Solar World Congress 2025

HYBRID SENSIBLE-LATENT HEAT THERMAL ENERGY STORAGE FOR CONCENTRATED SOLAR POWER APPLICATIONS: INSIGHTS FROM THE COOPERANT PROJECT

Summary

The COOPERANT project introduces an innovative hybrid Thermal Energy Storage (TES) system aimed at enhancing the efficiency of 3rd generation Concentrated Solar Power (CSP), specifically Central Receiver Systems (CRS), operating at extreme temperatures up to 1000°C. By integrating sensible and latent heat storage, the system incorporates advanced materials and optimized configurations to maximize heat transfer and storage capacity. Strategic methodologies in material selection, system design, and performance validation ensure technical robustness, economic feasibility, and sustainability. Ultimately, COOPERANT's advancements aim to set industry benchmarks, enabling scalable and dispatchable, high-performance CSP integration into renewable energy systems.

Keywords: Thermal Energy Storage, TES, hybrid storage, CSP-TES system, Phase Change Materials, PCM, high-temperature systems

1. Introduction

The effective integration of Thermal Energy Storage (TES) in Concentrated Solar Power (CSP) plants significantly improves their dispatchability and efficiency (US Department of Energy (DOE), 2020). Current CSP technologies, however, face challenges in maintaining efficiency at temperatures above 800°C (US Department of Energy, 2018), a requirement critical for next-generation power cycles such as supercritical CO_2 and gas Brayton cycles (Wang et al., 2023). The COOPERANT project (COOPERANT, 2025) addresses these challenges by proposing an advanced CSP-TES system designed for stable operation at extreme temperatures up to 1000°C. It includes the development of a prototype with three main features: (1) High-performance Open Volumetric Receivers for solar absorption and use of air as heat transfer fluid (HTF), (2) a TES hybrid packed bed system and (3) high-temperature solid-state mixtures and phase change materials. The arrangement of the novel system is shown in Fig. 1.

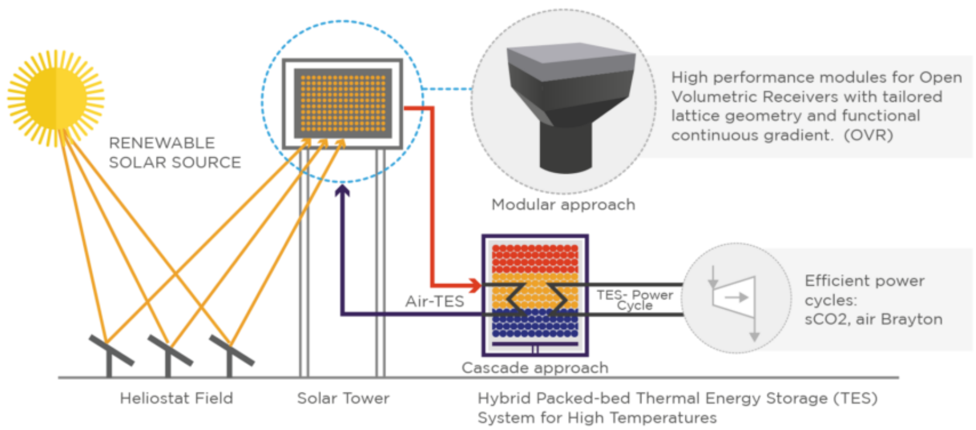

Fig. 1: Schematic arrangement of the components of the proposed Concentrated Solar Power – Thermal Energy Storage System (“COOPERANT,” 2025).

This work focuses on developing and validating novel TES materials with high thermal stability, efficient heat transfer, and long-term durability under extreme conditions providing comprehensive insights into novel material developments and structural optimizations designed to significantly improve thermal performance and reliability of CSP-TES systems.

2. Innovative Contributions

COOPERANT explores a hybrid TES approach integrating sensible heat storage with latent heat storage, leveraging advanced materials designed for extreme temperature stability and improved heat transfer properties. Specific innovations include:

- **Advanced Storage Materials:** Development and validation of molten salts, metallic Phase Change Materials (PCMs), and solid-state materials exhibiting exceptional thermal stability and durability at high temperatures.
- **Hybrid Storage Configurations:** Investigation of a range of configurations including cascade-packed beds and strategically designed structural geometries optimized for maximum heat transfer and effective thermal management.
- **Enhanced PCM Integration:** Development of advanced encapsulation methods and PCM distribution strategies within the TES system to maximize energy storage efficiency and durability.
- **Operational and Material Performance:** Implementation of material circularity strategies and evaluation of robust containment designs aimed at reducing heat losses and improving long-term operational stability.

By combining these advanced materials and innovative structural configurations, COOPERANT aims to set new performance benchmarks and significantly advance the state-of-the-art in CSP-TES systems.

3. Methodology

Sensible and latent heat storage components are strategically arranged within a TES unit to maximize heat transfer and storage density. The COOPERANT project employs a structured methodology to ensure comprehensive coverage of critical aspects for effective TES development. Initially, extensive requirement specifications are established, including detailed definitions of boundary conditions such as energy input and output parameters, system power capabilities, operational pressures, and precise temperature ranges required for seamless integration into high-temperature CRS power cycles. The methodology then involves the systematic optimization of various TES configurations, both physically and virtually, using AI tools and simulations. The focus is on structural analysis and heat transfer enhancement techniques, which are evaluated to determine optimal design parameters and material arrangements. Lastly, material selection involves a comprehensive assessment based on thermal performance, economic considerations, sustainability, and suitability for operation at high temperatures. Throughout these phases, iterative performance evaluations employing key performance indicators (KPIs) – such as thermal efficiency, energy density, operational robustness, and material durability – guide the validation process, ensuring continuous improvement and refinement of the TES system.

4. Expected Outcomes

The COOPERANT project is expected to deliver significant advancements in CSP-TES technology, notably through enhanced thermal performance, system reliability, and economic feasibility. Outcomes of this research are expected to:

- Establish a robust framework for hybrid sensible-latent heat TES integration into CRS systems.
- Provide comprehensive guidelines for material selection and configuration optimization, ensuring scalability and industrial applicability.
- Set a benchmark for future CSP-TES developments, facilitating integration with high-temperature power cycles and broader deployment in renewable energy infrastructure.

The outcomes from the COOPERANT project will contribute significantly to the sustainable growth of CSP technology, strengthening its role as a viable and economically competitive component of the global renewable energy landscape.

5. Acknowledgement

COOPERANT project is funded by the European Union under the Grant Agreement Nº 101172882. This work was supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract Nº 2400402.

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