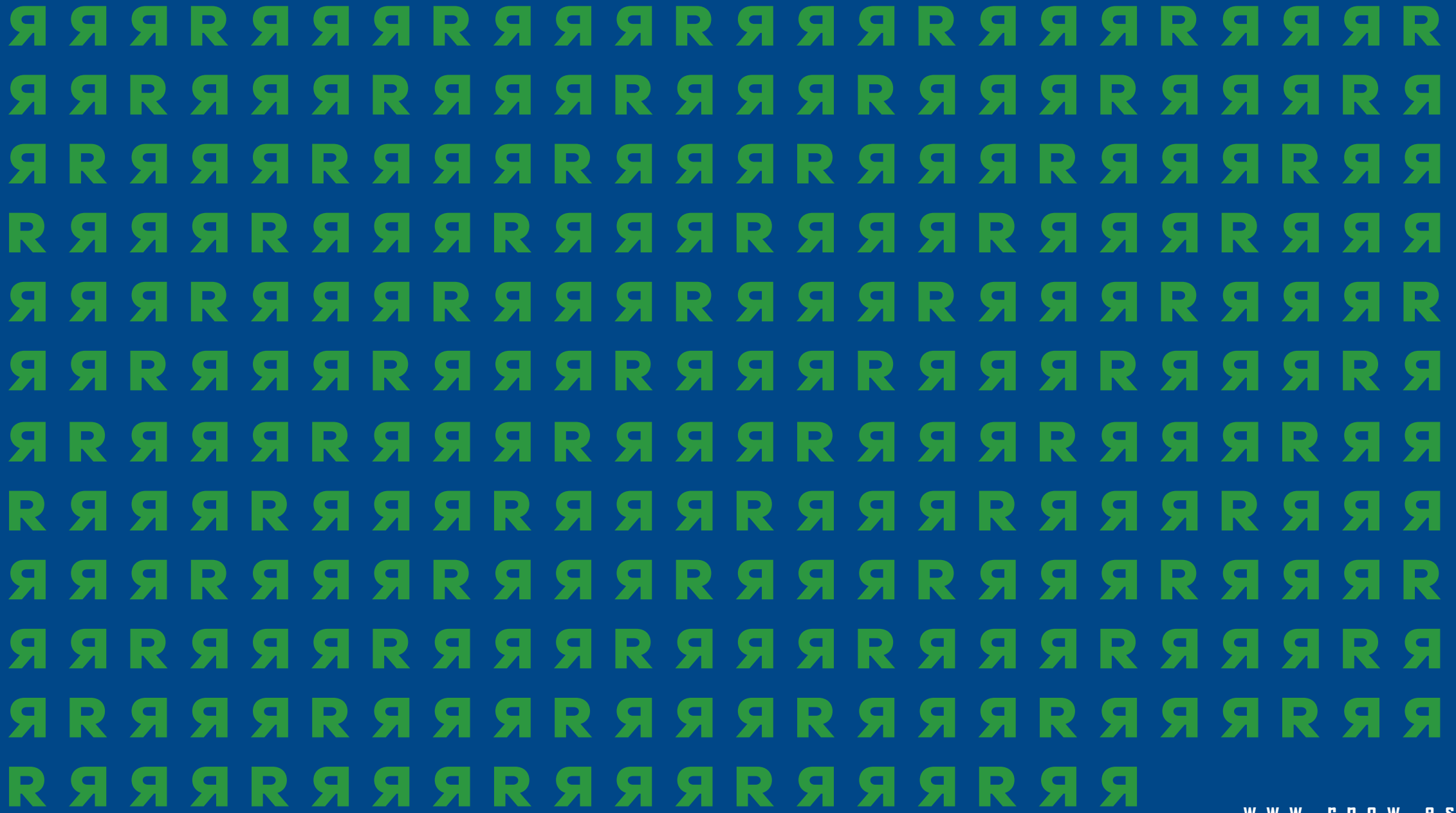
Molten Salt Thermal Energy Storage Applications and other TES Technologies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Index

COMPANY OVERVIEW

RPow

Based in **Spain, USA** and **United Arab Emirates**, and as an international energy consultancy company, **RPow** offers a broad range of technical and managing services.

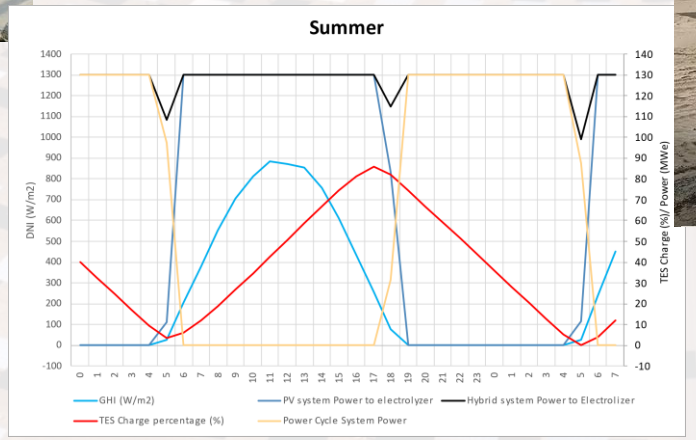
Such services relate primarily to the **energy sector**, both conventional and renewable.

Our Senior Engineers stand for Experience and International Competence in Africa, Asia, Europe, Middle East, North & South America.

Our services

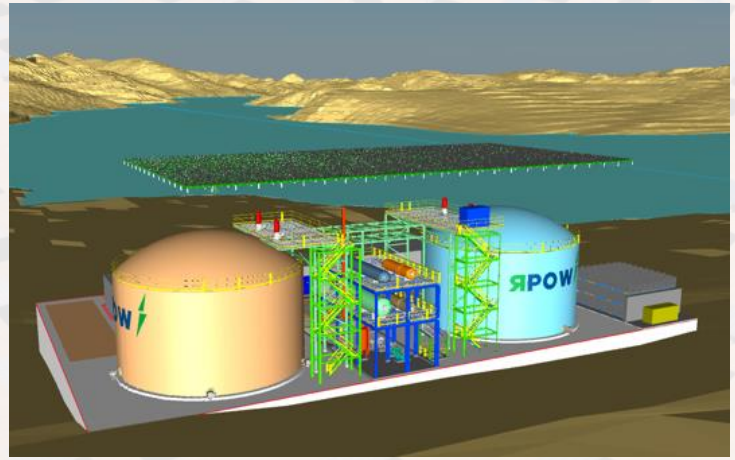
01 DESIGN AND TECHNICAL CONSULTANCY

02 OPERATION ASSESSMENT AND IMPROVEMENT



03 COMMISSIONING AND O&M SPECIALIZED SUPPORT

04 PRODUCT DEVELOPMENT, TES FOR INDUSTRIAL APPLICATIONS



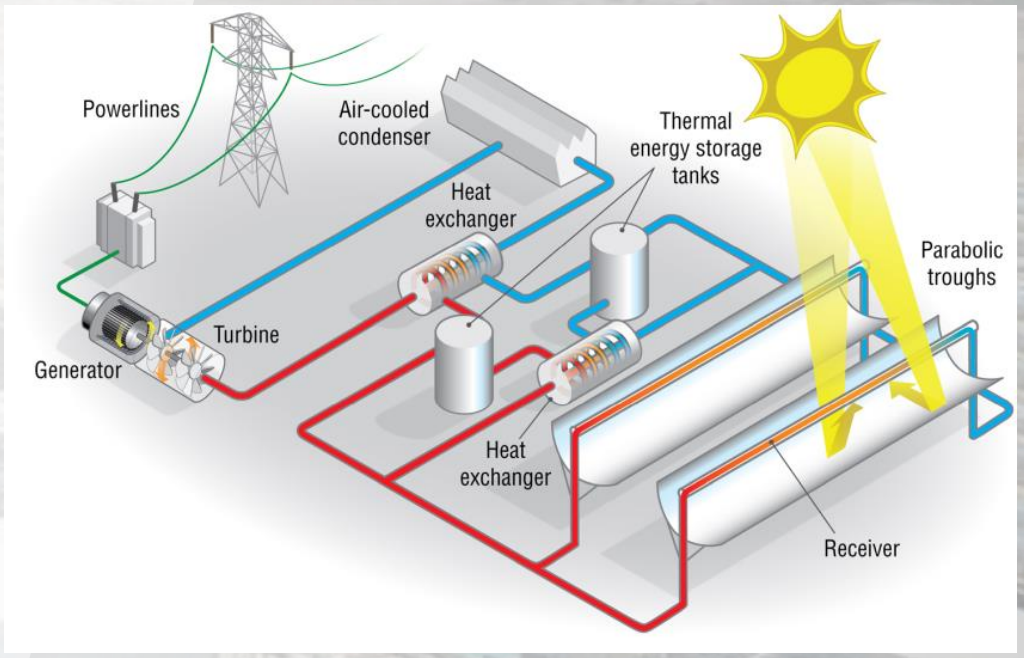
2

MOLTEN SALTS THERMAL STORAGE APPLICATIONS

2.1 MS Thermal Energy Storage Origin

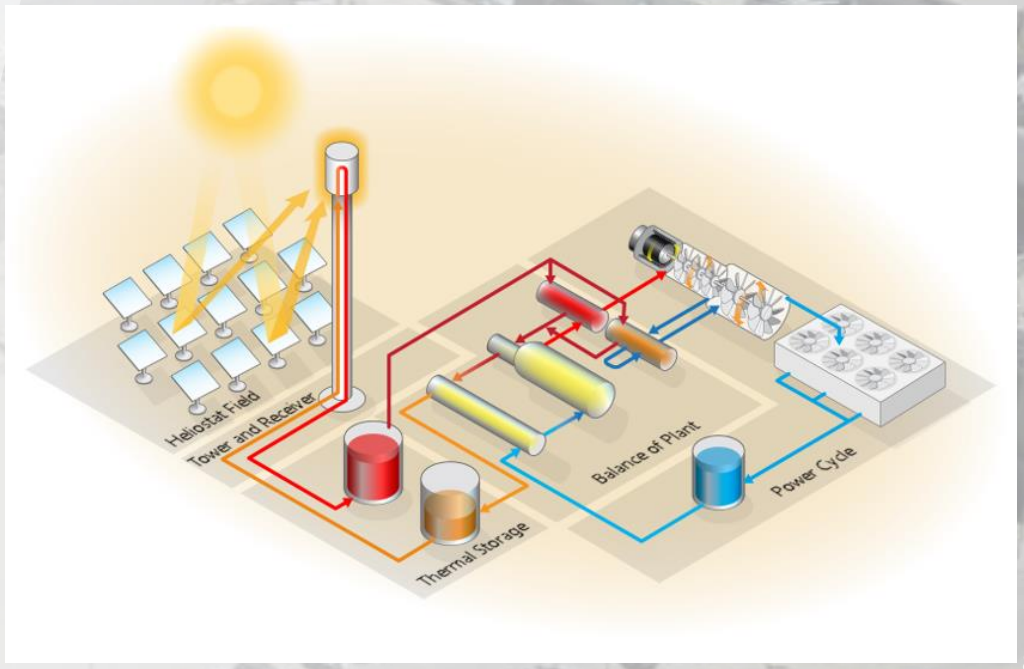
Parabolic Trough

- Sun is reflected into linear receivers where the Heat Transfer Fluid (Thermal oil) is heated up
- Thermal oil then heats up Molten Salts where thermal energy is stored. By means of a cold (290°C/554°F) tank and a hot (400°C /752°F) tank.



Central Tower

- Sun is reflected into a central receiver situated atop a tower where the Heat Transfer Fluid (Molten Salts) is heated up
- Molten salts are stored in the hot (565ºC/1049°F) tank and the cold (290ºC/554°F) tank when discharged.



2.2 Molten Salt Types

Binary Salts

- **Composition**:
  - KNO3 40% mass
  - NaNO3 60% mass
- **Temperatures**:
  - Cold: 290°C
  - Hot: 565°C
  - Freezing: 220°C
  - Degradation: 620°C

Binary salts are the most widely used at a commercial scale as they are the ones used in the CSP industry for Power production

Ternary Salts

- **Composition**:
  - KNO3 43% mass
  - NaNO3 15% mass
  - Ca(NO3)2 42% mass
- **Temperatures**:
  - Cold: 200°C
  - Hot: 390°C
  - Freezing: 130°C
  - Degradation: 500°C

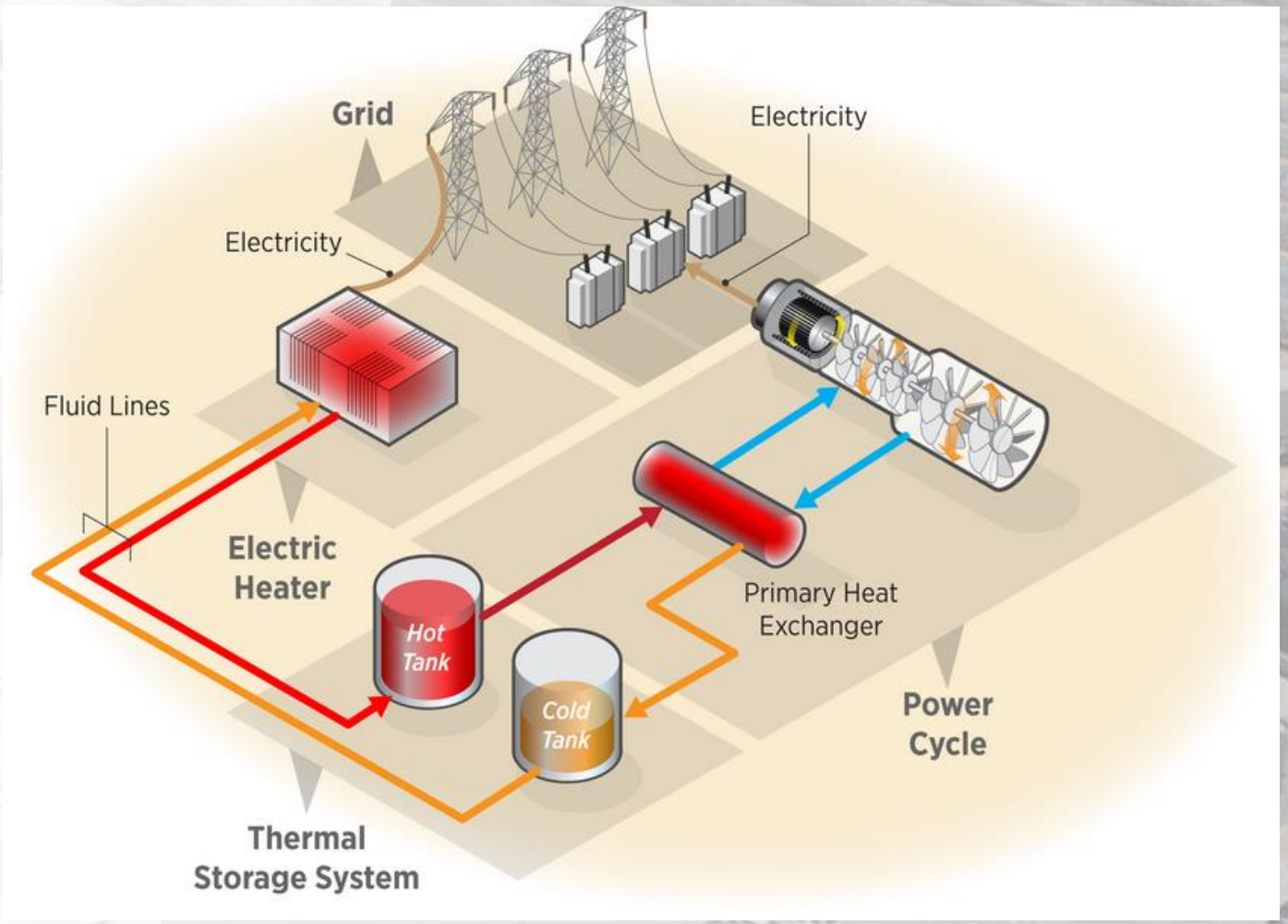
Ternary salts are not as widely used as they are a relatively new solution for thermal power generation

2.3 MS TES Applications

2.3.1 TES for Electricity Generation

TES grants the capacity to produce electricity on demand

- Binary Molten Salts are usually used as storage fluid
- MS are heated up through a series of electric heaters
- Heaters are fed either from a renewable energy source (PV or Wind) or directly from the grid
- Steam is generated in a Steam Generation System which feeds a Steam Turbine where electricity is generated
- Electrical power produced to either inject to the grid or feed an industry power

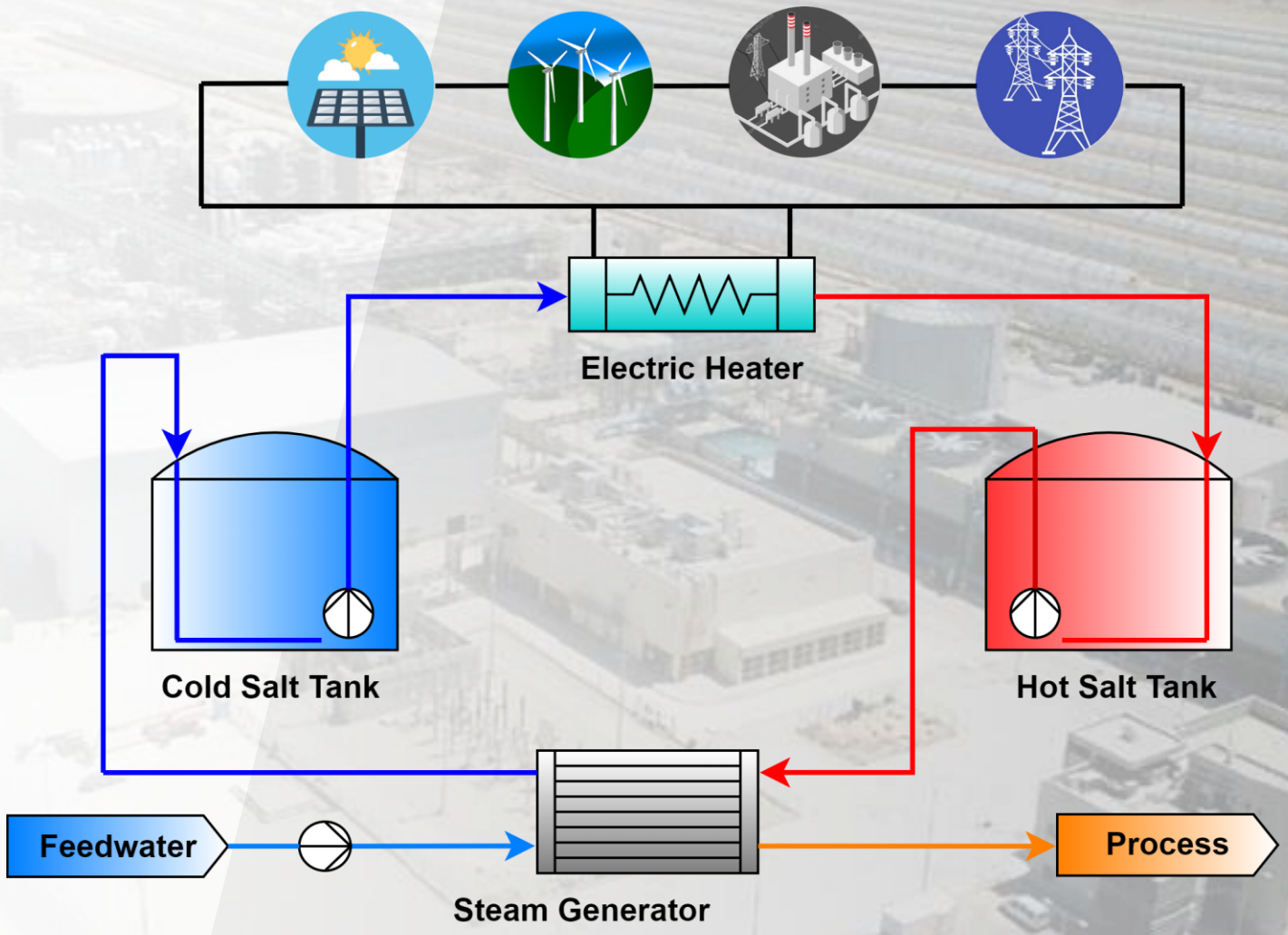


2.3 MS TES Applications

2.3.2 TES for Thermal Generation

TES fits into this frame through the need of industry decarbonization

- Molten Salts are used as storage fluid
- MS are heated up through a series of electric heaters
- Heaters are fed either from a renewable energy source (PV or Wind) or directly from the grid
- Steam to feed the different industrial processes is generated by a Steam Generation System

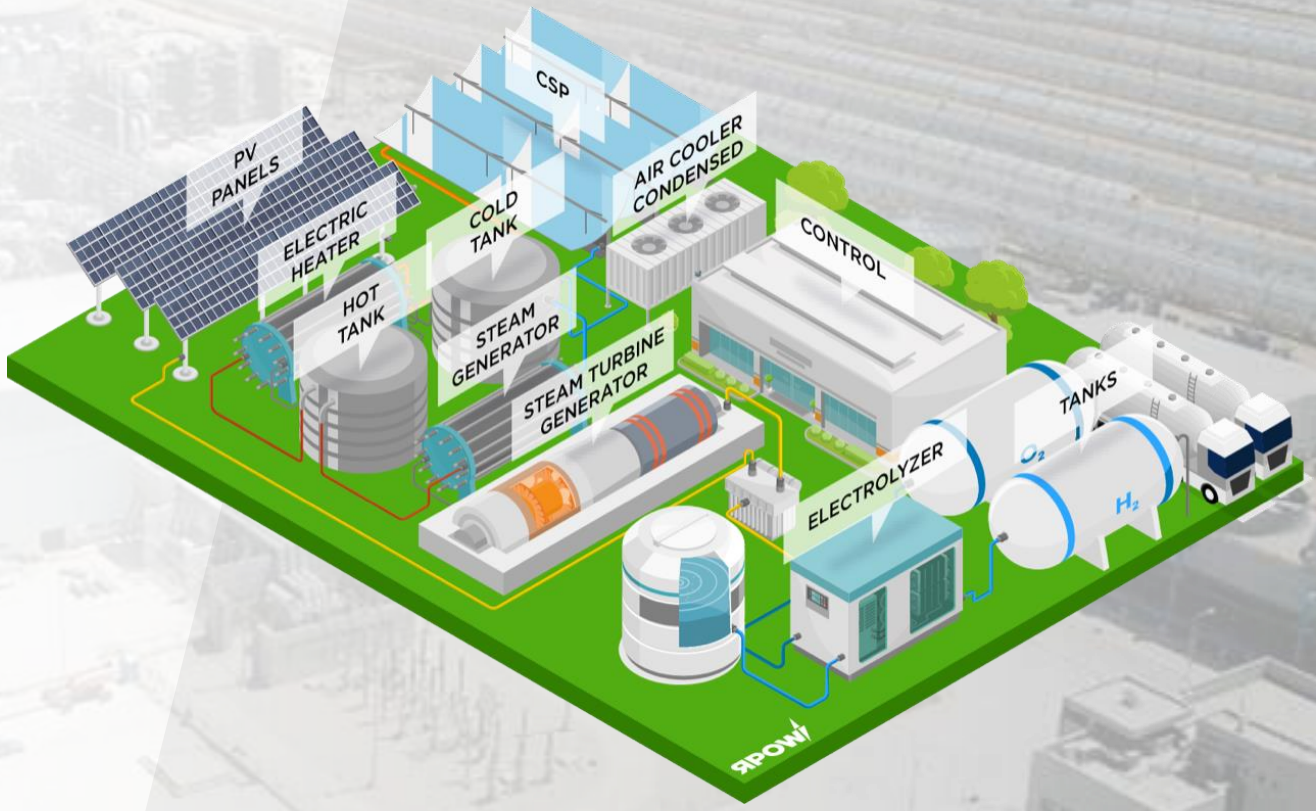


2.3 MS TES Applications

2.3.3 TES for H2 Generation

TES has an exceptional projection in the future of green hydrogen generation

- Molten Salts are used as storage fluid
- MS are heated up with thermal oil from CSP or directly through a series of electric heaters
- Steam is produced with MS and energy from PV panels in the Steam Generator System
- Steam Turbine feeds the electrolyzer with electricity
- Electrolyzer produces the H2, which is stored along 02 in tanks



2.3 MS TES Applications

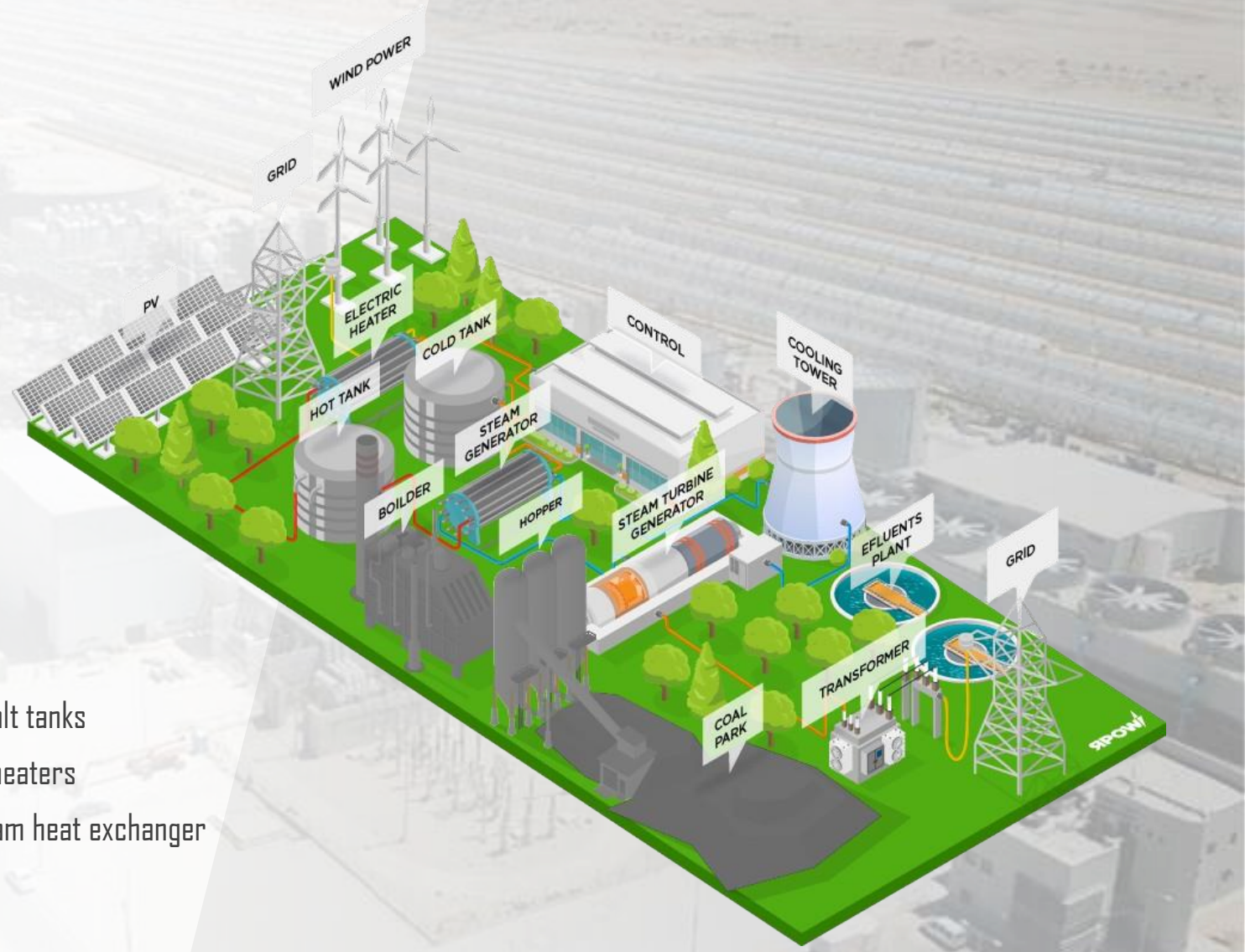
2.3.4 TES for Coal plants

This solution would allow to enhance the value of part of the coal-fired plants, maintaining their activity and giving a green change to their electricity production.

- To be **removed**:
  - Coal/fuel boiler
  - Coal park / fuel tanks

- To be **maintained**:
  - Turbine
  - Transformer
  - Cooling towers
  - Effluent treatment plant

- To be **added**:
  - Molten salt tanks
  - Electric heaters
  - Salt/steam heat exchanger



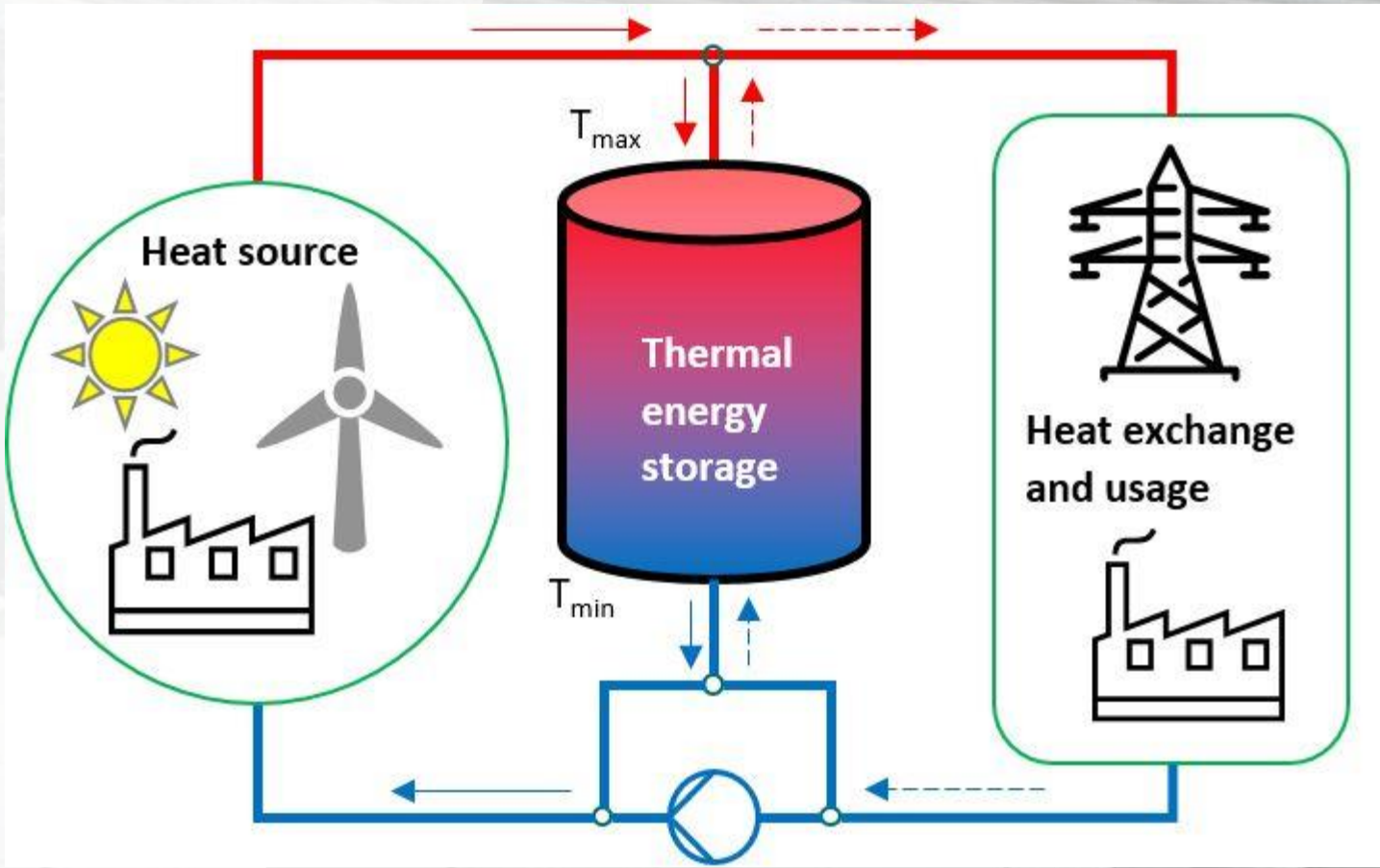
OTHER THERMAL ENERGY STORAGE TECHNOLOGIES

3.1 Introduction

The future is bright for Molten Salts technologies, but there are more options in Thermal Energy Storage technologies.

TES systems can be categorized into three main types:

- Thermochemical Storage
- Latent Heat Storage (PCM)
- Sensible Heat Storage



3.2 Thermochemical Storage

TRL: 3

Definition

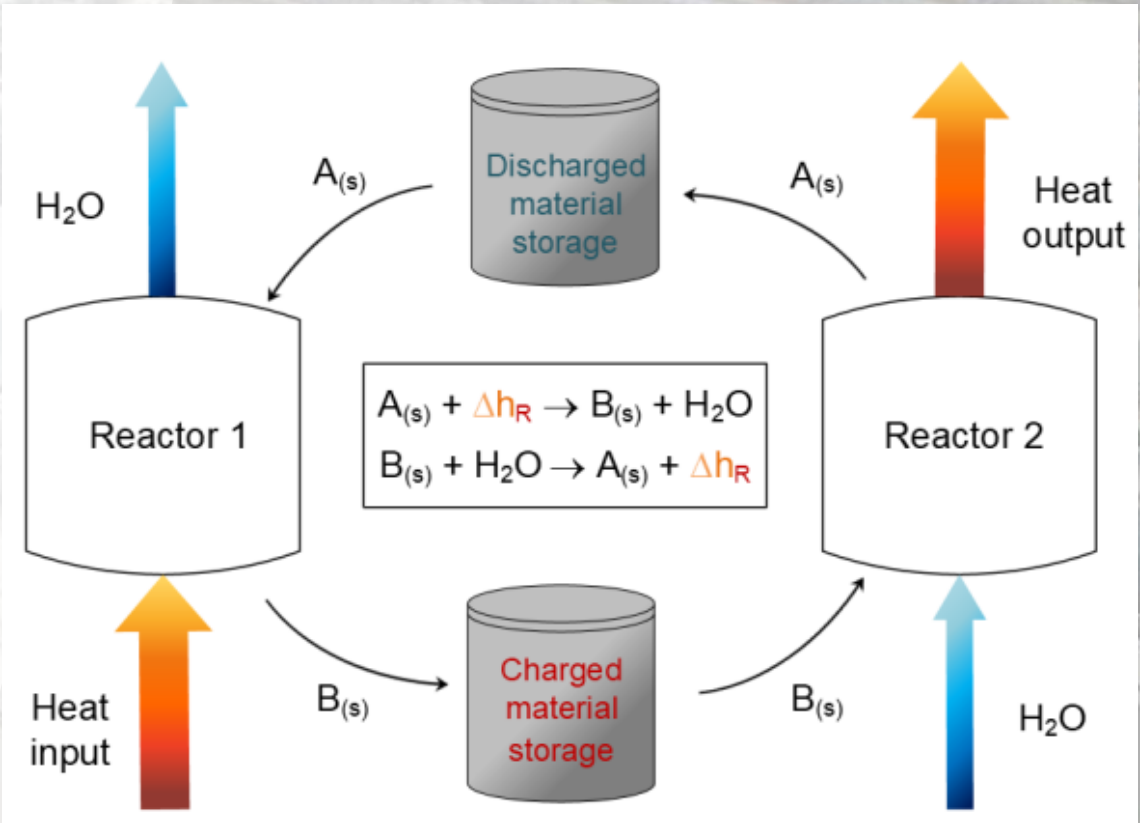
- Thermal energy is used to dissociate two reactive products that store heat separately
- A subsequent recombination of the reactants generates an exothermic reaction that releases the stored heat

Types

- **Reversible Chemical Reactions**: through absorption processes or dissolution of a material
- **Adsorption Reactions**: where the reactants separate during the energy storage process and the heat from the reaction is released upon recombination

Examples

- Absorption machines: *Ammonia-water* or *lithium bromide-water*



3.3 Latent heat Storage (PCM)

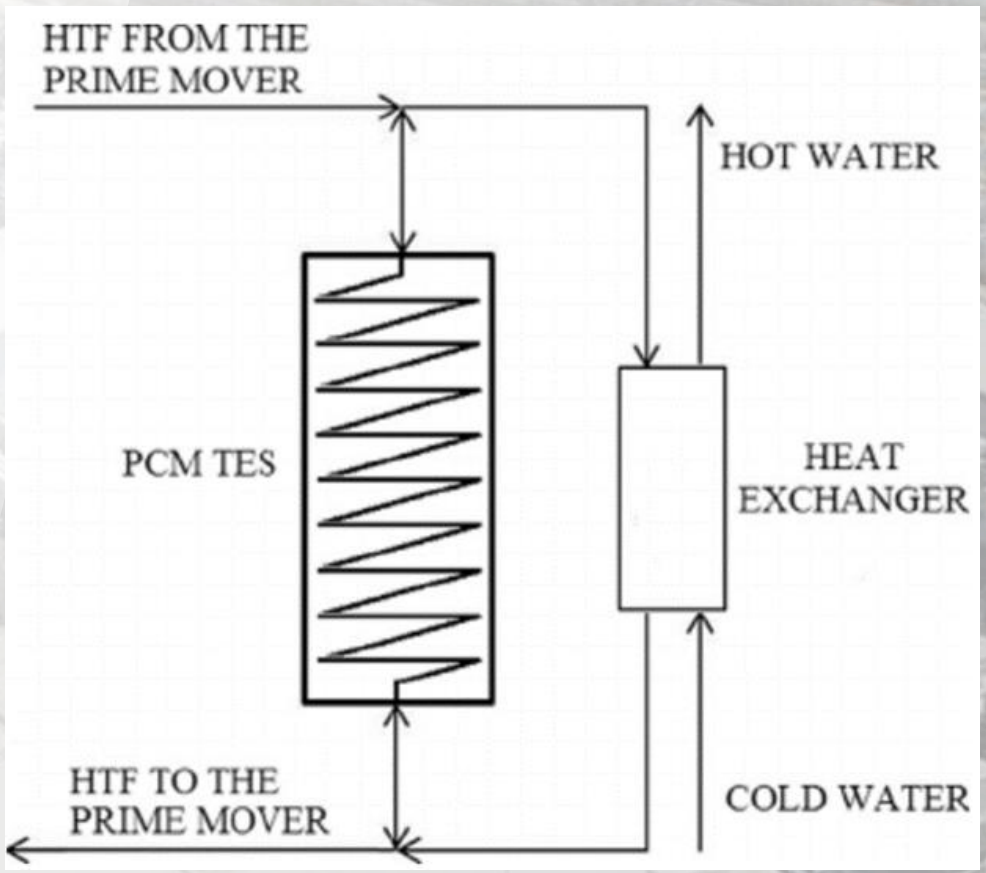
TRL: 4

Definition

- PCM module transfers the energy absorbed or released during their phase change, which occurs at a constant temperature, presenting a higher energy density than sensible heat technology

Types

- The selection of the material is made based on the temperature range required by the process:
  - **T < 0°C:** Aqueous salt solutions or ice
  - **90°C < T < 200°C:** Fatty acids, salt hydrates or alcohols
  - **T > 400°C:** Metals and carbonates



3.4 Sensible Heat Storage

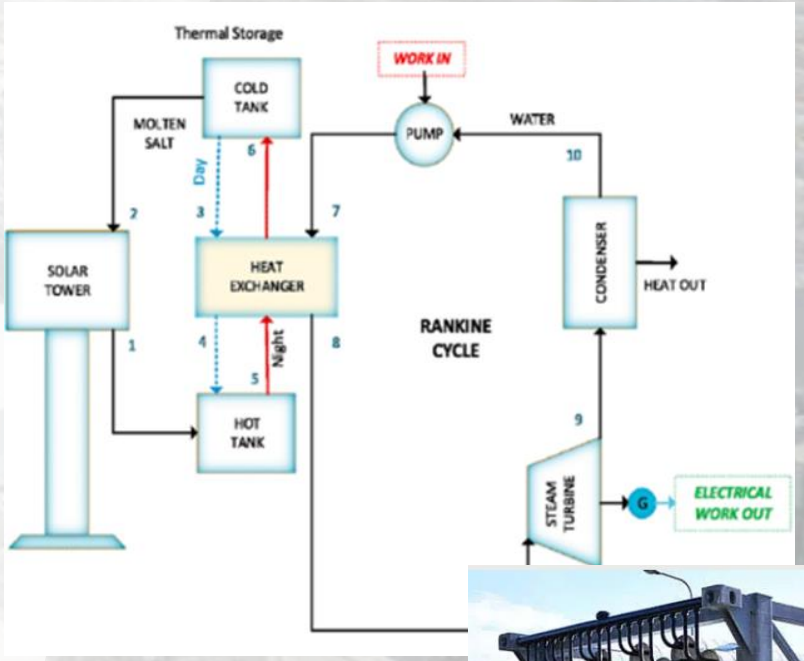
TRL: 9

Definition

- Operation is based on increasing or decreasing the temperature of a material, liquid or solid, with a high heat capacity with the aim of storing and releasing thermal energy when needed

Types

- Depending on the required objective, different materials or fluids are used as storage media:
  - **Low Temperature** (<120°C): Water
  - **High Temperature** (120°C < T < 700°C): Molten Salts
  - **Solid** (T > 700°C): Concrete



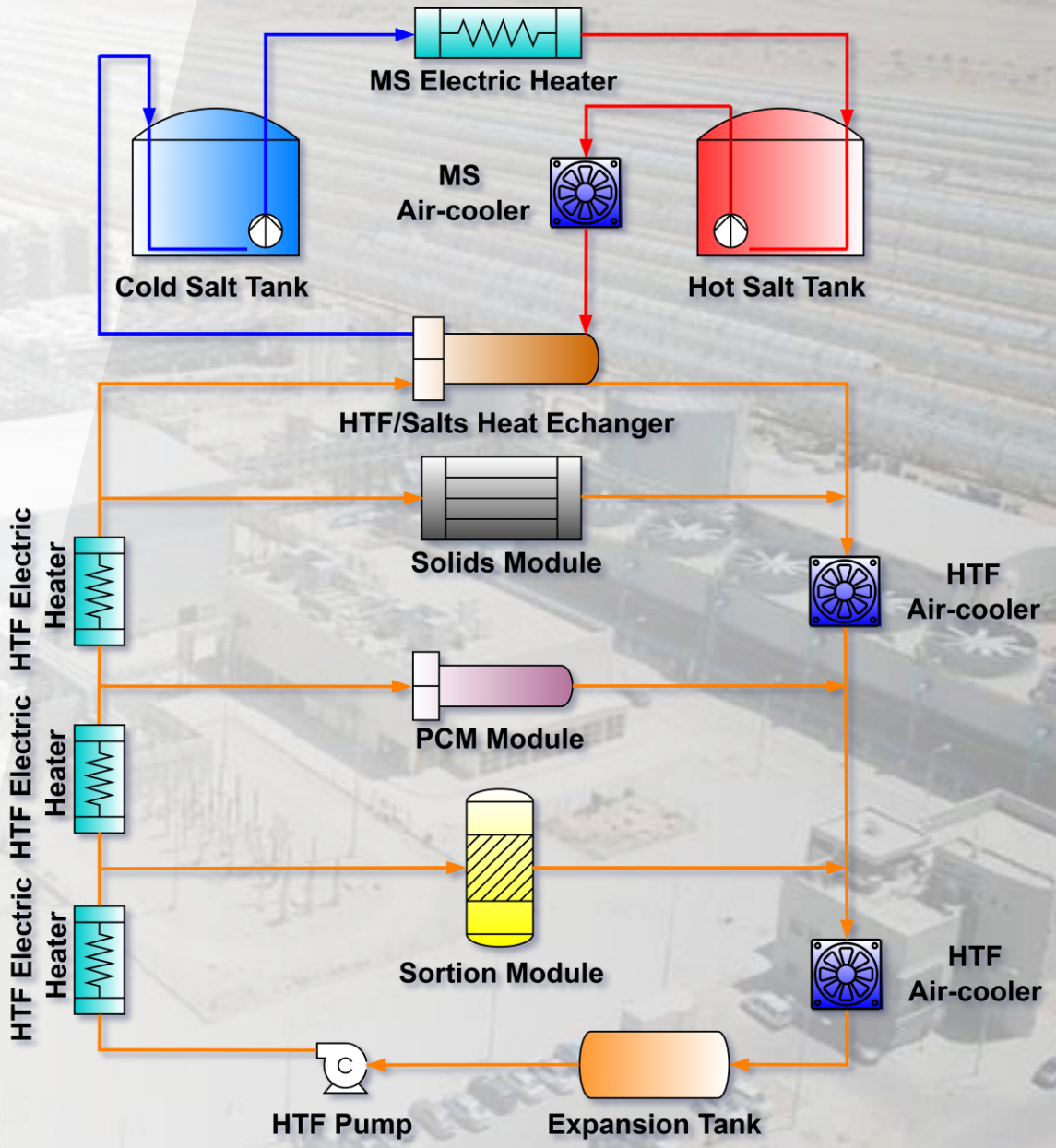
3.5 RPow references

EPC of Thermal Storage Pilot Plant at CIIAE Facilities (Spain)

The installation is designed to research and develop innovative Thermal Energy Storage technologies at the Iberian Research Centre for Energy Storage Research (CIIAE). This plant enables the research of charge-discharge integration at different temperature levels.

There are four technologies involved:

- **Molten salts**: Outlet temperature of the system is controlled by the air-cooler
- **Solids module**: Testing solid materials that have high heat capacity and stability at various temperatures
- **PCM module**: Contains a reactor-heat exchanger designed specifically for phase change materials
- **Sorption module**: Features an endless screw sorption reactor



04

4. Team Structure

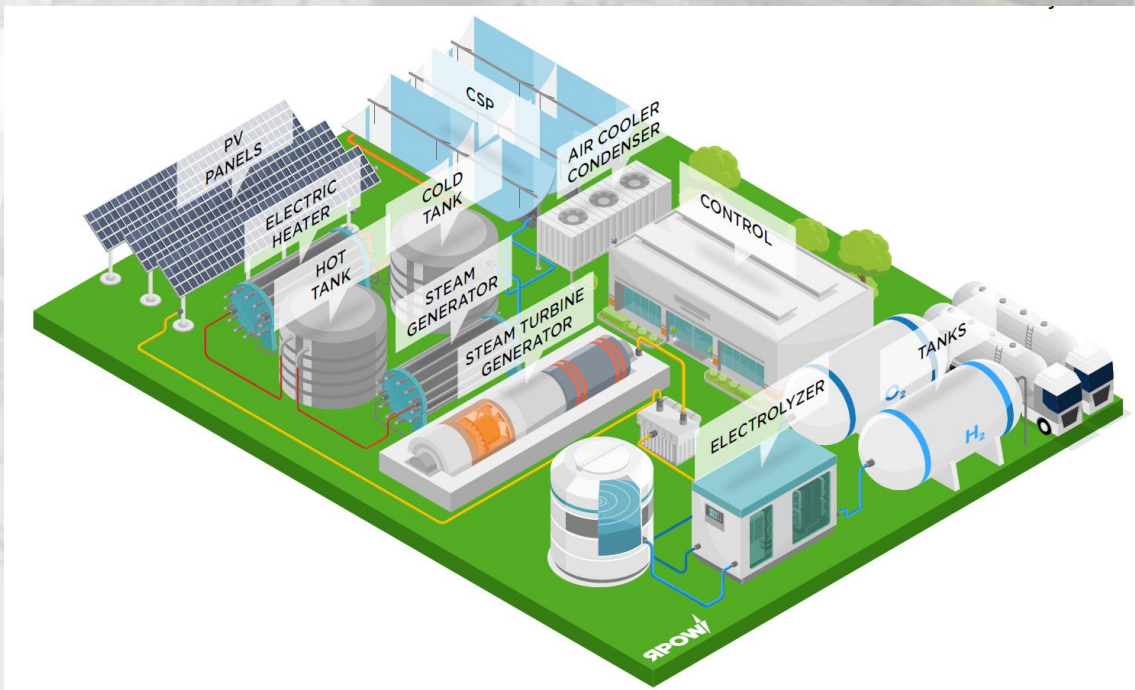
4.1 RPow references

Hidrógeno renovable
Cadena de valor

Next Generation EU – Renewable Hydrogen – Value Chain

H2-24/7 - Design and development of a system for electricity and steam production through thermal storage for green hydrogen generation via electrolysis.

- T 1.2: Research of molten salt-based TES components
  - ST1.2.1 System Study and Specification Definition
  - ST1.2.2 Study of the Electric Heater of salts and study of different mixtures of molten salts
  - ST1.2.3 Research of High Temperature Booster Heater
  - ST1.2.4 Study of the heating process of FW steam generator
- T2.2. Design and development of molten salt systems
  - ST2.2.1 Design and Technical Specification of Components
  - ST2.2.2 Engineering and Component Integration
- T.2.3. Integration and validation
  - ST2.3.1 Component Selection and Manufacturing
  - ST2.3.2 Integration of components into the system
  - ST2.3.3 Validation of the installation



This project is funded by the European Union NextGenerationEU, IDAE exp n. PR-H2CVAL4-C2-2023-000047

4.2 RPow references

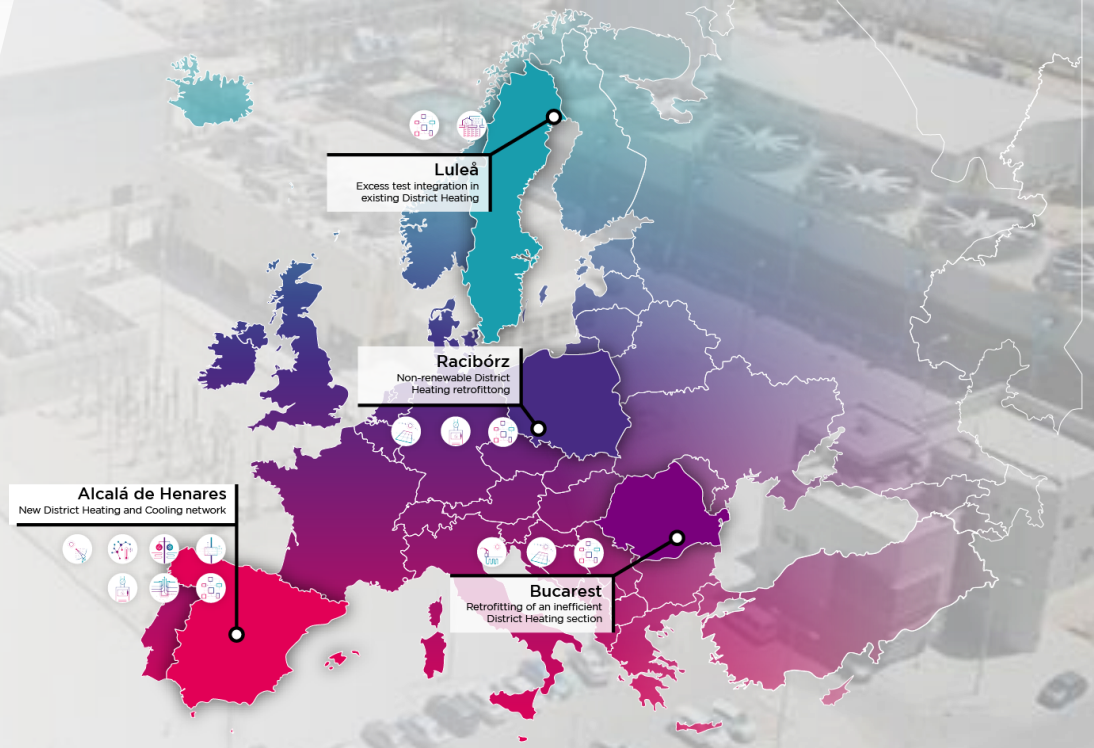
Horizon 2020

Industrial Heating H2020 European Union (Spain)

- **Execution of the following activities and services to support DH Ecoenergías in the European Union in the H2020 program**:
  - Critical equipment definition
  - General Design Criteria
  - MS pumping system
  - TES thermocline configuration design
  - Heat and mass balances
  - Overall Functional Description
- **District heating pilot plant with Thermal Energy Storage Systems with quaternary molten salts to be constructed and tested in Madrid.**

DH ecoenergías DISTRICT HEATING

W.E. DISTRICT Heating & cooling solutions



4.3 RPow references

Horizon Europe Projects

ISOP Project – Call HORIZON-CL5-2023-D3-01 (Marie Curie Actions)
Innovation in Supercritical CO_2 Power Generation Systems

- WP1: System Integrator
  - Host for DC 16
  - Utilization of CO_2 mixtures to enhance the performance of sCO_2 power system

This project is funded by the European Union Horizon Europe Grant Agreement n.101073266

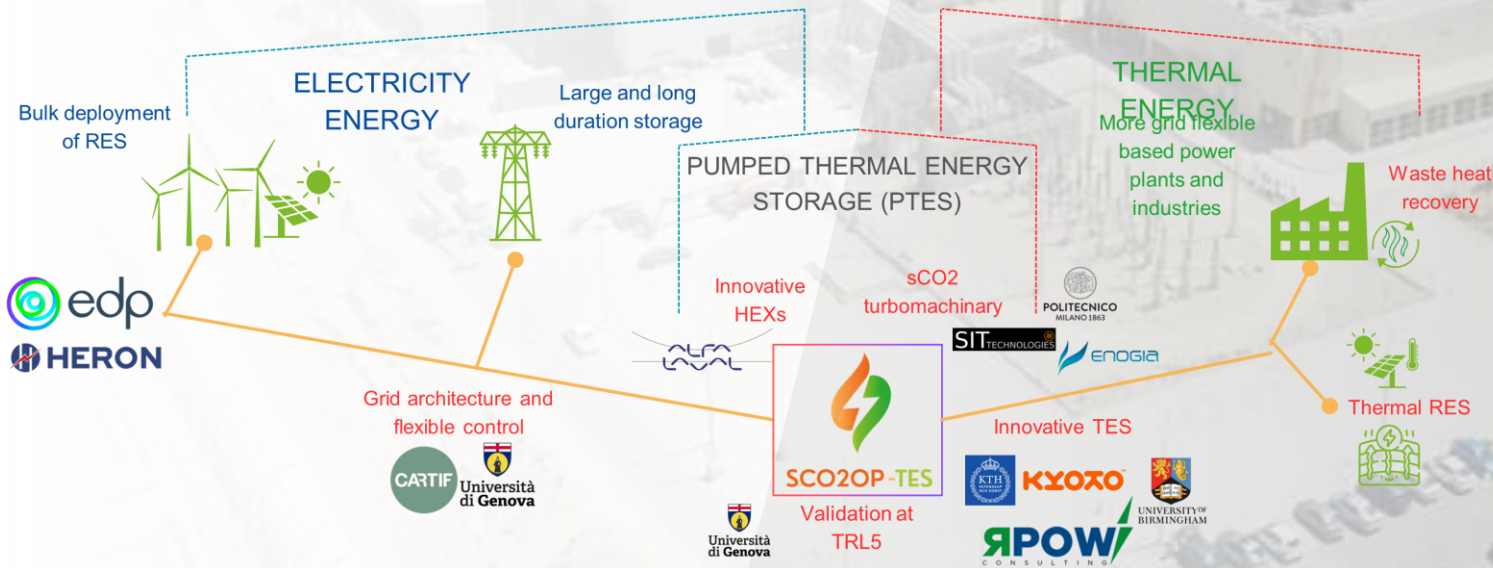
4.4 RPow references

Horizon Europe Projects

sCO_2OP-TES – Call HORIZON-CL5-2023-D3-01
sCO_2 Operating Pumped Thermal Energy Storage for grid/industry cooperation

SCO2OP-TES

- WP3: HEX/TES Solutions for sCO2OP-TES
  - Executive and optimized final design of Thermocline TES
  - Guidelines for TES for PTES application Upscale and replication



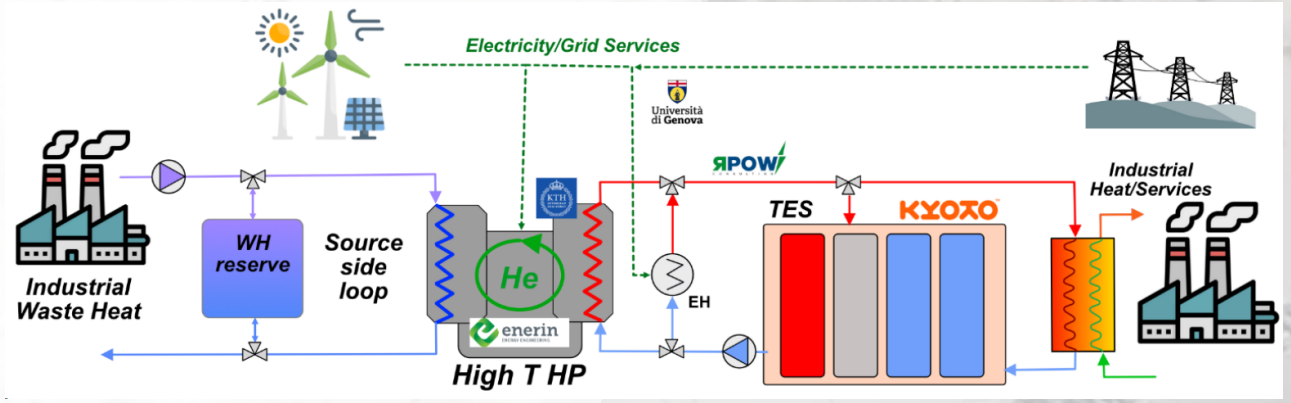
This project is funded by the European Union Horizon Europe Grant Agreement n.101136000

4.5 RPow references

Horizon Europe Projects

I-UPS – Call HORIZON-CL5-2023-D3-02
Innovative High Temperature Heat Pump for Flexible Industrial Systems

- WP 5: System level integration, performance and impact assessment, and upscaling recommendations
  - Upscaling recommendations and system integration comprehensive requirements optimization
- WP 6: Dissemination and communication, standardization and exploitation
  - Leader
  - Exploitation strategy and IPR management



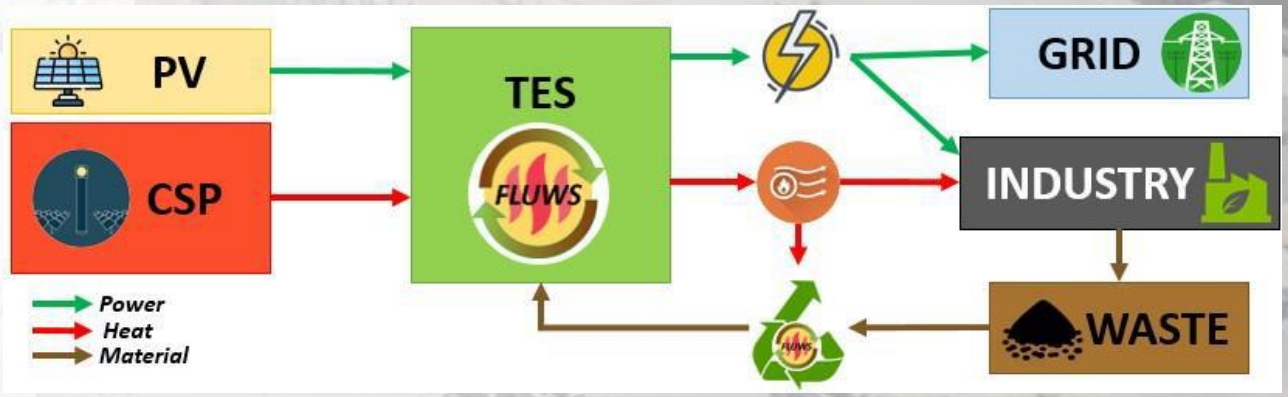
This project is funded by the European Union Horizon Europe Grant Agreement n.101147078

4.6 RPow references

Horizon Europe Projects

FLUWS-CSP – Call HORIZON-CL5-2023-D3-02
Flexible Upcycled Waste Material based Sensible Thermal Energy Storage for CSP

- WP 4: TES experimental campaign and validation at TRL 5 and upscaling recommendations
  - Final upscaling recommendation based on critical technical assessment
- WP 5: System-level integration, techno-economic performance evaluation and environmental and social impact assessment
  - Leader
  - Definition of integration layouts for replication cases and KPIs panel
- WP 6: Dissemination, communication and exploitation
  - Definition of roadmap towards TRL 9



This project is funded by the European Union Horizon Europe Grant Agreement n.101147257

4.7 RPow references

RPOW Preselected

- 1. Project title: Demonstrating Air-Based Concentrated Solar Thermal Receiver Toward
  - DOE Call: Concentrated Solar Flux to Heat and Power. FOA: DE-FOA-0003269
  - Project Location: Madison, Winconsin
  - Project partners:

- 2. Project title: Innovative High Temperature Heat Pump for Flexible Industrial Heat on Demand (UP-FLEXH)
  - H2020 Call: CETPartnership Joint Call 2023, UE
  - Project Location: N/A
  - Project partners: KTH, ENERIN, KYOTO, RPOW, MSG, ABS, TIGI.

This project is funded by the European Union Horizon Europe Grant Agreement n.101147257

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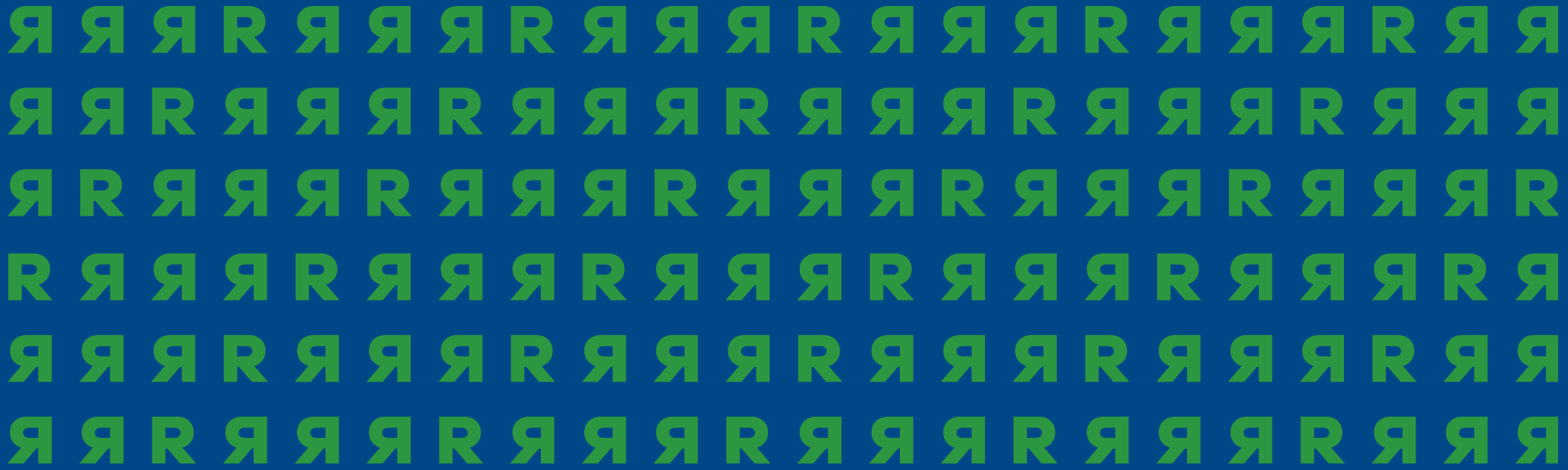

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