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Perspective

Integration of thermal energy storage in industrial processes: challenges and opportunities

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Abstract

The transition to sustainable energy systems is crucial in reducing greenhouse gas emissions and increasing energy efficiency. This paper synthesizes insights from industrial experts and academic researchers on the challenges, opportunities and solutions of integration of thermal energy storage (TES) in industrial energy systems. These insights were gathered during an international expert workshop on TES, organized by the European Energy Research Alliance as part of the Joint Program on Energy Efficiency in Industry (EERA-JP EEIP) on November 7th, 2023, discussing a white paper on industrial thermal energy storage. This paper provides a comprehensive overview of the current state and future potential of TES technologies. Demonstrating technology benefits, continuing material development, improving economic feasibility, enhancing system flexibility, developing innovative business models, fostering policy supports, and facilitating knowledge transfer are believed to be essential for the successful adoption of TES technologies in industry.

Keywords: thermal energy storage; industrial processes; energy efficiency; sustainability

1. Introduction

The EU and UK aim to be climate neutral by 2050, indicating a net-zero greenhouse gas (GHG) emission, which is in line with global climate action under the Paris Agreement [1,2]. To achieve this objective, decarbonization of industrial energy is necessary and urgent because industries consume about 25% of the total final energy consumption and emit about 20% of the total GHGs [3]. Integrating renewable energy sources can enhance the sustainability and energy efficiency in industries. It was expected that renewable energy sources must be established by 2030 with an investment of $4 trillion annually [4]. However, the intermittent nature of renewable energy requires energy storage to achieve a stable and reliable energy supply, ensuring that energy is available even when renewable sources like wind and solar are not available or at lower capacity.

In 2022, industries within the EU were responsible for 226,254 ktoe of final energy consumption, accounting for 25% of the total final energy consumption (902,152 ktoe) [3]. A significant portion of this industrial energy is used for thermal processes (80.1%), mainly process heating but also space heating and hot water, process cooling and space cooling. Non-thermal energy consumption (19.9%) is mostly electricity. As illustrated in **Figure 1**, process heating is the largest energy consumer in EU industries, with a 64.9% share, followed by space heating and hot water (11.2%), process cooling (3.2%), and space cooling (0.8%) [5]. Most of the energy used for industrial heating and cooling currently comes from non-renewable sources. Natural gas is the predominant energy source, accounting for 39% of all consumption. Renewable energy sources contribute only 10-25% of the energy for industrial heating and cooling. This includes direct use of renewables (9% biomass and 1% other sources) and potential indirect use through electricity use (7%) and district heating typically using a steam network (8%). Notably, in Nordic countries, biomass can make up as much as 50% of the total industrial energy mix. Overall, the predominant use of fossil fuel for industrial heating leads to an estimated greenhouse gas emission of 877.3 Mt CO_2 equivalent (2017) [6], which is only slightly lower than the emission in the transport sector.

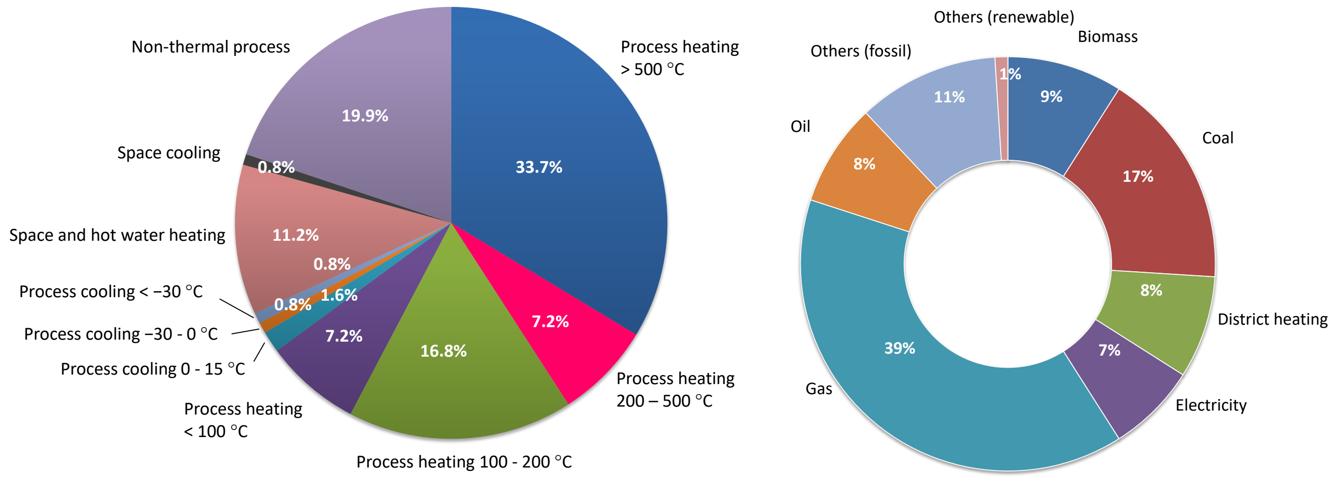

Figure 1 Break down of final energy consumption and energy resources used for heating and cooling in industries in EU in 2015 [5].

Thermal Energy Storage (TES) can have a significant role in the industrial energy system to assist the decarbonization of industrial energy while at the same time increasing industrial energy flexibility and security [7,8]. TES enables a higher share of renewable energy in industries and facilitates waste heat recovery. It can also decouple energy supply and demand enabling smart energy usage [9], store cheap off-peak electricity as thermal energy [10], shave peak electricity load benefitting electricity grid security, and provide energy emergency backup for robust operation [11].

However, the application of TES in industries is limited mainly due to the lack of awareness of the potential of TES, cost and interruption of existing energy system operation. Unlocking the full benefits of adopting TES in industries needs collaborative work by policy makers, industries, technology developers, energy suppliers and grid operators.

2. Overview of Thermal Energy Storage

Thermal energy storage involves capturing and storing heat for later use, allowing for greater flexibility in energy management. Thermal energy storage technology can be categorized into four main types [8]:

Sensible TES: Sensible TES simply changes the temperature of a material to a higher level for heat storage or to a lower level for cold storage, without changing phase. Typical examples are heat storage in water, sand or rocks. The storage capacity is dependent on the temperature change and the specific heat capacity of the material.

Latent Heat Storage: Latent TES involves phase change (or phase transition) of the used storage material. The used materials are called phase change material (PCM). For small temperature ranges, the latent heat involved in the phase change process is much larger than the sensible heat, making the material ideal for applications that require stable thermal environments. Typical PCMs are ice, paraffins, fatty acids and salt hydrates, while for higher temperatures sugar alcohols, inorganic salts and metals are investigated and used.

Sorption TES: Sorption reactions between gas and solid (adsorption) and gas and liquid (absorption) can be used for TES, typically for the temperature range below 200 °C. It has almost no heat loss during storage as long as the reaction products are stored separately, making it suitable for long-term storage applications. Solid adsorbents include porous-structured materials like zeolite, silica gel, and activated alumina which can adsorb vapours like water. Typical liquid absorbents are concentrated hygroscopic salt solutions, like aqueous solutions of LiCl, LiBr and NaOH, which can absorb water.

Chemical Reaction TES: This method is also named as thermochemical storage and has the highest thermal energy storage density. Similar to sorption TES, chemical reaction TES also has almost negligible heat loss during storage and is suitable for long-term storage applications. The used working pairs are normally a solid inorganic salt and a vapour, such as e.g., $CaCl_2$ and water vapour combined to a salt hydrate, or $SrCl_2$ and ammonia vapour combined to a salt ammoniate. Other types of chemical reactions includes hydroxide formation (e.g., $CaO/Ca(OH)_2$), oxidation (e.g., BaO_2/BaO), and carbonation (e.g., $CaO/CaCO_3$), which are suitable for high temperature applications.

3. Contributions to Industrial Energy

3.1 Decarbonizing industrial energy

The use of intermittent solar and wind resources in combination with TES allows industries to time-shift energy usage, while still providing a consistent process heat supply, thereby offering flexibility services to grid operators. This approach not only helps in decarbonizing industrial processes but also enhances overall energy system resilience.

One prominent example of TES application in industry is the buffering of solar thermal energy for use during non-sunny periods. By storing excess heat generated during peak solar hours, industries can maintain a steady supply of thermal energy for various processes, reducing reliance on fossil fuels.

TES also enables industrial waste heat recovery. For example, in the car manufacturing industry, 36% of the energy use that goes into the manufacturing of a car is in the painting process [12]. A significant amount of gas is used to heat the body to dry the paint coating. Then a large amount of electricity is used to cool the car body down again and control the air temperature and humidity in the paint booth. TES can be fit into this process to collect the waste heat to be reused elsewhere.

3.2 Economic savings

TES is recognized as one of the most cost-effective energy storage solutions, offering significant advantages over other storage technologies such as mechanical storage (e.g., pumped hydro), electrochemical storage (e.g., batteries), chemical storage (e.g., hydrogen), and electromagnetic storage (e.g., capacitors). Unlike batteries and hydrogen, which require additional energy conversion processes, TES can be directly used for industrial heating and cooling applications, enhancing energy efficiency. The integration of TES can help industries to achieve significant cost savings by reducing the need for expensive peak-load energy. In the UK, off-peak electricity rates can be up to 50% lower than peak rates [13]. This cost differential makes implementing TES highly advantageous, as it allows energy to be stored during off-peak hours and used later, effectively balancing the cost to match or even reduce energy expenses compared to peak-time usage. Waste heat recovery and reuse also contribute to economic savings by reducing primary energy usage. A report [14] highlights that the chemical industries in the Teesside Industrial Cluster, UK, generate approximately 6,213 GWh of waste heat with temperatures ranging from 40 °C to 200 °C. This waste heat has a potential value equivalent to £248 million in natural gas (based on £4p per kWh cost of natural gas [15]), offering significant opportunities for energy recovery and cost savings.

3.3 Energy flexibility

TES enables the decoupling of energy consumption from energy supply, enabling thermal energy to be offered as a service. Such energy flexibility can play a crucial role in optimizing the industrial energy usage by enabling industries to manage their energy consumption more effectively and respond to market signals. One approach is the creation of energy-as-a-service platforms [16] where companies can purchase thermal energy on a subscription basis. This model makes TES more accessible to a broader range of industries. Developing and implementing such business models requires close cooperation between technology providers, industry stakeholders, and regulatory bodies.

4. Challenges in Implementation

4.1 High initial investments

One of the major barriers to the widespread adoption of TES is the high cost of initial investments. While TES promises long-term savings, energy flexibility and security and environmental benefits, the upfront costs can be prohibitive for many industries, especially those requiring short payback periods. The TES investment cost is in the range of 8-100 €/kWh which is largely higher than the acceptable cost between 1.4 and 14.4 €/kWh (1–500 MWh) [17]. Financial incentives and supportive policies are needed to mitigate these costs and encourage investment. Government grants, low-interest loans, and tax incentives can play a crucial role in offsetting these initial expenses.

4.2 Integration with existing systems

Many old industrial processes still exist that are energy inefficient since they are based on the availability of cheap fossil fuel. Of course, the first objective would be the efficiency improvement of the core processes before implementing efficient heat recovery technologies and TES. Also, heat pumps can be considered for heat upgrading as most of the industrial waste heat is under 100 °C and needs to be upgraded to supply, e.g., process steam.

Integrating TES into existing industrial processes can be complex, requiring significant modifications to the current infrastructure. Ensuring compatibility and seamless operation is critical to achieve the desired energy efficiency and sustainability outcomes. Pilot projects and case studies can provide valuable insights and best practices for overcoming these challenges.

Another challenge is the need for skilled personnel to install, operate, and maintain TES systems. Training programs and certification schemes can help build a workforce capable of managing these advanced technologies.

4.3 Legal and regulatory challenges

A significant barrier to implement TES systems in waste heat sharing systems, results from legal and regulatory complexities. Many industries, especially large emitters of waste heat, are hesitant to enter into long-term contracts for sharing waste heat with external systems.

Industries may be unwilling to guarantee a consistent delivery of waste heat. For example, they may need to shut down for maintenance or may even consider relocating their operations in the future, making long-term commitments risky and unattractive. This uncertainty creates a fluid environment, where industries are unwilling to tie themselves down to "over-the-fence" heat-sharing agreements. Furthermore, external pressures, such as regulations aimed at reducing industrial emissions, may force industries to cut back on the amount of heat they release, which could jeopardise the viability of TES networks dependent on this heat source.

The potential for stranded assets is another major concern. Investing in infrastructure to capture and distribute waste heat could lead to large financial losses if the industrial source of the heat is no longer available or if emission-reduction policies make waste heat a less reliable resource. To avoid stranded assets, thorough risk assessments and long-term planning are essential, ensuring that TES projects are not overly dependent on a single industrial partner or type of waste heat.

Ultimately, addressing these legal and regulatory challenges requires a collaborative approach involving industries, policymakers, and local governments. Clear agreements, legal frameworks, and flexible contracts that account for future uncertainties can help mitigate these risks and create a more stable foundation for the long-term success of TES systems.

5. Real-World Applications

Energy Nest [18] has been at the forefront of implementing thermal storage solutions for industrial applications. Their systems, designed to operate between 140 °C and 400 °C, are suitable for various industries, such as chemical, steel, cement, and food and beverage and have been successfully deployed in the chemical industry and several CST plants. These systems not only provide energy buffering but also offer grid balancing services, enhancing overall energy system flexibility. A notable project involved integrating a 4 MWh TES system directly into the steam grid of a chemical plant, serving for steam grid balancing, which resulted in a 13 GWh reduction in energy consumption per year and a corresponding reduction in 6000 tonnes of CO_2 emissions [19,20]. The stored thermal energy was used to preheat raw materials, improving overall process efficiency. In addition, several other companies have successfully implemented industrial pilot projects, such as Brenmiller [21], Eco-Tech Ceram [22], Kraftblock [23] and Kyoto [24].

The RESlag project, as reported by CIC Energigune [25], demonstrated the usage of a packed-bed TES system for waste heat recovery at ArcelorMittal's steel plant in Spain. The system uses steel slag, a low-cost by-product from the plant, as the storage medium to capture heat from exhaust gases at around 700 °C. This stored heat is then utilized for preheating processes, steam generation, or other plant applications. The project estimates that fully leveraging 2.9 million tons of slag across EU steel industries for waste heat recovery could reduce CO_2 emissions by 71 kg per ton of steel produced, offering substantial environmental and economic benefits.

6. Future Directions and Recommendations

6.1 Proving technology benefits

Demonstrating the tangible benefits of TES is essential for gaining industry buy-in. This includes showcasing improvements in energy efficiency and energy security, cost savings, and reductions in greenhouse gas emissions. Real-world examples and performance data can help build confidence in these technologies, drive broader adoption and help attract investment and support from policymakers and regulatory bodies. Lifecycle assessments and cost-benefit analyses can provide a comprehensive understanding of the long-term impacts of these technologies.

6.2 Enhancing material performance

Ongoing research on developing advanced materials for TES is necessary. This includes specifically high-performance PCM and thermochemical materials. Enhancing the thermal properties of these materials will lead to more efficient and compact storage systems. Research into composite materials is also underway [26,27], that can offer enhanced thermal conductivity, higher energy density, and improved durability, making them suitable for a wide range of industrial applications.

6.3 Improvement in the economics of TES

Further improvement in the economics of TES is urgently needed and possible. In fact, low-cost TES options already exist that are economically feasible [17], however, many of these options are still in an early phase of the learning curve and will become cheaper in future when being massively produced. The development of standardized systems and modular components can also help reduce costs by enabling economies of scale. By producing components in larger quantities and streamlining installation processes, manufacturers can lower the overall cost of TES materials and systems.

6.4 Suitable business models

Business models for TES are evolving to incorporate innovative concepts such as supply chain cooperation, leasing arrangements, and service-based solutions. One promising model involves collaboration with energy companies to provide flexibility services, energy-as-a-service. The value of TES lies in its ability to deliver economic savings, emergency energy backup, reduced energy system investment, enhanced renewable energy integration and carbon emissions reduction. These benefits can be offered as services, contributing to the overall profitability of TES-based solutions. This approach not only optimizes energy use but also supports grid resilience. As grid operators become more open to these models, this type of cooperation could become increasingly valuable in the future.

6.5 TES system integration

For different TES technologies to be integrated with industrial energy systems, some suggestions are given as follows.

- Sensible heat storage – smart control is needed when integrating sensible heat storage into existing energy systems.
- Latent heat storage – integrates well with industrial steam systems.
- Chemical heat storage – has specific advantages because of potential large energy storage density, low heat losses and low cost, e.g., in solid form for long-term energy storage and in liquid form to be used as a heat transport medium.
- Underground heat storage is expected to have a limited role because of relatively low storage temperatures, long storage duration and low specific power. However, this may be important for integration with district heating networks supplying industrial waste heat to the built environment.

- For TES used for waste heat recovery, the integration with thermal upgrade technology, e.g., heat pumps and heat transformers, is encouraged to be used together to boost the waste heat temperature.
- Moreover, the integration of smart control systems and real-time monitoring technologies is essential for optimizing the performance of TES systems. These systems can dynamically adjust operations, based on energy demand, availability of renewable resources and market conditions, ensuring maximum efficiency and cost savings.

6.6 Policy and regulatory support

Supportive policies and regulations are crucial for encouraging the adoption of TES in industry, to ensure that energy efficiency, storage and flexibility are embedded as an integral part of EU, national, regional, and local energy transition plans. This includes financial incentives, carbon pricing mechanisms, and technical standards for TES and its energy service. Governments and regulatory bodies should collaborate with industrial stakeholders to develop frameworks that facilitate the deployment of these technologies.

Policymakers can also play a role in promoting research and development through funding programs and grants. By supporting innovation in TES technologies, governments can help to drive advancements that lead to greater efficiency and lower costs.

6.7 Collaboration and knowledge sharing

Industrial collaboration and knowledge sharing are vital for overcoming the challenges associated with TES integration. Platforms for sharing best practices, case studies, and research findings can accelerate the adoption of these technologies across different sectors. More specifically and importantly, promotion and knowledge sharing of demonstration systems, to demonstrate the potential of new storage technologies, should be emphasized.

Industry associations, research consortia, and collaborative projects can provide valuable opportunities for stakeholders to exchange ideas and develop solutions to common challenges. By working together, companies can leverage collective expertise and resources to drive progress in TES technologies.

6.8 Education and training

Investing in education and training programs is essential for building a skilled workforce capable of implementing and maintaining TES systems. This includes specialised training for engineers, technicians, and energy managers, ensuring they have the knowledge and skills required to leverage these technologies effectively.

Educational institutions can play a key role by developing curricula that cover the principles and applications of TES technologies. Certification programs and professional development courses can also help to ensure that the workforce is equipped to handle the complexities of TES technologies.

7. Conclusions

Thermal energy storage (TES) has the potential to revolutionize industrial energy systems by optimizing energy use, enhancing efficiency, and reducing environmental impacts. TES systems capture and store thermal energy for later use, offering a flexible solution that aligns with fluctuating energy demands and the increasing reliance on intermittent renewable energy sources. Adopting TES can lead to significant carbon footprint reductions and bolster energy security by reducing dependence on fossil fuels.

Experts from both industry and academia emphasize the need for a holistic approach to unlock the full potential of TES. This involves not only technological innovation but also the development of supportive policies and collaborative frameworks. Such an approach ensures that TES is integrated seamlessly into industrial processes while aligning with broader energy and climate goals. Innovative business models play a critical role by making TES financially viable and encouraging widespread adoption.

Looking forward, the potential for TES extends beyond industrial settings to include district heating, commercial buildings, and renewable energy systems. This versatility underscores its importance in achieving a sustainable, low-carbon future. Continued research, show-casing of pilot projects, and robust collaboration among multiple stakeholders, including governments, industry leaders, researchers, and businesses, are essential to enable TES to play a transformative role in global energy systems, driving both economic and environmental progress.

Declarations

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Competing Interests

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Reference

1. Burnett N, Edwards T, Watson N. The UK's plans and progress to reach net zero by 2050 [Internet]. London, UK: House of Commons Library; 2024 [cited 2024 Dec 01]. Available from: https://commonslibrary.parliament.uk/research-briefings/cbp-9888/.
2. European Commission. 2050 long-term strategy [Internet]. 2019 [cited 2024 Dec 01]. Available from: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en.
3. Eurostat. Complete Energy Balances [Internet]. 2024 [cited 2024 Dec 01]. Available from: https://ec.europa.eu/eurostat/databrowser/view/ten00124/default/table?lang=en&category=t_nrg.t_nrg_indic.
4. Osman AI, Chen L, Yang M, Msigwa G, Farghali M, Fawzy S, et al. Cost, environmental impact, and resilience of renewable energy under a changing climate: a review. Environ Chem Lett. 2023;21(2):741-764. DOI
5. Fleiter T, Elsland R, Rehfeldt M, Steinbach J, Reiter U, Catenazzi G, et al. Heating roadmap Europe. Deliverable 3.1: Profile of heating and cooling demand in 2015 [Internet]. 2017 [cited 2024 Sep 23]. Available from: https://heatroadmap.eu/wp-content/uploads/2018/09/3.1-Profile-of-the-heating-and-cooling-demand-in-the-base-year-in-the-14-MSs-in-the-EU28-2.pdf.
6. European Environment Agency. Greenhouse gas emissions by aggregated sector. Copenhagen, Denmark: European Environment Agency; 2021.
7. Miró L, Gasia J, Cabeza LF. Thermal energy storage (TES) for industrial waste heat (IWH) recovery: A review. Appl Energy. 2016;179:284-301. DOI
8 Zhang H, Baeyens J, Cáceres G, Degreve J, Lv Y. Thermal energy storage: Recent developments and practical aspects. Prog Energy Combust Sci. 2016;53:1-40. DOI
9. Rahnama S, Bendtsen JD, Stoustrup J, Rasmussen H. Robust aggregator design for industrial thermal energy storages in smart grid. IEEE Trans Smart Grid. 2015;8(2):902-916. DOI
10. Ma T, Li Z, Lv K, Chang D, Hu W, Zou Y. Design and performance analysis of deep peak shaving scheme for thermal power units based on high-temperature molten salt heat storage system. Energy. 2024;288:129557. DOI
11. Ren H, Jiang Z, Wu Q, Li Q, Yang Y. Integrated optimization of a regional integrated energy system with thermal energy storage considering both resilience and reliability. Energy. 2022;261:125333. DOI
12. Giampieri A, Ling-Chin J, Ma Z, Smallbone A, Roskilly A. A review of the current automotive manufacturing practice from an energy perspective. Appl Energy. 2020;261:114074. DOI
13. Gocompare.com. Economy 7 [Internet]. 2024 [cited 2024 Dec 01]. Available from: https://www.gocompare.com/gas-and-electricity/economy-7/.
14. Roskilly T, Ma Z, Wang R. Mapping and distributing GC and ITP waste heat within ICs and local regions [Internet]. 2022 [cited 2024 Dec 01]. Available from: https://idric.org/wp-content/uploads/4.2-Mapping-and-distributing-GC-and-ITP-waste-heat-within-ICs-and-local-regions.pdf.
15. Bolton P. Gas and electricity prices during the 'energy crisis' and beyond [Internet]. 2024 [cited 2024 Dec 01]. Available from: https://commonslibrary.parliament.uk/research-briefings/cbp-9714/.
16. Britton J, Minas AM, Marques AC, Pourmirza Z. Exploring the potential of heat as a service in decarbonization: Evidence needs and research gaps. Energ Source Part B. 2021;16(11-12):999-1015. DOI
17. Puschnigg S, Lindorfer J, Moser S, Kienberger T. Techno-economic aspects of increasing primary energy efficiency in industrial branches using thermal energy storage. J Energy Storage. 2021;36:102344. DOI
18. ENERGYNEST AS. ENERGYNEST [Internet]. 2011 [cited 2024 Dec 01]. Available from: https://energy-nest.com/.
19. ENERGYNEST AS. YARA: Steam grid balancing in integrated chemical plant unlocks new energy flexibility [Internet]. 2022 [cited 2024 Dec 01]. Available from: https://energy-nest.com/portfolio/case-study-yara/.
20. Energy Tech Review. ENERGYNEST: Pioneering Green Energy Storage Solutions [Internet]. 2023 [cited 2024 Dec 01]. Available from: https://www.energytechreview.com/energynest.
21. Project - Brenmiller. BRENMILLER: Our projects [Internet]. 2024 [cited 2025 Jan 17]. Available from: https://bren-energy.com/projects/

22. Recovery of waste heat - Eco-Techceram [Internet]. 2024 [cited 2025 Jan 17]. Available from: https://ecotechceram.com/en/references/.
23. Projects & Customers | Kraftblock [Internet]. 2024 [cited 2025 Jan 17]. Available from: https://www.kraftblock.com/projects.
24. Revolutionizing Renewable Energy | Norbis Park Heatcube by Kyoto Group [Internet]. 2024 [cited 2025 Jan 17]. Available from: https://www.kyotogroup.no/projects/norbispark.
25. Ortega-Fernández I, Rodríguez-Aseguinolaza J. Thermal energy storage for waste heat recovery in the steelworks: The case study of the REslag project. Appl Energy. 2019;237:708-719. DOI
26. Zhang P, Xiao X, Ma Z. A review of the composite phase change materials: Fabrication, characterization, mathematical modeling and application to performance enhancement. Appl Energy. 2016;165:472-510. DOI
27. Zhang Y, Wang R. Sorption thermal energy storage: Concept, process, applications and perspectives. Energy Storage Mater. 2020;27:352-369. DOI