NEWSLETTER

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PUBLIC OVERVIEW OF HESS PROJECT

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Heat Storage in post-mining shaft

WP5 tested how heat can be stored safely and efficiently so that post-mining infrastructure can support advanced compressed-air energy storage system.

Even if a mine stops producing coal, its infrastructure can support the energy transition. The HESS project examines how post-mining sites can be adapted for large-scale energy storage. Work Package 5 (WP5) focused on the heat generated by compressed air energy storage system (CAES) that can be recovered during electricity generation.

The transformation of power systems, driven by the growing share of Renewable Energy Sources (RES), requires new forms of operational flexibility capable of balancing fluctuating generation and demand. One of the key technological responses to this challenge is the integration of Thermal Energy Storage with large-scale energy systems, in particular with Adiabatic Compressed Air Energy Storage operating within post-mining infrastructure. In such configurations, surplus energy is converted into heat during the compression process and stored in a dedicated storage unit, then recovered during the discharging stage to increase the enthalpy of the working medium before expansion in a turbine. Although a thermal storage tank may appear to be a simple component, its performance depends on complex heat transfer phenomena, fluid flow through porous media, pressure losses, and the thermophysical properties of the storage material. The work carried out within the Hybrid Energy Storage System Using Post-Mining Infrastructure project (HESS) focused on experimental and numerical investigations of storage units based on sensible heat in solid materials and latent heat in phase change materials, with particular emphasis on their applicability to energy storage systems.

What problem did we solve?

Heat is stored when energy is available and recovered when it is needed.

In an adiabatic compressed air energy storage (ACAE) system, electrical energy is used to compress air, which generates a substantial amount of heat. Instead of dissipating this thermal energy to the environment, it is captured and stored. During discharge, this stored heat is used to reheat the compressed air before expansion. This increases the system's useful energy output and improves its overall efficiency.

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WP5 evaluated candidate materials across three broad operating temperature ranges: approximately 100°C, 300°C, and 500°C. The assessment considered not only heat-storage capacity, but also material availability, safety, mechanical strength, chemical stability, ease of handling, and cost, in order to identify the most practical options for each temperature range. More detailed results can be found in Deliverable 5.1. Thermal energy storage material studies.

ROCK BED	PHASE-CHANGE MATERIAL (PCM)
Hot air flows directly through a packed bed of stones, such as basalt, transferring heat to the solid material. The stones absorb and store thermal energy during charging and release the stored heat back to the air during discharge.	A salt mixture absorbs thermal energy when it melts and releases it when it solidifies. Encapsulation keeps the phase-change material contained and prevents leakage within the packed bed.

Both approaches offer viable thermal storage solutions with distinct performance characteristics. Rock beds are simple and robust, and they are based on materials that are widely available. Phase-change material (PCM) beds have a higher volumetric heat storage capacity and release heat over a narrower temperature range. However, they require careful formulation, encapsulation, and management of material compatibility.

From material choice to a validated rock-bed model

SUT connected laboratory measurements with models that can support larger designs.

- The container is 3 meters high and has a diameter of 219 mm
- Basalt packed beds with a diameter of approximately 14 mm and 19 mm
- Porosity of the rock packed bed about 38%
- Maximum allowable air capacity approximately 240 kg/h
- Maximum allowable air temperature 110 °C

The SUT laboratory test rig and the basalt packed bed used to study thermal energy storage.

SUT led the initial assessment of potential thermal storage materials, evaluating their heat storage performance alongside practical criteria such as mechanical strength, availability, and cost. Basalt aggregate emerged as a promising option for large-scale applications. However, tests on an engineered ceramic material demonstrated that favorable thermal properties alone do not guarantee economic viability.

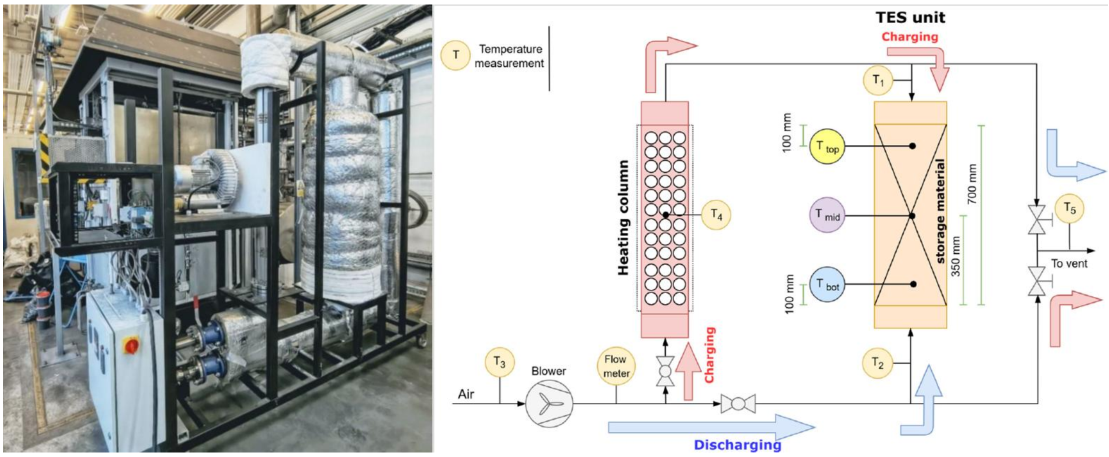
A researcher from SUT subsequently designed and operated a three-meter laboratory-scale storage column filled with basalt. The team monitored air and bed temperatures, pressure drop, and thermal breakthrough—the point at which heat reached the column outlet—across 34 measurement series. The results revealed a significant design trade-off: while increasing the airflow rate accelerates heat transfer, it also increases the energy needed to push air through the packed bed.

Computational fluid dynamics (CFD) simulations successfully reproduced the main temperature trends observed during the experiments. This validation provides engineers with a reliable tool for investigating the behavior of full-scale storage systems. The tests also showed that sufficient bed volume is essential to delay thermal breakthrough and prevent useful heat from leaving the store prematurely.

Measurements from the laboratory-scale system provide a sound basis for designing natural-rock thermal stores. Engineers can use these data to balance charging rate, heat-recovery performance and airflow-related energy losses before progressing to a larger installation.

Comparison between sensible and latent heat storage

ITPE compared sensible and latent heat storage under controlled operating conditions.



The ITPE test rig combines a heated-air supply with an instrumented storage column for charging and discharging tests. Taken from [2].

ITPE screened several phase-change materials (PCMs), and the complete evaluation is presented in a paper published in Energies [1]. The conducted research showed that practical handling is as important as laboratory-scale thermal performance. Solar Salt offered the best overall balance for experimental testing. However, the study also revealed significant encapsulation challenges, such as moisture sensitivity, volume expansion, and pressure buildup within the capsules.

ITPE then tested two storage materials: a basalt aggregate and macroencapsulated Solar Salt. The researchers compared temperature profiles, recovered energy, thermal power, efficiency, and pressure drop. Both configurations achieved high thermal efficiencies. The PCM system stored more energy per unit volume, while the basalt bed provided higher short-term thermal power. More details are provided in Deliverable 5.2 and in Energies journal [2].

[1] Jurczyk, M.; Spietz, T.; Czardybon, A.; Dobras, S.; Ignasiak, K.; Bartela, Ł.; Uchman, W.; Ochmann, J. Review of Thermal Energy Storage Materials for Application in Large-Scale Integrated Energy Systems-Methodology for Matching Heat Storage Solutions for Given Applications. *Energies* **2024**, *17*, 3544. https://doi.org/10.3390/en17143544

[2] Spietz, T.; Dobras, S.; Kulik, K.; Fryza, R.; Czardybon, A. Experimental Comparison of Sensible and Latent Heat Storage in a Packed-Bed Thermal Energy Storage System. *Energies* **2026**, *19*, 3196. https://doi.org/10.3390/en19133196

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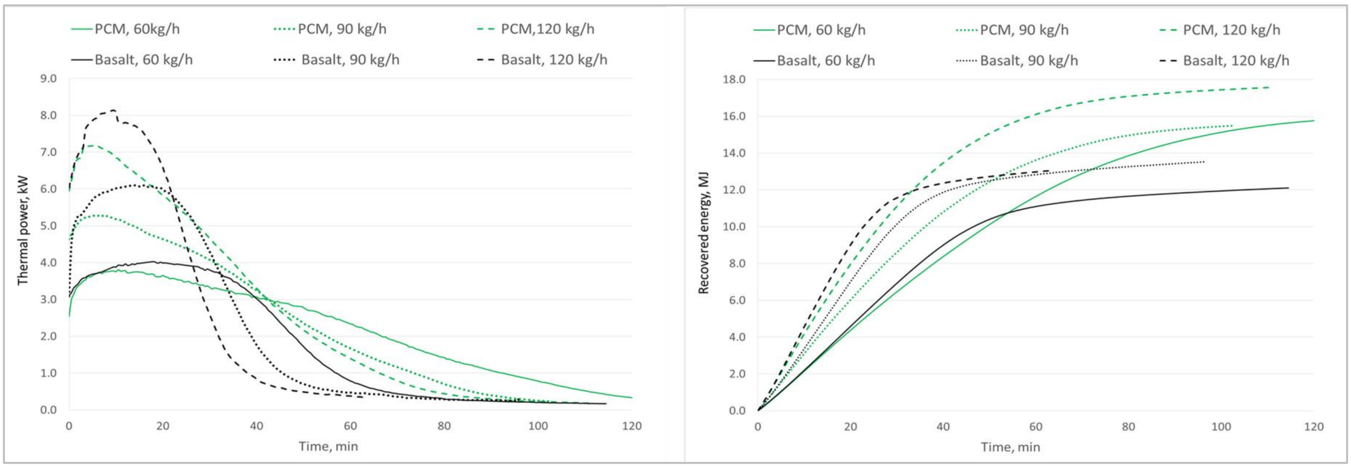
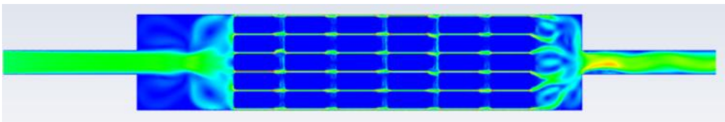
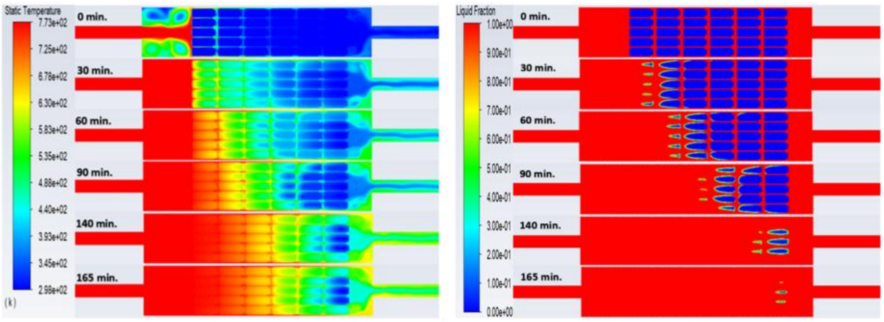


Comparison of (a) thermal power output and (b) recovered thermal energy during discharging for basalt aggregate and encapsulated solar salt-packed beds at different air flow rates. Target packed-bed temperature: 290 °C. Taken from [2].

A numerical simulation of the heat storage unit was performed using ANSYS Fluent software. CFD (Computational Fluid Dynamics) modelling was used, which allows for accurate analysis of air flow and heat exchange in the installation. In the first stage, a simplified computational model was used to enable a general assessment of the temperature distribution. Next, a more advanced model variant was developed, representing a heat storage column (TES) filled with a PCM-packed bed, through which hot air flows, supplying thermal energy. This approach enabled a more precise assessment of the installation's operating conditions and the energy storage process over time.



Air flow through the TES column



A CFD result shows the thermal front moving through the PCM bed as charging progresses.

The results demonstrated that the storage material efficiently absorbs the supplied heat, with the heating and utilization of its capacity occurring gradually and reaching full efficiency within three hours of operation. Observed changes in the temperature of the outgoing air confirmed effective heat exchange between the medium and the storage material. Comparing a detailed component-level model with an averaged model allowed evaluation of the system design's impact on efficiency under identical operating conditions.

PCM can reduce the required storage volume and deliver heat over a more stable temperature range. However, these advantages must be weighed against the additional complexity of material preparation, encapsulation and system integration.

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EVIDENCE FROM WP5

Key Results

The experiments and models turned material options into practical engineering guidance.

1. **Natural rock provides a strong baseline.** Basalt is widely available, mechanically robust and suitable for high-temperature operation. It also enables direct heat exchange with flowing air.

2. **PCM can store more heat in a smaller volume.** Encapsulated Solar Salt achieved a higher volumetric storage density and delivered heat over a longer, more stable temperature range.

3. **Flow rate affects both performance and operating cost.** Higher airflow increases charging and discharging power, but also raises pressure losses and the electricity demand of fans or compressors.

4. **Validated models reduce scale-up uncertainty.** CFD models verified against experimental data can predict temperature and airflow development within the store, supporting design decisions before investment in a full-scale installation.

Final WP5 recommendations: Use a natural-rock packed bed as the preferred main thermal store for an adiabatic compressed-air energy storage system. Consider encapsulated PCM at selected points where compactness or a narrower heat-release temperature range is worth the additional complexity.

We invite you to explore more details of the work on the HESS project website
https://itpe.pl/en/hess/

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