SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Technology Position Paper

Compact Thermal Energy Storage

June 2023

Technology Collaboration Programme
by iea

Contents

This document was prepared by Wim van Helden, AEE INTEC, Austria, Task Manager of SHC Task 67: Compact Thermal Energy Storage Materials Within Components Within Systems of the Solar Heating and Cooling Technology Collaboration Programme with input from: Benjamin Fumey, Univ. of Applied Sciences Lucerne, Switzerland; Gerald Englmair, Technical University of Denmark, Institute of Civil and Mechanical Engineering; Florian Kerscher, Technical University Munich, Germany; Ruud Cuypers, TNO, The Netherlands; Dominic Groulx, Dalhousie University, Canada; Daniel Lager, Austrian Institute of Technology; Stefania Doppiu, CICenergiGune, Spain; and Christoph Rathgeber, ZAE Bayern, Germany.

DOI: 10.18777/ieashc-task67-2023-0001

This position paper provides an overview of the compact thermal energy storage technologies market, outlining its importance, potential, and development. It addresses policy, decision makers, and influencers and aims to present high-level information as a basis for uptake and further development. It concludes by highlighting actions needed to further exploit thermal energy storages with minimal space requirements and accelerate more efficient energy systems, including sector coupling, with a higher share of renewables.

1 Introduction and Relevance

Half of the world's final energy demand is used for heating and cooling purposes. To match the variability of renewable sources and optimize the performance of thermal systems, thermal energy storage systems are needed.

Compact thermal energy storage (CTES) systems make use of either phase change materials (PCM) or thermochemical materials (TCM). They enable the storage of heat or cold in a more compact manner compared to water or other sensible storage technologies. In addition, they enable the storage at very stable temperatures (PCM) or with very low heat losses over time (TCM). With these qualities, they both allow for more efficient heating or cooling systems and increased use of renewable sources. TCM, in particular, enable longer storage times, even bridging seasons.

Some important application areas of CTES technologies are:

- Sector Coupling: improved efficiency in the operation of networks and coupling different energy sectors by peak-shaving and demand flexibility options.
- Energy efficiency in buildings for both cooling and heating, including domestic hot water.
- Heat recovery in industrial processes: enabling heat transfer between different processes or between subsequent batches of production.
- Cold storage for data centres or other cooling processes and solar-driven cooling.
- Areas in which thermal storage is combined with drying or steam production processes (e.g., the zeolite dishwasher).
- Seasonal thermal storage of solar energy (heat or electricity).

2 Current Status

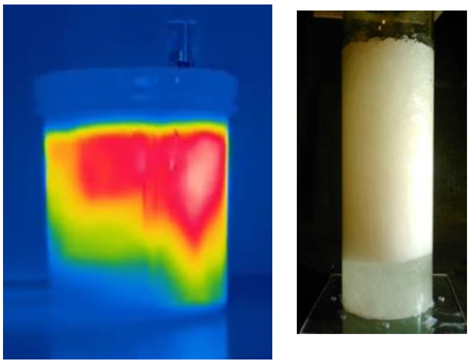
A growing number of compact thermal energy storage technologies are on the market. **PCM-based products** are available that guarantee a stable temperature when transporting vulnerable goods or that stabilize indoor temperatures while simultaneously increasing the efficiency of the heating/cooling system[1]. Furthermore, there is a growing market for compact, domestic, PCM-based hot water storage systems[2].

For the time being, there are only a few **TCM-based products** on the market.

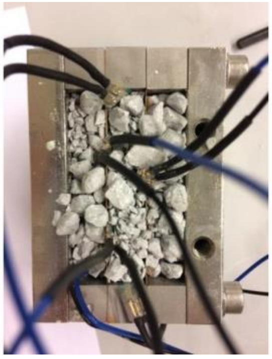
[1] https://pluss.co.in/; https://www.pcmproducts.net/; https://phase-energy.com/pcm-products/; https://www.rubitherm.eu/en/

[2] https://sunamp.com/how-thermal-batteries-work/

Nevertheless, one very successful example is the zeolite-assisted dishwasher. This appliance reduces energy demand by 20% by combining the water heating and the drying steps using the sorption process of the zeolite. In addition, several small companies are working on **prototypes or early market products** of compact thermal energy storage, either with zeolites[3] or with salt hydrates[4]. The challenges in further developing these technologies are improving materials and components and reducing the cost of the complete device.



PCM crystallization from supercooled phase – temperatures obtained with a thermal camera (left) in a cylinder with PCM solidifying from top to bottom. (Source: Technical University of Denmark)



Grains of potassium carbonate in a test set-up. It is a TCM material used for seasonal solar thermal energy storage for domestic applications. (Source: Eindhoven University of Technology, Netherlands)

Different aspects of the technologies have been and are being studied and further developed by a relatively small group of researchers worldwide. The main classes of PCM and TCM have been investigated but are **not yet fully understood** regarding stability, performance increase through materials combination, and cost reduction possibilities. **Components** developed for the charging, storage, and discharging of materials have been **proven** in the laboratory and **demonstration systems**. **Systematic knowledge** of the possibilities to improve component performance already in the design phase is **still lacking** but necessary for cost reduction. Reliable measurement techniques for state-of-charge determination are currently being investigated. And a diverse number of **compact thermal storage systems** have been **demonstrated**, giving valuable insight into the system integration and control requirements while proving the technologies' potential for efficiency increase and better use of renewable sources.

Three prototype modules for a seasonal solar thermal storage system using potassium carbonate as TCM, CREATE project. **(Source: AEE INTEC, Austria)**

Liquid-sorption-based heat storage system developed at the Lucerne University of Applied Science. **(Source: University of Applied Sciences, Lucerne, Switzerland)**

---

[3] https://zeosys-energy.de/
[4] https://cellcius.com/en/

Zeolite beads in the heat exchanger of the zeolite dishwasher. (Source: ZAE Bayern)

The Sunamp Plentigrade PCM thermal storage system. (Source: Sunamp)

3 Potential

There is a broad application base for PCM/TCM thermal storage technologies in the built environment, industry, and sector coupling.

Estimates of the potential of a limited number of applications are shown below, with the assumption that the total potential is much higher.

Seasonal storage of solar energy

In moderate climate regions, seasonal thermal energy storage of solar energy, coming from solar thermal systems or PV systems, enable a year-round, 100% renewable heating and domestic hot water supply while providing short-term storage. Especially in multifamily or single-family houses in areas without district heating, these systems can play an important role, as they are less dependent on electricity in the heating season. In a first estimate, about 5% of the houses in moderate climate regions could be equipped with these storage systems. This would be in the order of 25 million homes, with an average heat demand of about 15 MWh leading to 375 TWh of energy savings annually.

Dishwasher potential

An innovative dishwasher has been commercially available since November 2009 and reduces energy consumption compared to a conventional dishwasher from about 1.05kWh to 0.80kWh per washing cycle, or energy savings of about 20%[5]. Worldwide, there are about 450 million dishwashers. If 20% of these are zeolite-equipped with 250 washing cycles per year, the annual electricity savings would be 4.7 TWh.

Distributed power–to–heat

With compact thermal energy storages like the Sunamp system, excess renewable electricity from the grid can be stored locally and used for heating later. With 100 cycles per year, a unit can use 1,500 kWh of additional renewable electricity annually. With 10% of the world’s households using such a storage and a rough estimate of 2 billion

[5] https://www.bosch-home.com/de/produkte/geschirrspueler/perfectdry

households, the annual renewable energy uptake by household compact thermal energy storage appliances is 300 TWh.

Data center cooling

Globally, the electricity demand of data centers is estimated to be between 220 and 320 TWh, or around 0.9 to 1.3% of global final electricity demand in 2021[6]. The electricity consumed in data centers is almost completely converted into low-temperature heat – which indicates high cooling demand. The main advantage of PCM is the high storage density in small temperature intervals – which is applied in “free cooling” systems using ambient air as a cooling source and in hydronic cooling systems to maximize the operation flexibility of chillers.

Researchers recently found that data centers in the European electricity system could provide up to 10 GW of demand response capacity by 2030[7].

Thermal comfort in buildings

In the context of global warming, more extreme weather periods are being observed. Thus, keeping thermal comfort in buildings (domestic and industrial) becomes increasingly important – both during warm and cold seasons. The global energy demand from air conditioners is expected to triple by 2050[8]. Therefore, compact storage solutions will be increasingly important regarding peak shaving of cooling and heating loads and to ensure demand-side flexibility for maximized utilization of renewable energy via heat pumps and chillers.

Industrial processes

About 90% of the global industrial process heat demand below 400°C is provided by fossil fuels[9]. CTES systems can supply flexibility to industrial heating systems by re-using heat in batch processes or by enabling the use of low-cost renewable electricity in power-to-heat systems[10],[11],[12]. If 15% of the process heat demand can be covered by power-to-compact thermal energy storage systems, approximately 1,600 TWh of fossil fuels could be replaced.

4 Actions Needed

The potential drivers for a successful implementation of CTES are:

- The need for distributed thermal storage enables better utilization of excess renewable energy and accelerates the replacement of fossil fuels by

[6] https://www.iea.org/reports/data-centres-and-data-transmission-networks
[7] C. Koronen, M. Åhman, and L. J. Nilsson, “Data centres in future European energy systems—energy efficiency, integration and policy,” Energy Efficiency, pp. 129–144, 2019.
[8] The Future of Cooling. Opportunities for energy efficient air conditioning. Edited by IEA Publications, International Energy Agency (IEA), 2018.
[9] IRENA (2014), Renewable energy options for the industry sector: global and regional potential until 2030
[10] Project envIoTcast PCM storage for die-casting; https://projekte.ffg.at/projekt/3849163
[11] Project EDCSproof, PCM storage for industry, 100 – 200 °C; https://www.nefi.at/de/projekt/edcsproof
[12] Project HySteps, retrofitting of steam storage with PCM; https://www.ait.ac.at/themen/efficiency-in-industrial-processes-systems/projekte/hysteps

renewables, with no additional grid infrastructure needed.

- Higher volatility of arbitrage prices will translate the thermal storage added value to an energy system into monetary value.
- The need for a diversification of energy supply and, therefore, an increased security of supply.
- Lowering the material and component costs.

These potentials can be opened up by addressing the following challenges:

Challenge	Action needed	Action by whom
Added value to the energy system is not monetarized	Include CTES in **total system costs** and compare these to other system configurations with the same performance.	Application/system engineers
	Pass volatility of energy prices on to the operators of CTES storage technology.	Policy makers, electricity companies
Relatively high cost	Long-term market introduction **support program**.	International and national policy makers
Slow progress of technology development and innovation	National and international, long-term and dedicated **R,D&D support programs** for basic CTES materials research. Targeted support to small and highly **innovative CTES companies**. Dedicated **demonstration programs** to monitor and evaluate performance and stepwise improve CTES performance.	International and national policy makers
Low industry involvement	Targeted demonstration and market introduction **support programs** to avoid 'valley of death' in development.	International and national policy makers, and Industry decision makers
Thermal technologies are not seen	Increase **awareness** among decision makers and the broader public on the potential of compact thermal energy storage.	Industry decision makers, R&D community, and Professional organizations