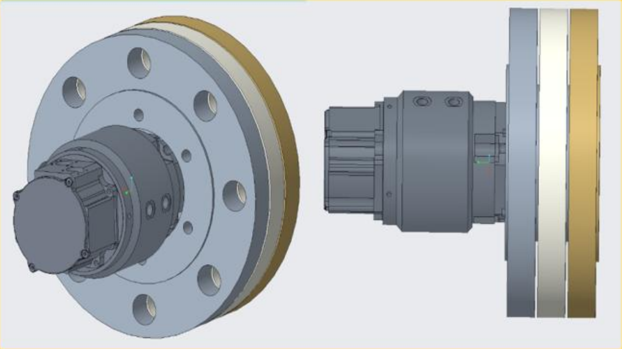
## $sCO_2$ COLD MACHINES

Cold Compressor :

- Off the shelf volumetric machines.
- 5 parallel units to achieve the design mass flow rates.

Cold Turbine :

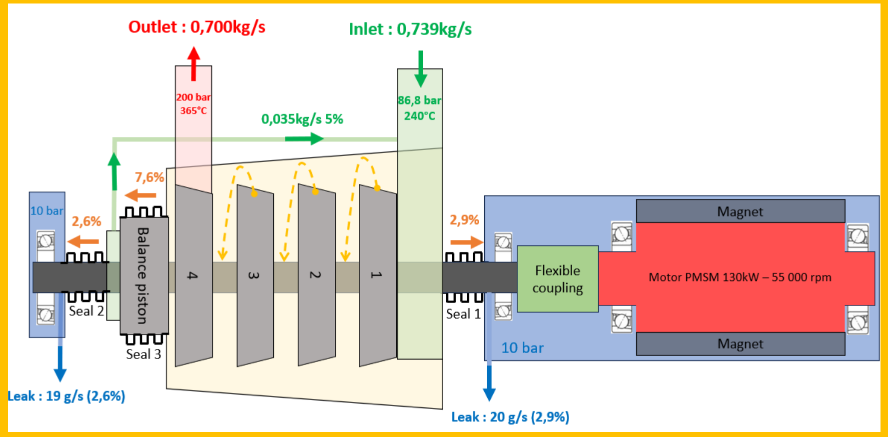
- Bladeless expander
- Nominal Power: 15 kW



## $sCO_2$ HOT MACHINES

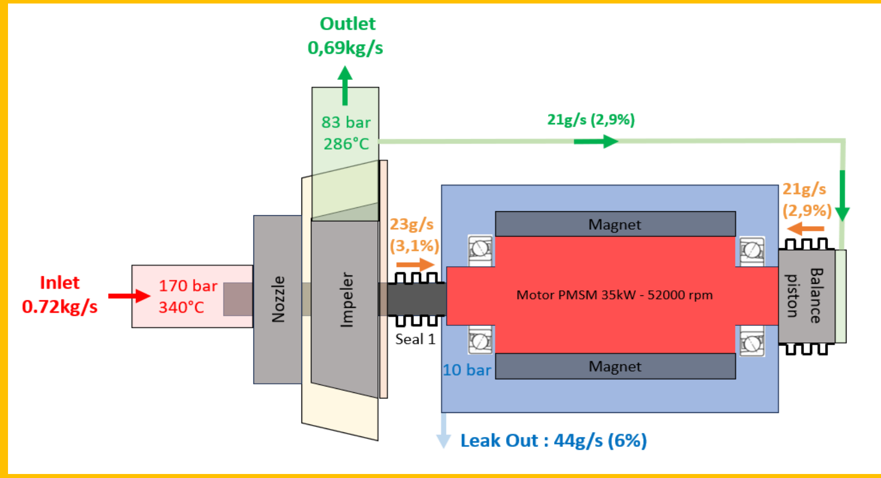
Hot Compressor :

- 4 stage radial compressors.
- Nominal Power 120 kW:
- Max Speed= 55000 rpm




Hot Turbine :

- Single stage radial turbine.
- Nominal Power: 35 kW
- n = 52000 rpm





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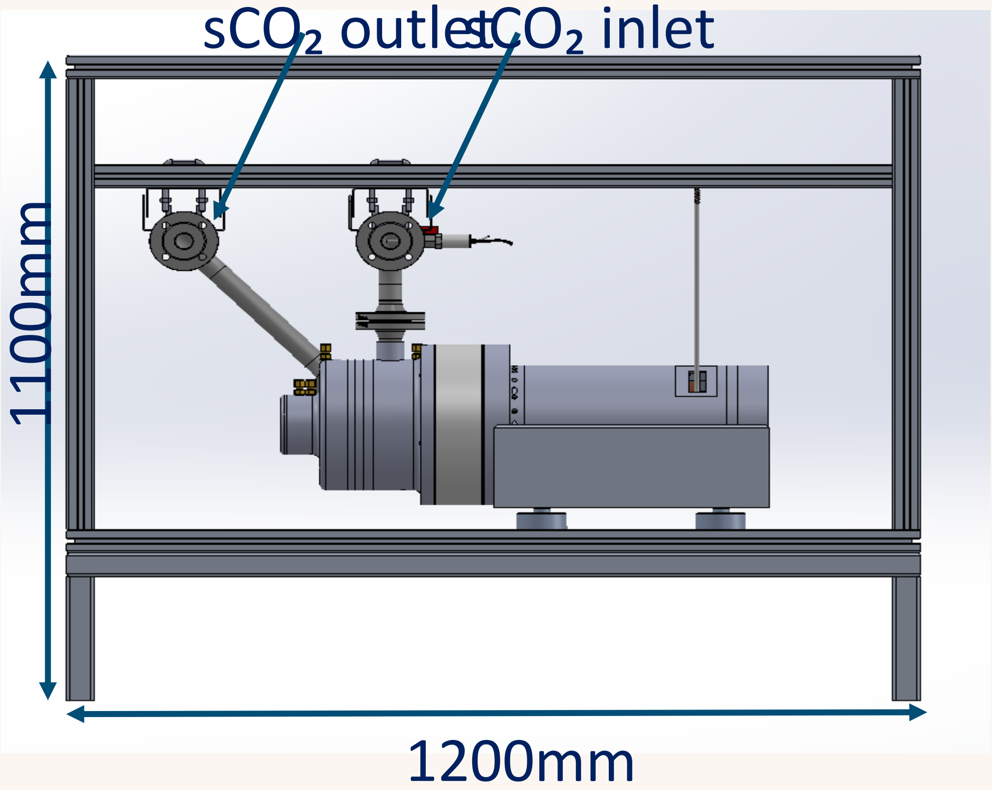
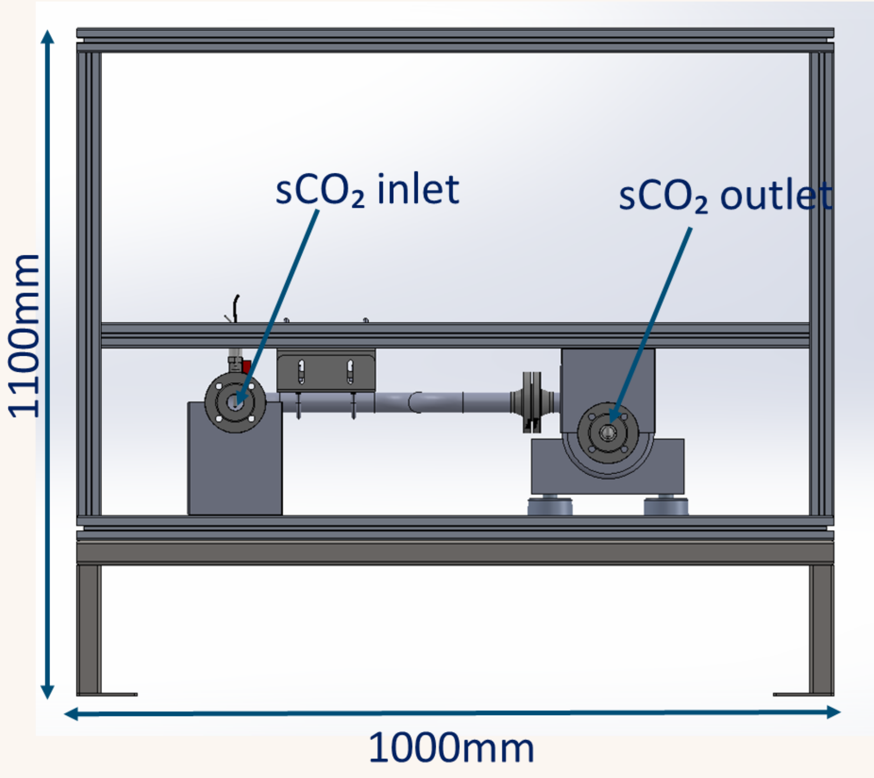
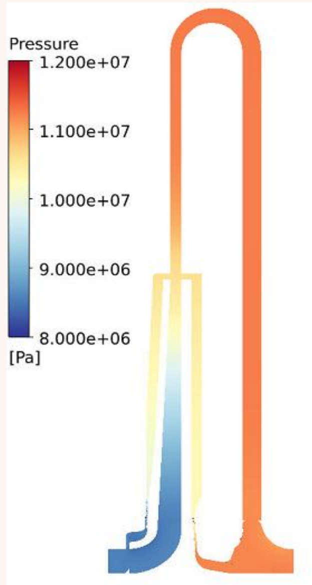
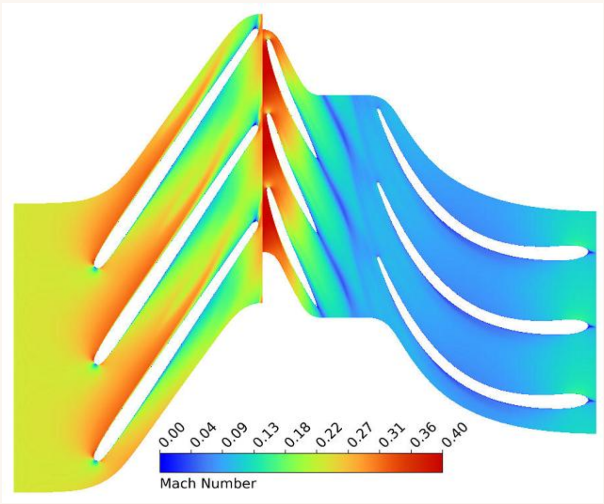
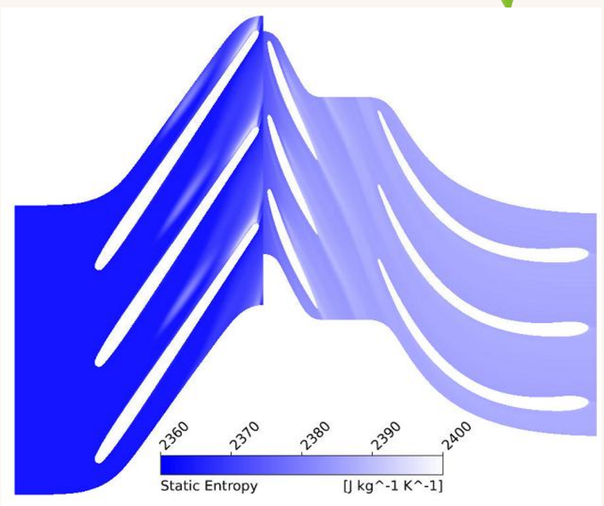
# PROJECT PRELIMINARY RESULTS

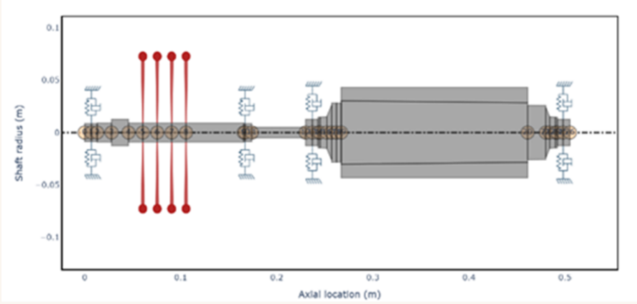


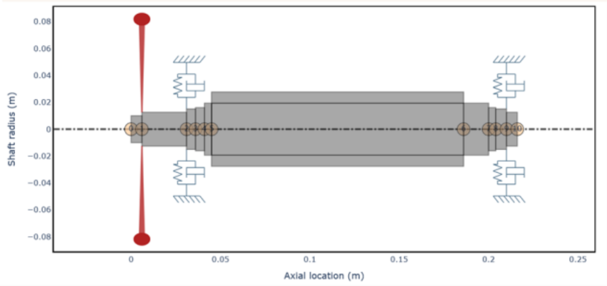



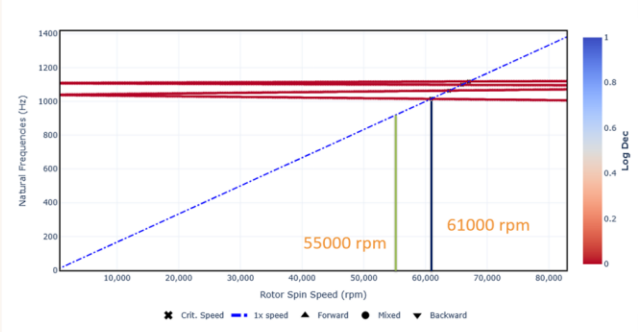



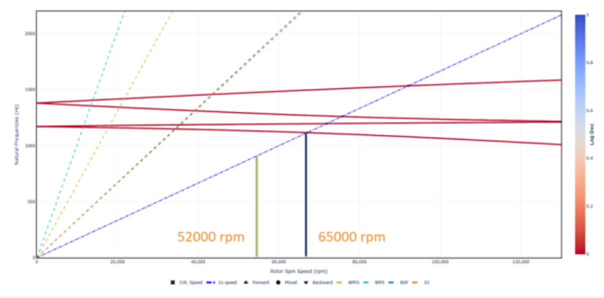







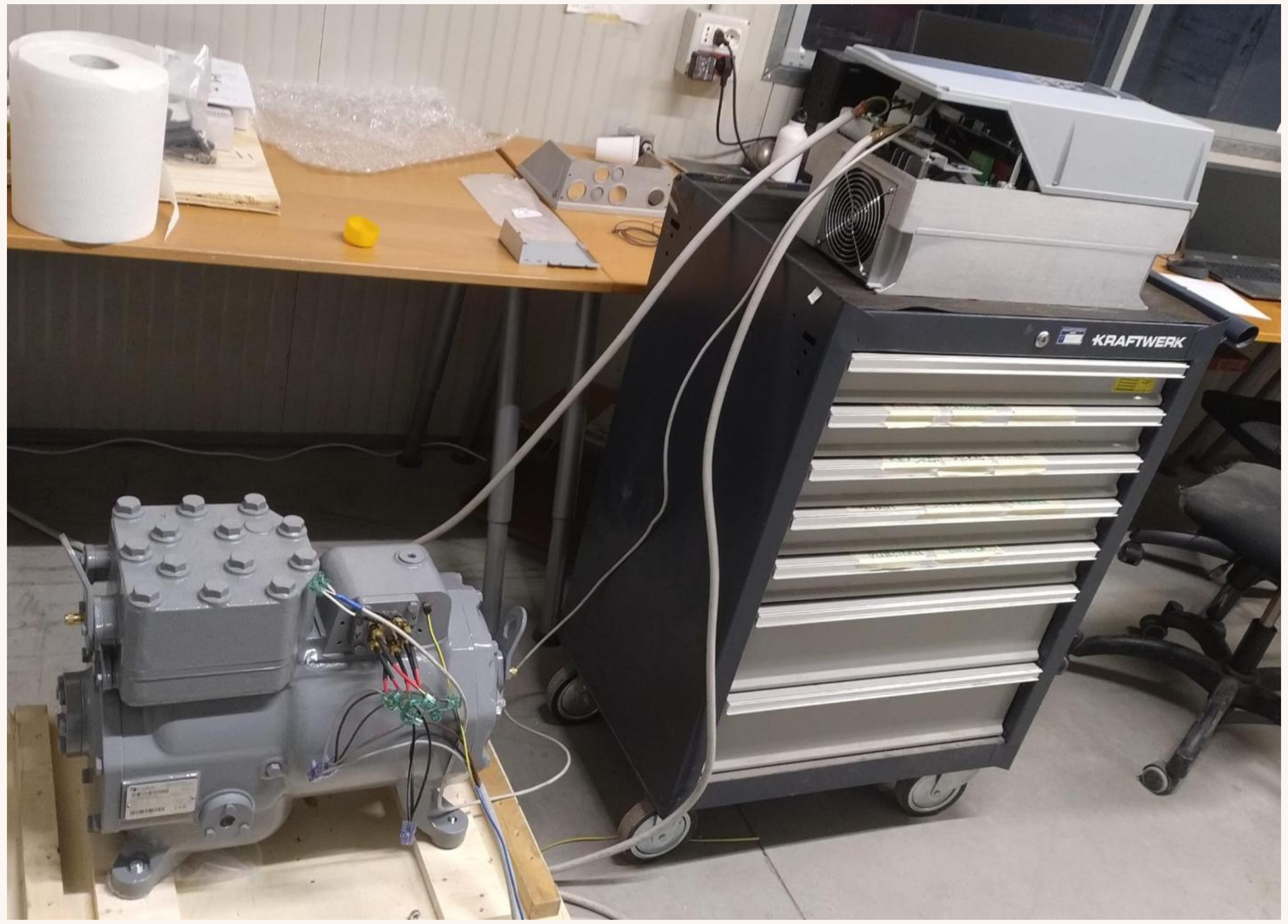




## *HOT MACHINES: FULL FLUID-DYNAMIC (MEAN LINE AND CFD) AND ROTOR-DYNAMIC DESIGN + COMPRESSOR/TURBINE SKID DESIGN*

Funded by the European Union

This project is funded by the European Union Horizon Europe Grant Agreement n.101136000

# PROJECT PRELIMINARY RESULTS




***COLD MACHINES:** ADAPTATION OF CO2 REFRIGERATION MACHINES AND CHARACTERIZATION*

Funded by
the European Union

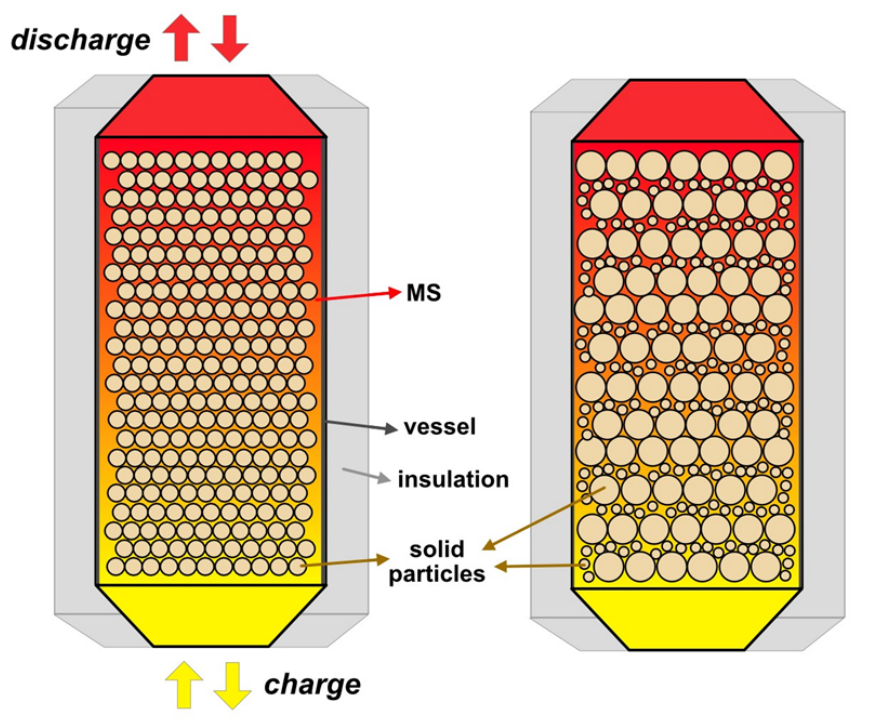
This project is funded by the European Union Horizon Europe Grant Agreement n.101136000

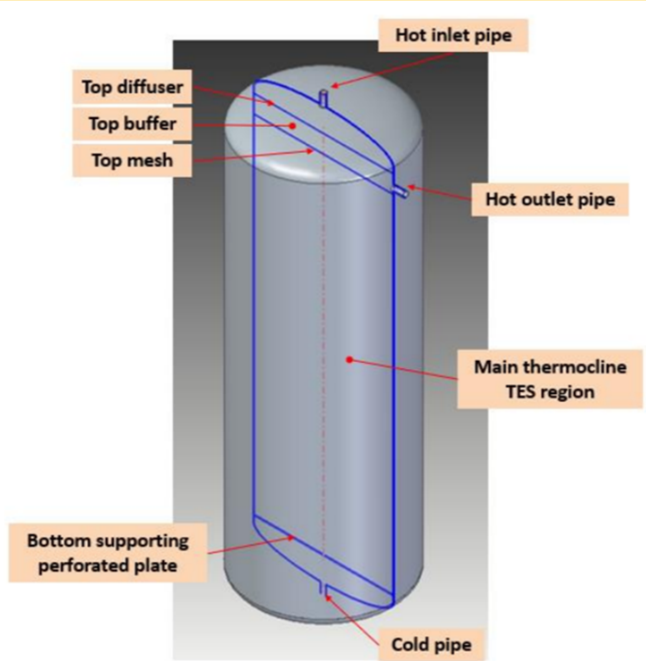
# PROJECT PRELIMINARY RESULTS

**Thermal energy storage**

Single tank, hybrid solid media (slags), thermocline TES operated via a MS loop

| Parameter | Value |
|---|---|
| Max working temperature (°C) | 352.5 |
| Min working temperature (°C) | 178 |
| Mass flow rate (kg/s) | 0.56 |
| Rated energy capacity (kWh) | 400 |
| TES preliminary efficiency (%) | 80 |
| Void fraction | 0.38 |
| Solid particle diameter (m) | 0.02 |
| TES packed bed height (m) | 2.09 |
| TES packed diameter (m) | 1.4 |
| Aspect ratio | 1.5 |



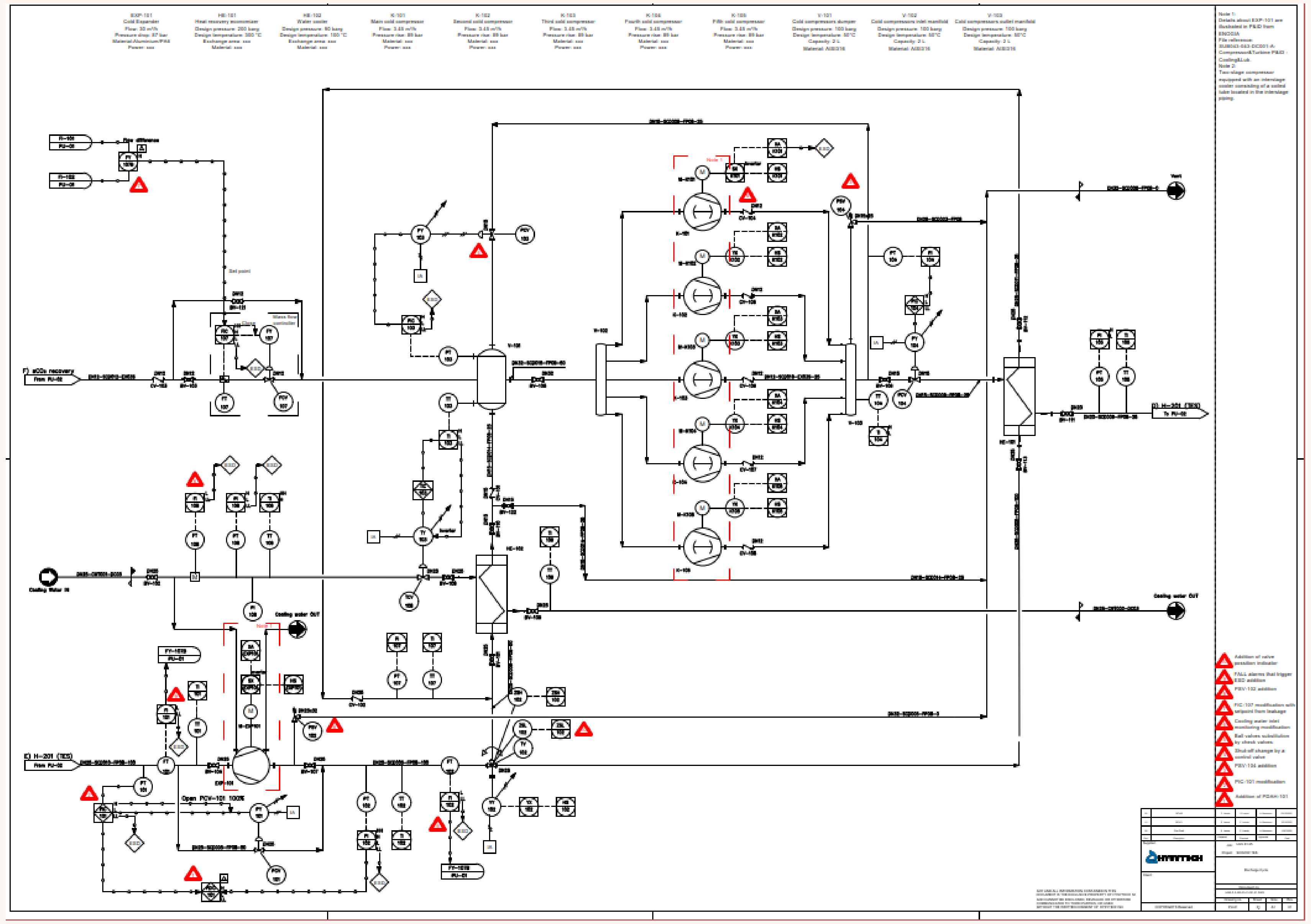



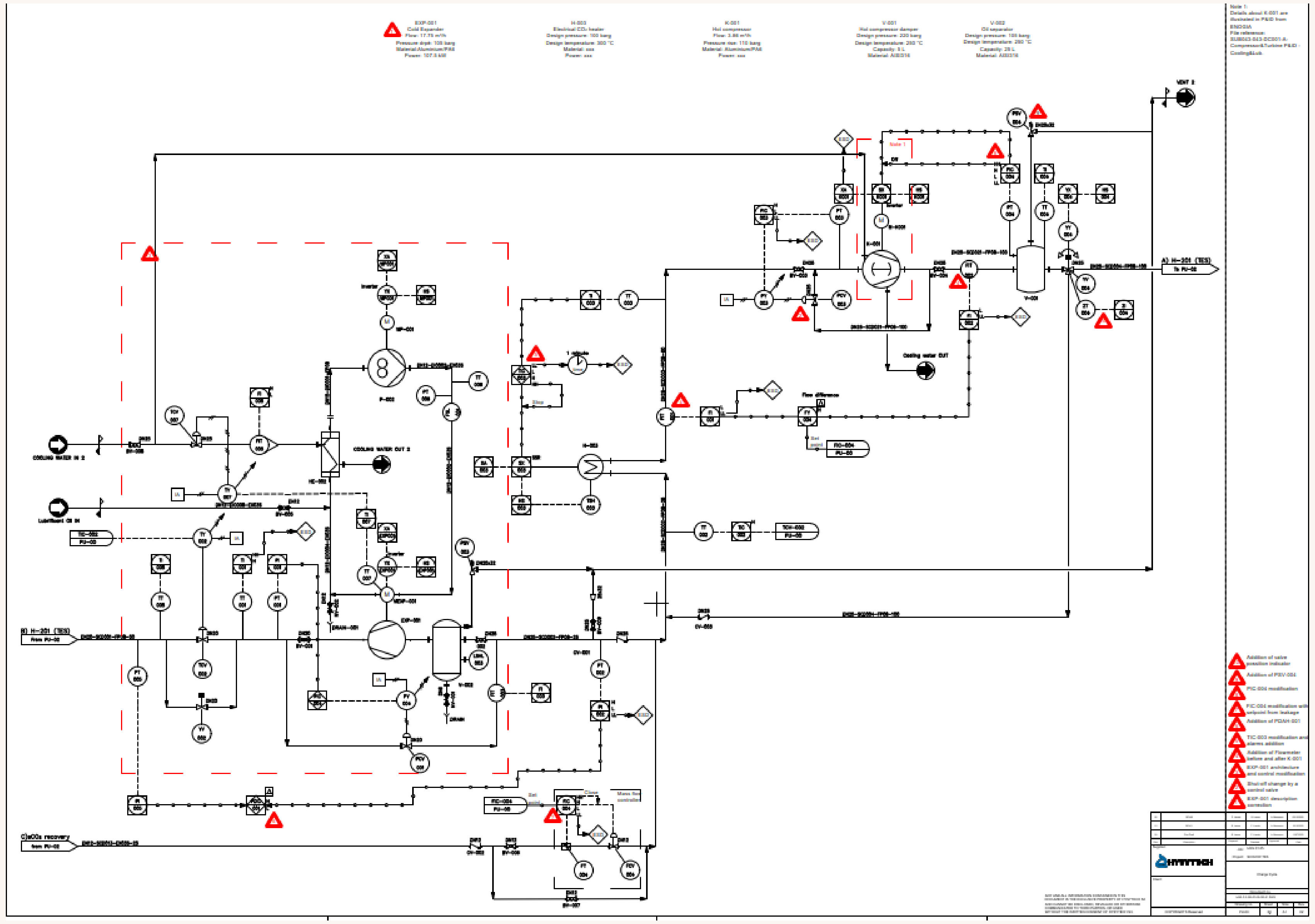

## *CFD AND FEM MODELLING OF THE TES*

Funded by the European Union

This project is funded by the European Union Horizon Europe Grant Agreement n.101136000

# PROJECT PRELIMINARY RESULTS



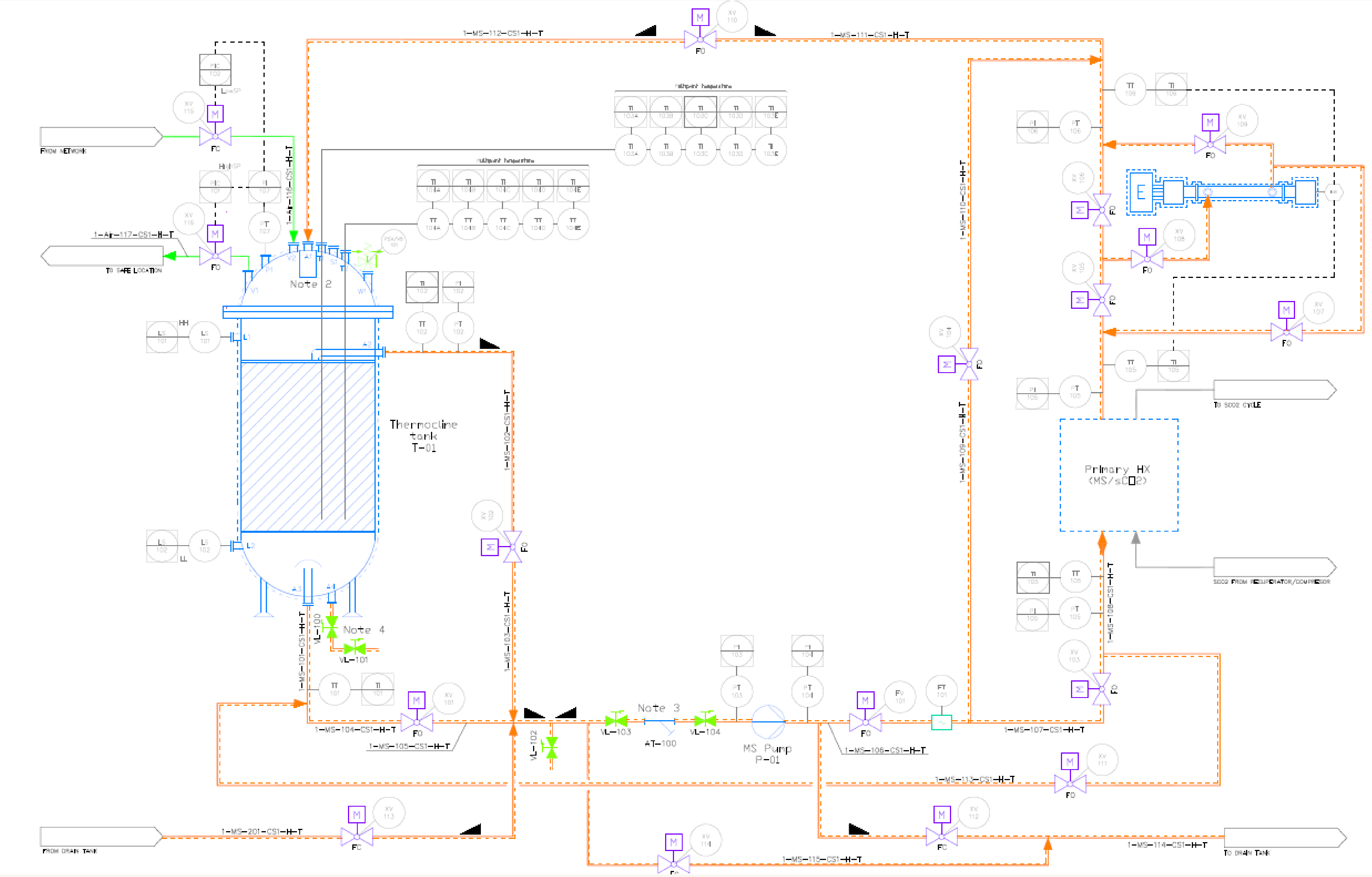


***FULL ENGINEERING OF THE sCO2 LOOPS CHARGING AND DISCHARGING CYCLES ALSO FOLLOWING HAZOP***

Funded by the European Union

This project is funded by the European Union Horizon Europe Grant Agreement n.101136000

# PROJECT PRELIMINARY RESULTS




***FULL ENGINEERING OF THE TES MS LOOP AND OF THE THERMOCLINE TES TANK ALSO FOLLOWING PROCESS HAZARD ANALYSIS***


Funded by
the European Union

This project is funded by the European Union Horizon Europe Grant Agreement n.101136000

# NEXT STEPS

- *Cold Machines characterization*
- *Machine executive design (FEBRUARY 2026) and start of the manufacturing*
- *Thermocline TES prototyping*
- *Full laboratory commissioning/integration within end of 2026*
- *Further alternative layouts investigation (Integration with CSP)*
- *Further Dispatchment Analysis in flexibility markets too*
- *First environmental impact assessment (LCA)*

Funded by
the European Union

This project is funded by the European Union Horizon Europe Grant Agreement n.101136000

# FOLLOW US!

www.sco2op-tes.org

SCO2OP-TES Project

Project Coordinator
Stefano.barberis@unige.it

This project is funded by the European Union
Horizon Europe Grant Agreement n.101136000

SCO2OP-TES

sCO2 Operating Pumped Thermal Energy Storage
for grid/industry cooperation

# Grid-Scale Long Duration Energy Storage using $sCO_2$ – Technology and Project Updates

6 February 2026

# Acknowledgment and disclaimer

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DE-AR0000996 Advanced Research Projects Agency - Energy
DE-CD0000033 Office of Clean Energy Demonstrations
DE-EE0008997 Office of Energy Efficiency and Renewable Energy
DE-EE0009814 Office of Energy Efficiency and Renewable Energy
DE-EE0011192 Office of Energy Efficiency and Renewable Energy

## Echogen has developed a platform $sCO_2$* technology to reduce industrial $CO_2$ emissions and enable the transition to 100% renewable energy

## Waste Heat Recovery and primary cycle

Skid based solution to utilize high temperature waste heat to produce electricity or mechanical drive.  Ideal for cement, steel, powergen applications as a replacement to the HRSG

## Industrial Heating

High efficiency heat pump technology to electrify low and medium temperature industrial applications

## Long Duration Energy Storage

Pumped thermal energy storage (PTES) to enable baseloading renewable energy resources at the Utility scale


8 MW EPS100 Waste Heat Recovery System

*$sCO_2$ – Supercritical $CO_2$

# Our Solution: ECHOGEN Pumped Thermal Energy

## Cost-Effective

**~65%** LCOS compared to li-ion batteries

Low-cost materials for storage media

## Ultra Long-Life

Targeting **60** years of life lifespan with unlimited cycles

No performance degradation

## Safe & Sustainable

**100%** non-toxic with no hazardous materials

Fully recyclable at end of life.

## License Partner: Westinghouse Electric Company

ECHOGEN

# Energy Storage Systems – Key characteristics

**Cost**
- Capital and operating

**Safety**
- Fire, toxicity and other risks

**Efficiency and performance**
- RTE, turndown

**Flexibility**
- Construction, usage

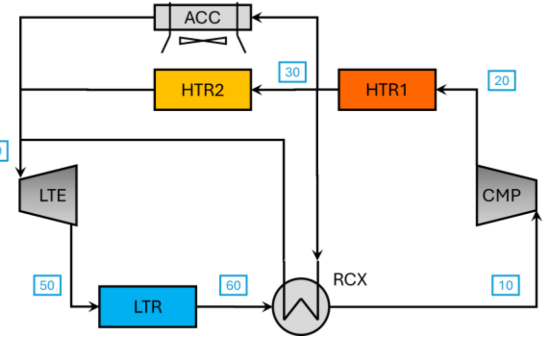
**Grid stability**
- Inertia & VAR support

**Environmental**
- Construction, operation and EOL

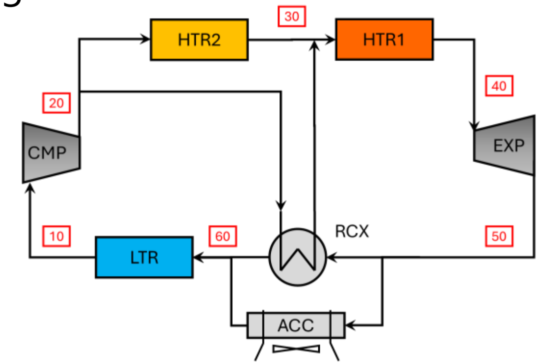
**Materials usage**
- Local and global availability

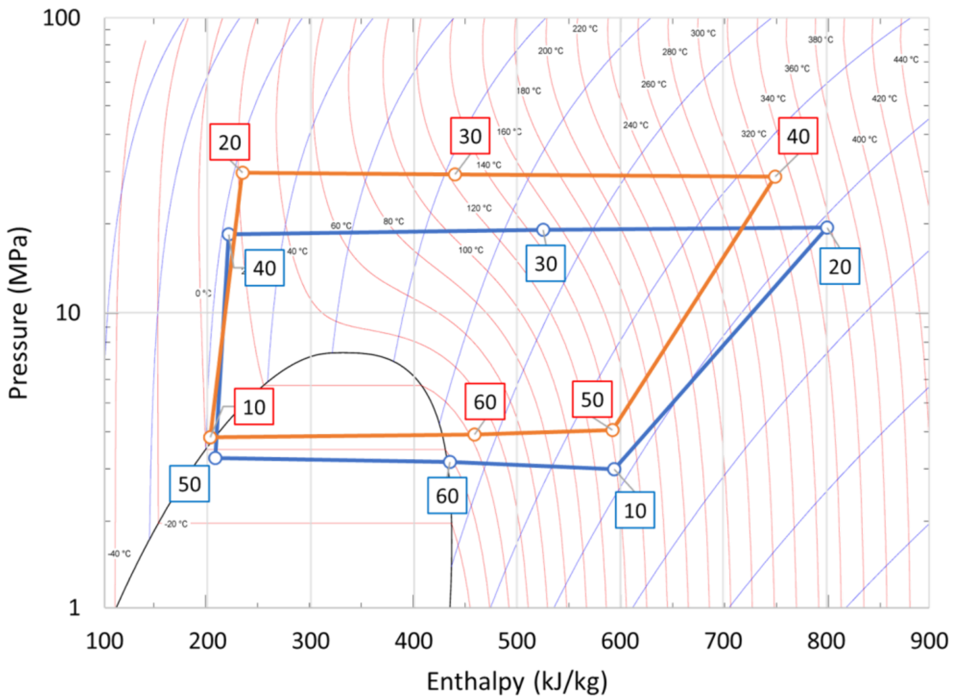
# Pumped Thermal Energy Storage basics

Charging




Generating



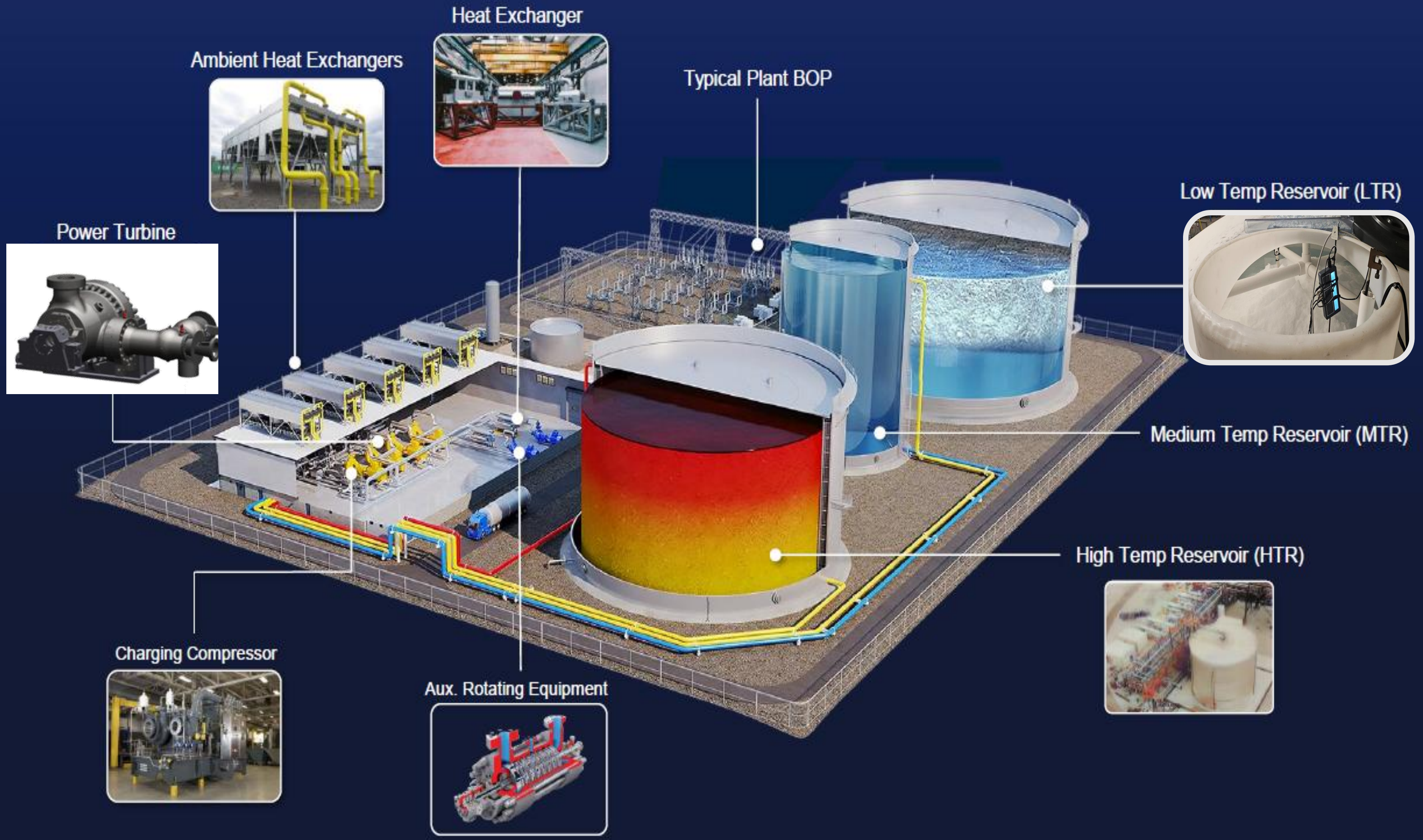
## Systems

Generation

The EPS100 is a commercially available generating system with over 330 hours of operation

Heat Pump

Large pilot scale system used to validate models



# Power generation turbine will be largest operational $sCO_2$ unit at time of deployment

~62 MW net output

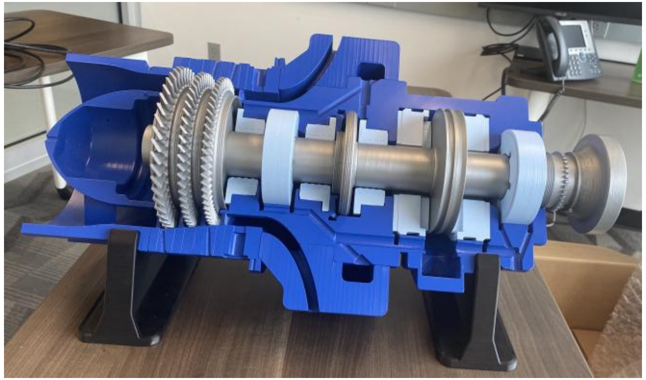
HP steam turbine derivative

Multi-stage axial design, synchronous generator

# Large-scale axial compressor development program

ETN Global

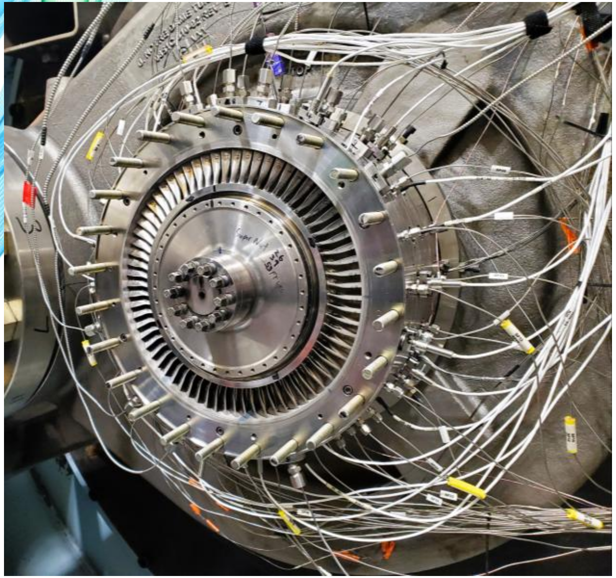
- Initial deployments are multiple centrifugal compressors in parallel
- Pumped thermal energy storage requires grid-scale compression - >100 MW – better served by axial
design

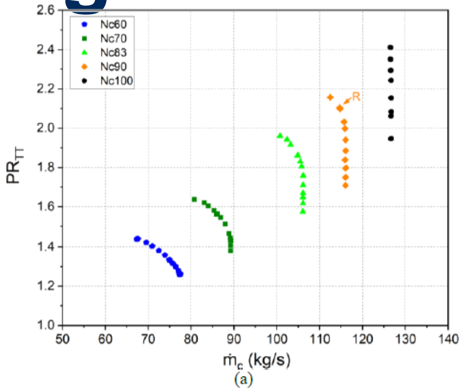


- DOE/EERE funding
- Univ. Cincinnati optimized blade aero
- Univ. Notre Dame Turbolab design/test

# Advanced 3-stage axial $CO_2$ compressor design & demonstration

ETN Global





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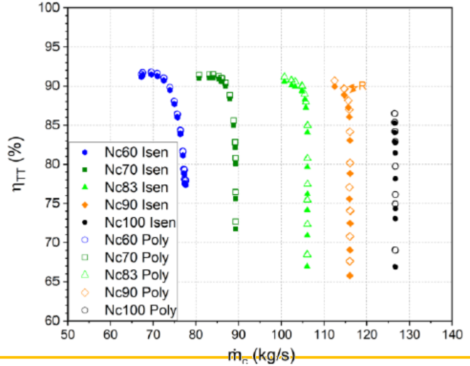
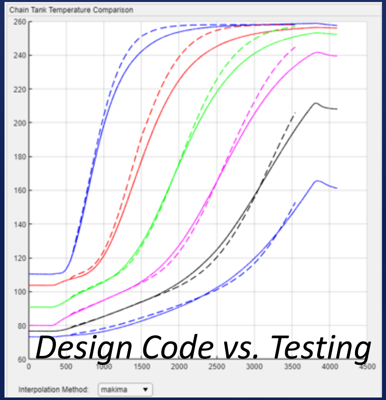


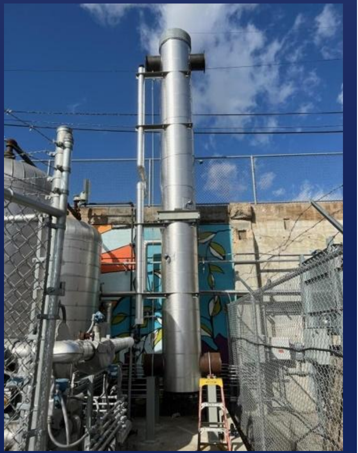

- Advanced blade aero design & optimization
- Met projected performance (pressure ratio and isentropic efficiency)
- Highest $sCO_2$ isentropic compressor efficiency to date
- In discussions with OEMs for potential commercialization
- 2 ASME IGTI Best Paper awards (2024 and 2025)

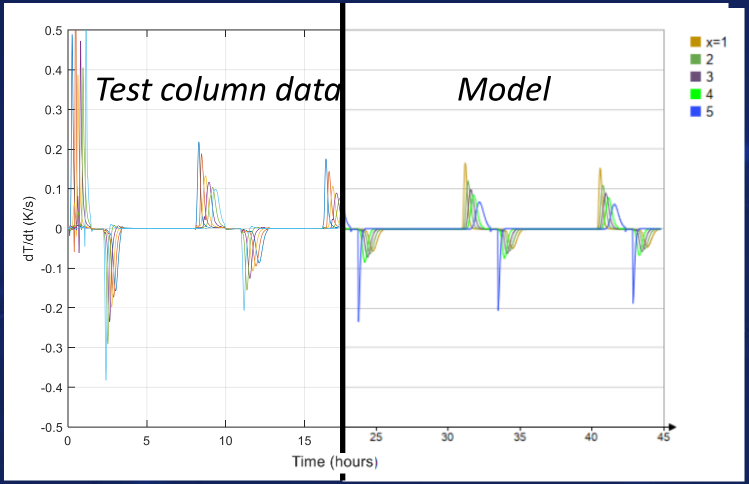
# Thermal Reservoirs

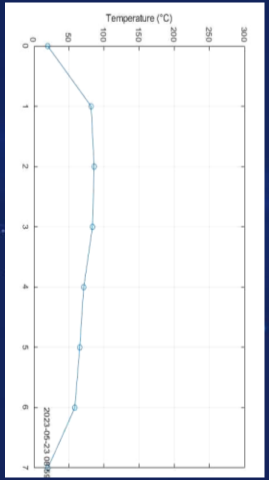
## Packed Bed + Heat Transfer Fluid

- Westinghouse proprietary engineered concrete fill
- Testing of thermal column
  - Multiple fill materials tested
  - Simulation tools validated against data
- Active test & simulation programs
  - Packing fraction + DEM* simulation program
  - Durability (cycle) testing
  - Manufacturing automation
  - Integrated effects (large-scale) test








*Discrete Element Modeling

# Thermal Reservoirs

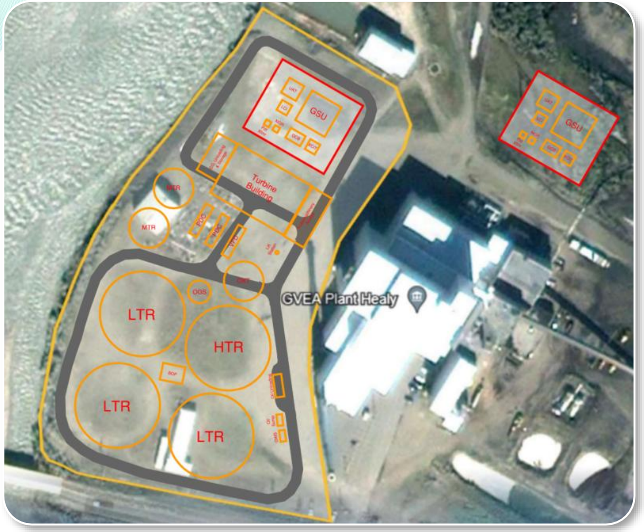
## Ice/water slurry thermal energy storage

- Supercooled water IWS generation
- Laboratory-scale testing complete
  - Multiple heat exchanger coatings evaluated
  - Reliable supercooling without freezing obtained
- Large-scale testing in 2026

ECHOGEN

# Commercial development

# POLAR Project in Healy, AK - One of the largest planned installations of long-duration energy storage in the United States




- Prime recipient: Westinghouse Electric Company
- US DOE awards project to deploy 50MW, 24-hour (1.2 GWh) long-duration energy storage
- Bolsters energy security for the region
- Mitigates transmission system limitations, balances load
- Enables future integration of renewable energy
- Air quality and electricity pricing benefits to community
- Leverages existing utility staff skillsets

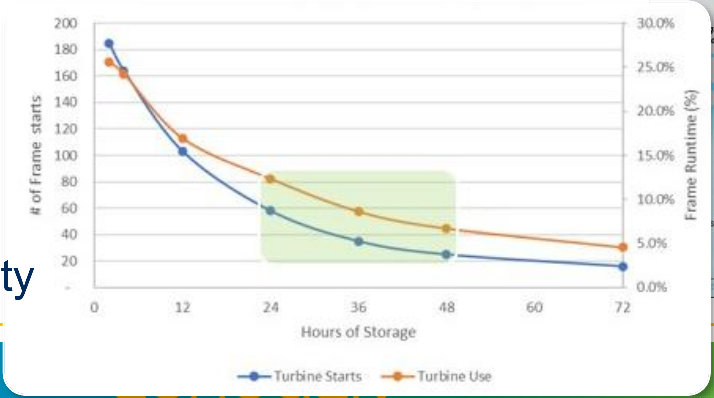
| Submission to DOE | Award Date | Contract Signed | Phase 1 Feed Study | Design Completed | Construction Started | COD |
|---|---|---|---|---|---|---|
| March 2023 | Sept. 2023 | July 2024 | July 2024 | Q4 2025 | Q1 2026 | Q1 2029 |

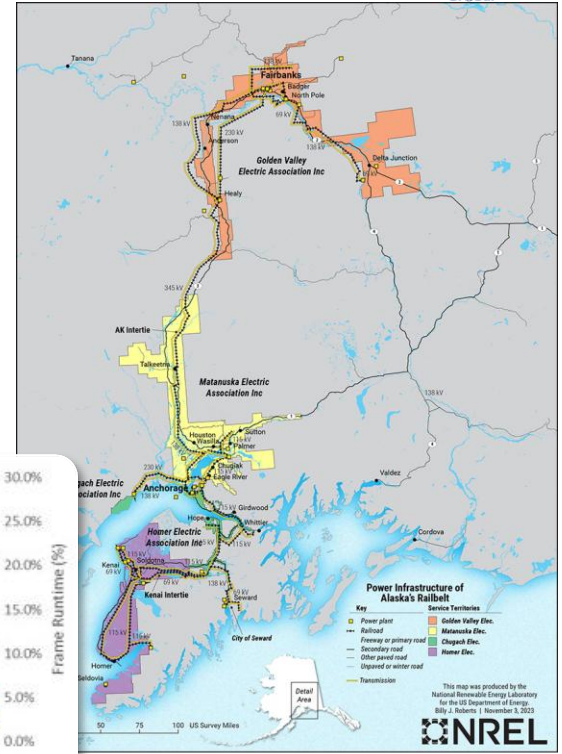
EPRI ELECTRIC POWER RESEARCH INSTITUTE · Shell · Westinghouse · ECHOGEN · ASRC ENERGY SERVICES · GVEA

# GVEA use case

ETN Global

- Current generation assets (~300 MW)
  - Coal – (Healy, 88 MW)
  - Simple cycle frame gas turbines, ULSD/Naphtha (Fairbanks 38 MW, North Pole 120+60 MW)
  - Wind (Eva Creek, 24.6 MW, 33% CF)
  - Hydro (Bradley Lake, 15 MW)
  - Purchased power from Interties – no longer available
- Low-cost energy to be used to charge PTES, avoid frame gas turbine usage during generation shortfall
- Electricity price, air quality advantages
- High premium on charge and generation rate flexibility



# Project status

- FEED study on track for EOY completion
- Preliminary P&IDs, equipment specs transmitted to potential suppliers, quotes received
- No component show-stoppers
- Steady-state and quasi-steady-state modeling near completion –
  - Design point
  - Turndown
  - Ambient temperature
  - Reservoir capacity imbalance recovery
  - Reservoir temperature variation
- Transient model and control simulation underway

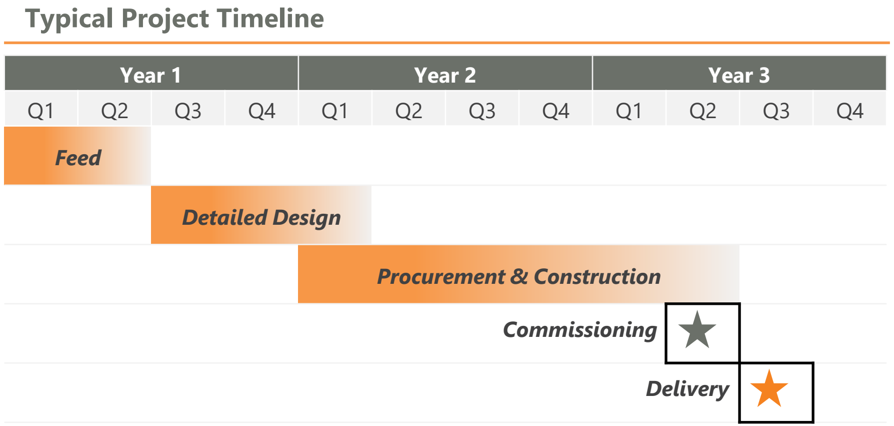
# International PTES Deployment

<u>**Vodohospodárska Výstavba (VVB)**</u>

- MOU signed in Washington, D.C. in 2025
- Feasibility study and use case analysis completed
- Use case to store and utilize significant unused hydroelectric power → 200MW PTES system
- Expected COD 2030

<u>**Africa**</u>

- Late-stage discussions to deploy first PTES project in Africa
- Expected 50MW PTES system with COD 2030



# PTES Roadmap

### PTES Design & Technical Modeling
2017 – 2024

- Concept developed and key cycle IP position created
- Detailed steady-state and initial transient models developed and validated against EPS100 data
- Techno-economic design optimization tools created and utilized
- Component and system cost models developed
- Pre-FEED studies completed with Southern Company, EPRI and Advisian Worley

### Small Scale Testing
2017 – 2026

- 100 $kW_{th}$ $CO_2$ test loop
- Integrated heat pump, thermal reservoir, heat engine operations
- Operation and controls methodology development and optimization
- Repeatable cyclic operations demonstrated
- Large-scale axial compressor design validated through testing

### Large-scale Testing and Grid Modeling
2024– 2026

- FEED studies at initial commercial deployment sites initiated
- Grid modeling studies conducted with EPRI, commercial developers
- Detailed control system model, demonstration and optimization
- Large scale HTR demonstration

### Initial Commercial Projects
2026 – 2030

- Won highly-competitive $50M DOE Energy Storage Grand Challenge award for a first commercial project
- Two > 1 GWh projects ongoing
  - 50 MW 24-hr system in AK
  - 200 MW 10-hr in Slovakia
- Two additional projects expected to COD by 2030

### PTES Mass Deployment
2030+

# Thank you for your attention

# Thank you and see you next time!

# Question / comments?

# js@etn.global