Excerpt

DLR

Thermal Energy Storage Handbook

Technology providers and reference projects for industrial process heat

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Welcome

Industrial thermal energy storage has moved beyond the stage of conceptual design. Across the world, a wide range of technologies is already being deployed in real industrial environments – supplying process heat for everyday products such as food and paper, stabilizing energy systems and enabling the large-scale integration of renewable energy without compromising operational reliability or productivity. These applications demonstrate clearly that thermal energy storage is no longer a promise for the future, but a practical and available solution today.

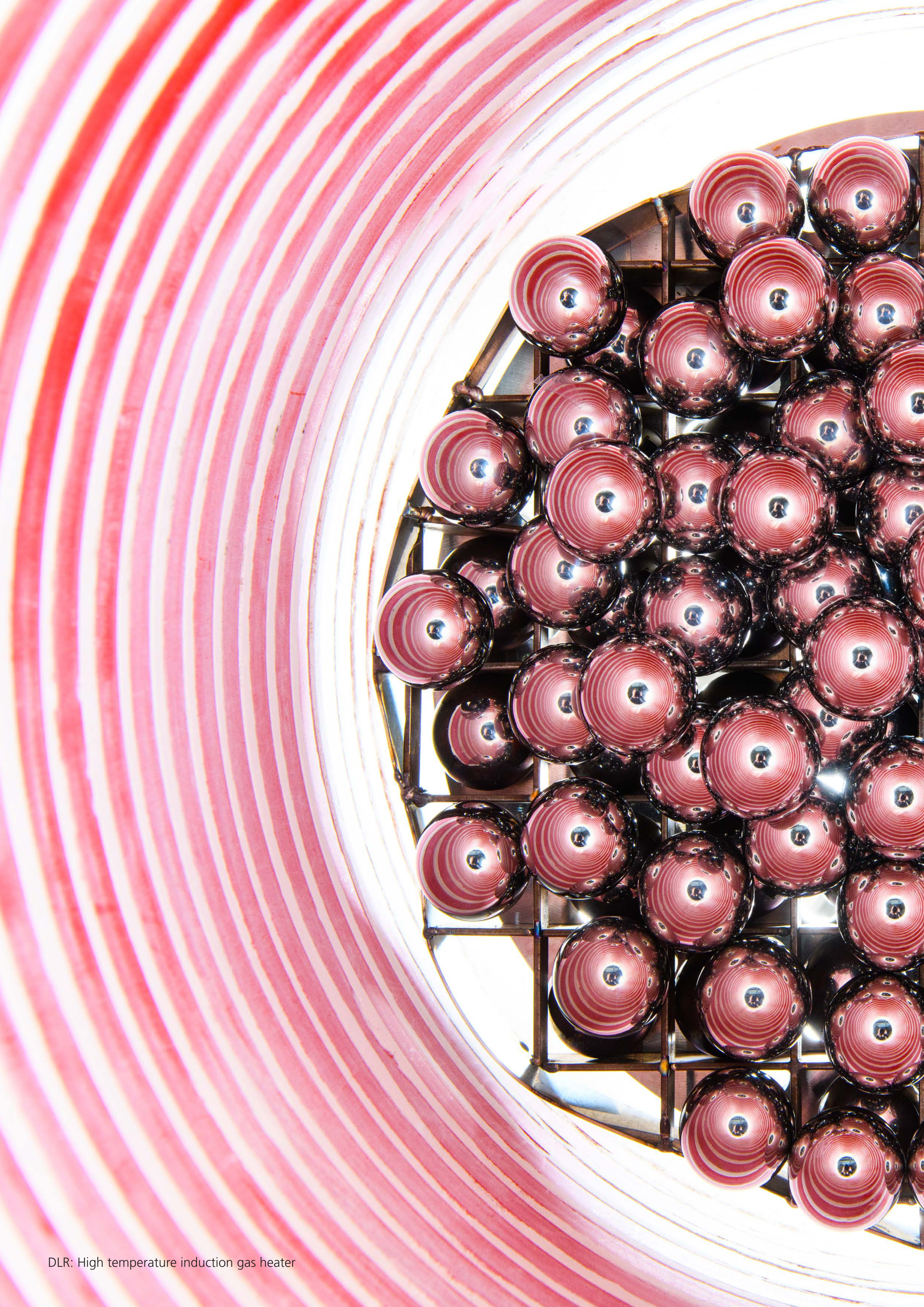
At the same time, the market for thermal energy storage is still at an early stage. While European and national policy frameworks increasingly recognise the potential of renewable and electrified heat-supported, for example, through the European heat auctions or the German BIK Funding programme – many industrial end-users remain uncertain about which storage technologies are suitable for their specific applications, how these systems can be effectively integrated into existing processes and what performance can realistically be expected.

This handbook is intended to address these questions. It provides an overview of proven thermal energy storage solutions and compiles storage projects that are already operating or being implemented in real-world applications. The showcased projects demonstrate tangible benefits, including CO_2 emission reductions, improved system flexibility and a reduced reliance on imported fossil fuels.

At the German Aerospace Center (DLR), thermal energy storage has been a core research topic for more than three decades. Developing this handbook is part of our effort to advance storage-supported heating solutions: by sharing independent technical knowledge, system-level insights and practical experience from applied research, we aim to support both industrial end-users and technology providers in the successful implementation and further development of thermal energy storage under real operating conditions.

We hope that this handbook will serve as a useful reference for industry, research and decision-makers and that it will stimulate collaboration in further advancing industrial thermal energy storage as a key element of a sustainable energy system.

Prof. Annelies Vandersickel
Department of Thermal Process Technology
Institute of Engineering Thermodynamics
German Aerospace Center (DLR)



DLR: High temperature induction gas heater

Preface

Thermal energy storage is a key enabling technology for the decarbonisation of industrial heat supply. By decoupling heat generation from heat demand, it enables the efficient use of renewable electricity and waste heat, increases system flexibility and supports reliable industrial operation under changing energy system conditions.

The thermal energy storage landscape is evolving rapidly. A wide range of storage concepts is currently being developed, targeting improvements such as lower costs, better temperature matching to industrial processes and increased system lifetime. At the same time, the number of technology providers entering the market is growing, reflecting both rising demand and increasing technological maturity. This dynamic development makes it increasingly challenging for industrial stakeholders to maintain an overview of available solutions and their practical applicability.

This handbook brings together contributions from a broad range of providers to illustrate the current state of industrial thermal energy storage and the diversity of available approaches. It covers different storage principles, temperature ranges and integration concepts and presents real-life projects in which thermal energy storage is used to supply process heat, integrate renewable energy sources, utilise waste heat and increase operational flexibility.

The focus of this booklet is on high-temperature, industrial-scale thermal energy storage systems that are commercially available or close to market entry, with particular emphasis on systems that have been implemented under real operating conditions. While this provides a solid snapshot of the current market, the overview is not intended to be comprehensive and does not cover all technologies or providers.

Aim of this handbook

Overall, this handbook aims to facilitate the uptake of thermal energy storage in industrial applications by improving transparency and orientation in a rapidly developing market. In particular, it seeks to:

- provide a structured overview of commercially available high-temperature thermal energy storage technologies and key market actors,
- support early-stage planning and technology selection for industrial decarbonisation projects,
- highlight key drivers and benefits for thermal energy storage implementation, including integration concepts, operational advantages and emerging business models.

DLR competences

The German Aerospace Center (DLR) is a national research institution with longstanding expertise in energy, transport, space and security. At the Institute of Engineering Thermodynamics, we focus on applied research delivering real-world solutions for sustainable heat supply and storage. With more than 30 years of experience in the development and integration of thermal energy storage systems, we contribute to accelerating innovation by addressing key challenges at material, component, system and integration levels.

To reflect the wide diversity in the heating sector, the department's technology portfolio spans a broad temperature range – from low-temperature district heating to high- and ultra-high-temperature industrial processes. Our portfolio includes molten salt, solid media and thermochemical energy storage systems, complemented by electrical heaters, heat pumps and advanced heat management solutions. By combining deep material expertise with experimentally validated models and pilot-scale demonstration, we push current technologies toward higher temperatures, increased energy density and reduced costs.

A key strength of DLR lies in its extensive small- and large-scale test infrastructure, which enables proof-of-concept and operation under industry relevant conditions. This infrastructure allows new technologies to be de-risked prior to large-scale deployment and supports the optimisation of existing solutions already on the market.

Through close collaboration with industry, startups and technology providers, DLR supports the implementation of thermal storage systems into real processes and infrastructures. By bridging the gap between research and application, the institute contributes to improving performance, durability, cost efficiency and system integration – strengthening the role of thermal energy storage as a reliable cornerstone of the energy transition.

In short, DLR offers:

For technology providers:

- support in technology development and optimisation along the entire innovation chain, based on in-depth scientific and engineering expertise,
- access to testing and qualification at relevant scale to de-risk components and validate system performance.

For industrial end-users:

- independent technical expertise and advanced modelling tools to support the development of decarbonisation concepts,
- supplier-neutral assessment of integration concepts, including support in tender preparation and evaluation,
- advanced simulation models and digital twins to optimise operation for specific industrial use cases.

Four Core Technologies

Solid Media
high and ultra-high temperature heat and storage

Molten Salt
a versatile solution for process heat and (solar) power plants

Phase Change Materials
reliable green steam for the process industry

Thermochemical Systems
storage with an additional feature

Addressing a wide range of applications

for 100 °C up till 1200 °C

- Dispatchable renewable electricity (and heat) from solar power plants & Power-to-Heat-to-Power
- Renewable 'on-demand' heating for districts and industry
- Utilization and management of industrial process heat
- Large-scale electricity storage (CAES, LAES, Carnot Batteries)
- Thermal management for vehicles, buildings and processes

DLR projects

Ultra high temperature air heater

Industries requiring process heat well above 1,000 °C are a key challenge for decarbonisation. To address this need, high-temperature Power-to-Heat solutions are developed and tested, including compact induction heating systems that convert electrical energy into high-temperature heat with high efficiency and power density. These systems are designed to meet strict requirements in terms of performance, cost-effectiveness and industrial robustness, making them a viable retrofit option for replacing fossil-fired burners. By focusing on high conversion efficiency (> 90 %) and scalable induction heating technology, sustainable electrification of industrial heat supply is enabled, accelerating the heat transition across multiple application domains.

Project: KEINER

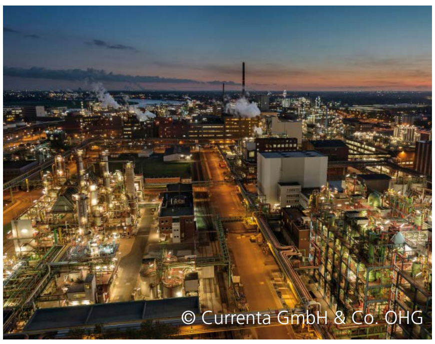
CO2 neutral electrical steam generation with latent heat storage

Steam is a critical process energy carrier in many industries, traditionally supplied by fossil gas. In the PCM-Grid project an electric steam generator with a storage function of 3 MWh is being developed and integrated into the industrial process of an end customer. This is based on the finned tube latent heat storage concept developed jointly by DLR and KI-Alu. To charge the storage, a suitable phase change material is melted at high temperatures using electrical heaters. During discharging, the phase change material solidifies and process steam is provided to an industrial process. This approach decouples steam generation from volatile electricity availability and enables CO_2-neutral industrial steam supply with high flexibility and reliability.

Project: PCM-Grid
Project consortium: Viessmann Industriekessel Mittenwalde GmbH, RuLa-BRW GmbH, IFAM

Zero emission chemical site

The chemical industry is adopting increasingly ambitious greenhouse gas emission targets, driving the need for scalable decarbonization concepts. This research examines a utility system for chemical sites based on renewable power purchase agreements and green hydrogen, complemented by a molten salt thermal energy storage system. Thermal energy storage enables efficient integration of photovoltaic and wind power, reducing overall system costs by up to 27 % while significantly increasing resilience against fluctuations in hydrogen prices. At the same time, the approach achieves maximum renewable integration, covering up to 85 % of the total energy demand.

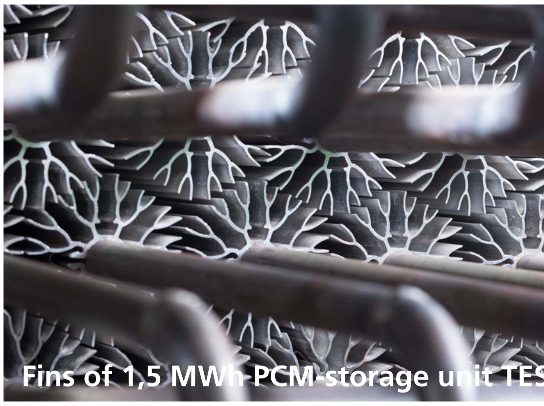


Project: TransTESChem
Partner: Currenta GmbH & Co, Covestro Deutschland AG, TSK FLAGSOL Engineering GmbH, Gesellschaft zur Förderung Angewandter Informatik e. V, JPM GmbH

Basalt bulk material for liqud salt in a single-tank storage

Sensible media storage in HOTREG test bed

PCM storage system of CHESTER Carnot Battery



Fins of 1,5 MWh PCM-storage unit TES

Solidified storage salt

Molten salt storage TESIS test section

Direct steam generation with PCM and fins


Limestone storage

Key paramenter

Parameter	Value	Context
Energy source	power and heat	TES solutions can be charged directly by heat, generated for example by a concentrated solar thermal plant (heat-to-heat), or by electricity using resistive heating (power-to-heat).
TRL	7-9	As this Handbook focuses on operational solutions, the Technology Readiness Level (TRL) is high.
Spacial usage	0.5 to 4,5 m^2/MWh (TES only) 10 m^2/MWh (full system)	The footprint of TES solutions is up to 60 times smaller than that of Li-ion batteries due to their higher energy density and the ability to stack storage containers vertically.
Architecture	modular, scalable	Most systems are built with stacked storage containers, which gives the ability to easily scale systems.
Operating mode	Parallel charging and discharging	Most TES solutions can simultaneously be charged and discharged.
LCOH	80-235 €/kWh (full price) 60-100 €/kWh (only TES stack)	It depends on which components are included in the calculated levelised cost of heat (LCOH). The shown values have to be handled with care.
Energy input and output	steam, hot air, electricity	High flexibility in media; output is often tailored to industrial steam or process heat.
Dis-/Charging temperature	300 °C up to 1350 °C	Ranges from medium-temperature rock storage to high-temperature ceramic or sand.
Power in and out	up to 150 MW_{in} and 50 MW_{out}	Primary focus is thermal output, though some offer Power-to-Power.
Heat in and out	up to 100 MW	Thermal power ratings vary based on modular configuration.
Dis-/Charging efficiency	95% to 100%	High internal efficiency for heat transfer; electrical round-trip is lower (approx. 40%).
Storage material	molten salt, rock, graphite, or ceramics	Most systems that are on the market today are using sensible storage material. Phase change materials, e.g., are also increasing.
Storage temperature	up to 1300 °C	Higher temperatures correlate with high-density ceramic or graphite media.
Storage capacity	up to 1000 MWh	Highly scalable from single 20 ft container modules to large-scale tank farms.
Standstill losses	2% to 7% per day	The loss of stored energy per day is highly dependent on the size of the system.

DLR at a glance

The German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt; DLR) is Germany's national research and technology centre for aeronautics, space, energy, transport, security and defence. DLR's work spans a wide range of applications, delivering results and innovations that benefit industry and business, government agencies and the public sector. At the heart of DLR's mission is its commitment to society, which it fulfils through extensive knowledge sharing and targeted technology transfer. Therefor it is funded through federal resources. The German Space Agency at DLR is responsible for planning and implementing German space activities on behalf of the federal government. Additionally, two project management agencies at DLR manage research and industrial funding programmes.

Earth's climate is changing, along with global mobility and technology. DLR harnesses the expertise of its 51 research institutes and facilities to develop solutions to these challenges. All 11,000 employees share a common mission: to explore Earth and space while developing technologies for a sustainable future. DLR's technologies are not confined to the laboratory, but are transferred to wider society, strengthening Germany's position as a prime location for research and industrial innovation.

About Department Thermal Process Technology

The Department of Thermal Process Technology is an integral part of the Institute of Engineering Thermodynamics. It develops advanced thermal storage systems that drive the decarbonization of heat supplies and enhance the resilience of the electricity grid. Through the integration of Power-to-Heat and Power-to-Heat-to-Power solutions, the department enables a demand-oriented energy supply from renewable sources, ensuring grid stability across Central Europe.

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Address:
Pfaffenwaldring 38-40, 70569 Stuttgart
E-Mail info-tt@dlr.de

DLR.de

Cover image: DLR, TESIS large storage facility

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