

Thermal Energy Storage Case Studies

Examples of Thermal Energy Storage projects
with link to grid flexibility



WP2-D1 Thermal Energy Storage Case Studies

Report prepared by Codema
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Introduction to different forms of TES

Before exploring the different forms of thermal storage, it is important to first highlight the key reasons for incorporating Thermal Energy Storage (TES) into your heating system. TES offers three main benefits:

- Allowing your heating equipment to operate at the load condition that is most efficient, independently of heat demand i.e. it allows maximum efficiency/COP of heat pumps to be attained and removes need to run less efficient equipment (boilers) during periods where demand is outside operational range (i.e. demand is above the max output or below the minimum output) of more efficiency heat production equipment
- Allows electricity consumption to be moved to periods where electricity is cheaper thereby reducing the cost of heat production – implicit flexibility where price signals are used to change demand profiles is a good example of this and is discussed in the how-to guides which accompany this TES case study document.
- Allows heat production to be interrupted without any interruption to heat supply - enables provision of flexibility services without negatively impacting your primary business

At a national level, thermal storage can provide demand flexibility for the national electrical grid at a fraction of the cost of current battery storage options and across a broader range of storage durations. It also has a higher energy density by footprint. Its lifespan also far exceeds battery technology. Due to the national level target for district heating of 2.7 TWh and for domestic heat pumps (which will have hot water cylinders attached, thermal storage will already exist so it will not incur any additional cost outside of meeting these targets other than the possible additional cost of controls where needed. It also promotes system integration between the heat and electricity sectors, with the potential to provide services to the electricity grid such as balancing and frequency response.

There are many different types of thermal energy storage. The use of thermal storage can allow participation in a wide array of grid service markets, particularly where the duration times are longer or for applications where interruption to heat supply can cause issues.

1.1. Energy Storage technology and grid integration introduction

Based on the findings from the literature review, it is hard to present a clearly defined framework for categorising energy storage technologies and their different attributes as they can be regrouped through multiple dimensions. For example, it can be looked at considering the form of the energy while it is stored such as heat (hot component), chemical energy (electro-chemical battery), potential energy (dam, pumped hydro power), kinetic energy (flywheel), pressure, etc.

However, usually each storage unit is defined by its energy carrier considering that the boundary to the energy system is the input and output of this same energy carrier. For example, while a flywheel stores kinetic energy, it will usually be defined as an electricity storage. Therefore, the conversion from electricity to kinetic energy and back again is included in the storage technology characteristic but is not particularly relevant in itself as regards its interaction with the broader system, what really matters for the system integration is the input and output energy carrier. ¹

¹ Energistyrelsen, Danish Energy Agency, 2020, Technology Data Catalogue for Energy Storage (Version 0007), <https://ens.dk/en/analyses-and-statistics/technology-data-energy-storage>

Each energy storage technology can then be used for different applications, at different scale, sometimes for a mix of them. These applications might need to couple the energy storage with other technology into the broader system.

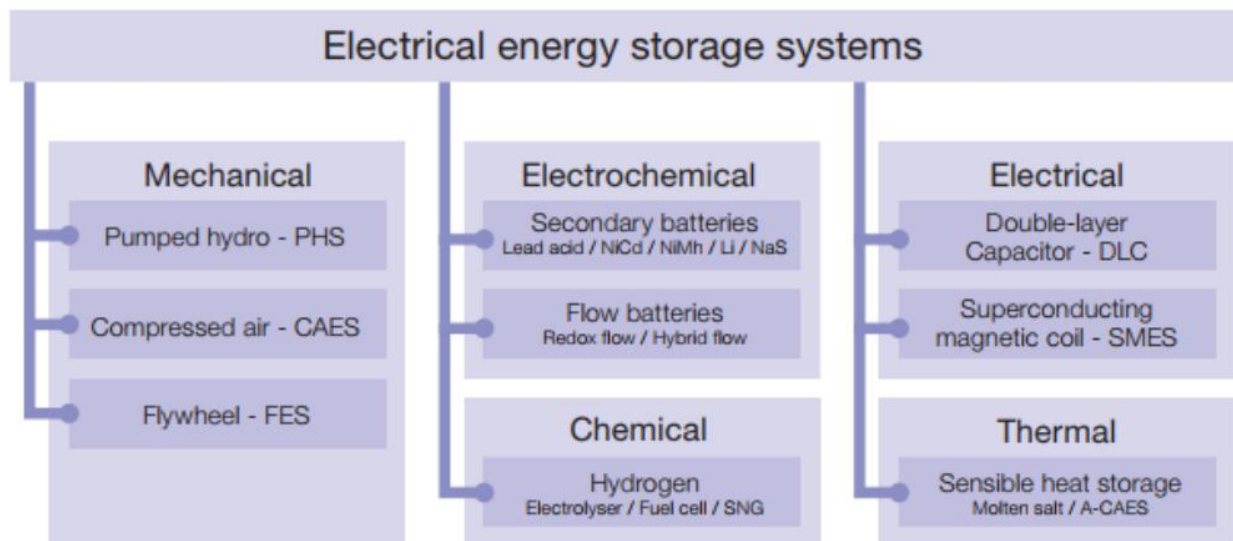


Figure 1: Classification of Electrical Energy storage systems (Energistyrrelsen, 2020)¹

When focusing on the actual energy output and end uses, energy storage can be classified as in the Figure 2. The possible forms of “useful” energy stored are reduced to electricity, heat or gas. The applications are divided into system or local level. While the former includes large-scale technologies to provide system services, the latter refers to household level or other smaller size applications.¹

		Application	
		System level	Local level
Form of energy stored	Electricity	Flywheel (FES) Large Batteries (NaS, VRB, SoNick) Stationary lithium-ion batteries	Lead-acid batteries Flywheel (FES) Stationary lithium-ion batteries Electric car batteries
	Heat	Seasonal Heat storage – Water pits Aquifer thermal energy storage (ATES) Large Scale Hot Water tank	Small scale hot water tank
	Gas	Underground natural gas storage (caverns and aquifer) Hydrogen Storage above ground Hydrogen Storage in caverns	Compressed hydrogen storage

Figure 2: Simplified Energy storage technology table1

This classification is still reductive, in particular a lot of the applications for flexibility services have for end target the electrical grid and so, electricity as the energy carrier is a very important parameter. When reviewing the potential of thermal energy storage for flexibility service (heat category in Figure 2), the potential conversion of electricity to heat during the charging phase and/or to heat to electricity during the discharge, through different pieces of technology can also be beneficial to the grid but does not form part of this project which focuses on demand response rather than generation.

1.2. Types of Thermal Energy Storage

Based on the heat storage mechanism, thermal storage options can be split into three different “physical principle” category:¹

1. Sensible heat storage (SHS), which use the heat capacity of the storage material (traditionally water for its high specific heat content per volume, low cost and non-toxic medium but can also be sand, rock, oil bricks, etc.).
2. Latent heat storage (LHS), which make use of the storage material’s latent heat during a phase change (solid/liquid, etc) at a constant temperature. This form of storage is also commonly referred to as phase-change material or PCM as this is the storage medium for this form of storage.
3. Thermo-chemical heat storage (TCS), which use the heat stored in a reversible chemical reaction. In particular, sorption stores, which use the heat of ad- or absorption of a pair of materials such as zeolite-water (adsorption) or lithium bromide (absorption), are examples of chemical stores.

LHS and TCHS are less mature technologies compared with sensible heat storage (SHS) technologies, but they are continuously improving². While less commercially mature, there are several demonstration and pilot projects, as described in Section 4 and 5.

These heat storage principles can be implemented at different scales and for different applications, and can be delivered through various technology solutions.

As part of this comparative study Codema reviewed the following thermal energy storage technologies:

- Large-scale Tank Thermal Energy Storage (TTES),
- Pit Thermal Energy Storage (PTES),
- Underground Thermal Energy Storage - Aquifer Thermal Energy Storage (ATES) and Borehole Thermal Energy Storage (BTES)
- Domestic Hot Water Tank
- Sand Batteries
- Phase-change material (PCM)
- Thermo-chemical material (TCM)

1.2.1. Sensible heat storage

In the case of sensible stores, which are traditionally the most common thermal storage option, the main technologies are:

- Tank Thermal Energy Storage (TTES),
- Pit Thermal Energy Storage (PTES),
- Aquifer Thermal Energy Storage (ATES),
- Borehole Thermal Energy Storage (BTES)

² Khan, Muhammad & Asfand, Faisal & Al-Ghamdi, Sami G. (2022). Progress in Research and Development of Phase Change Materials for Thermal Energy Storage in Concentrated Solar Power. Applied Thermal Engineering. 219. 119546. 10.1016/j.applthermaleng.2022.119546,.URL :

https://www.researchgate.net/publication/364767107_Progress_in_Research_and_Development_of_Phase_Change_Materials_for_Thermal_Energy_Storage_in_Concentrated_Solar_Power

- Others (building mass thermal storage, heat networks, etc)

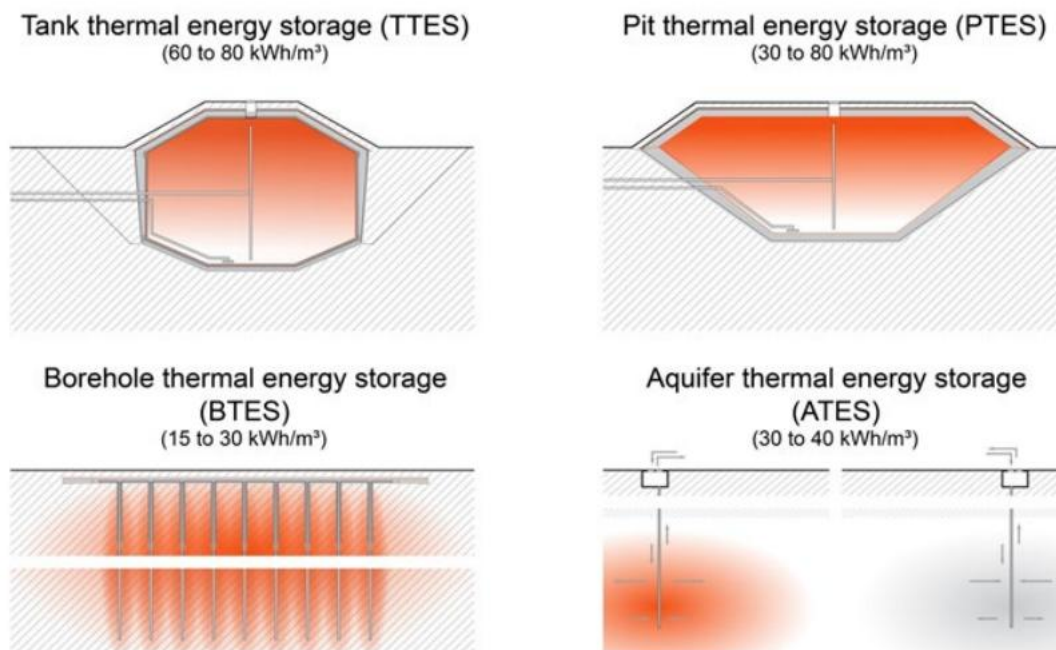


Figure 3: Seasonal thermal energy storage – concepts (Energistyrelsen, 2020) 3

1.2.2. Latent heat storage

For latent heat storage, the main component is usually a phase change material (PCM). Phase Change is a material that can change its state by releasing and storing thermal energy. PCMs have the properties that enable them to store energy at a nearly constant temperature with high energy storage density.

The phase transition of PCM can be grouped into three types: ⁴

- solid-liquid,
- solid-gas,
- liquid-gas.

However, because of their small variation of volume when changing phase, solid-liquid PCMs are usually preferably used compared with solid-gas and liquid-gas. The process depends on the surrounding temperature, in most cases the PCM will be in liquid state when the temperature exceeds its melting temperature (that is how the heat is stored). On the other hand, the PCM will release the heat, and return to the solid state when the temperature gets lower than the melting point of the PCM.⁴

³ Energistyrelsen, Danish Energy Agency, 2020, Technology Data Catalogue for Energy Storage (Version 0007), <https://ens.dk/en/analyses-and-statistics/technology-data-energy-storage>

⁴ Ahmad Fariz Nicholas, Mohd Zobir Hussein, Zulkarnain Zainal, Tumirah Khadiran, Chapter 12 - Activated Carbon for Shape-Stabilized Phase Change Material, In Micro and Nano Technologies, Synthesis, Technology and Applications of Carbon Nanomaterials, Elsevier, 2019, Pages 279-308, ISBN 9780128157572, <https://doi.org/10.1016/B978-0-12-815757-2.00013-9>, <https://www.sciencedirect.com/science/article/pii/B9780128157572000139>

PCM can be classified into: ⁴

- inorganic compounds (salt hydrates, salts, metals, and alloys),
- organic compounds (paraffins, nonparaffins, and polyalcohols),
- eutectics of inorganic and/or organic compounds.

A common Phase change material technology used in TES applications is Molten salt.

1.2.3. Thermo-chemical heat storage

Thermo-chemical heat storage solution, which use the heat stored in a reversible chemical reaction, are less commonly used in TES applications or at least not for mainstream commercial applications.

1.3. Comparison of Different forms of TES

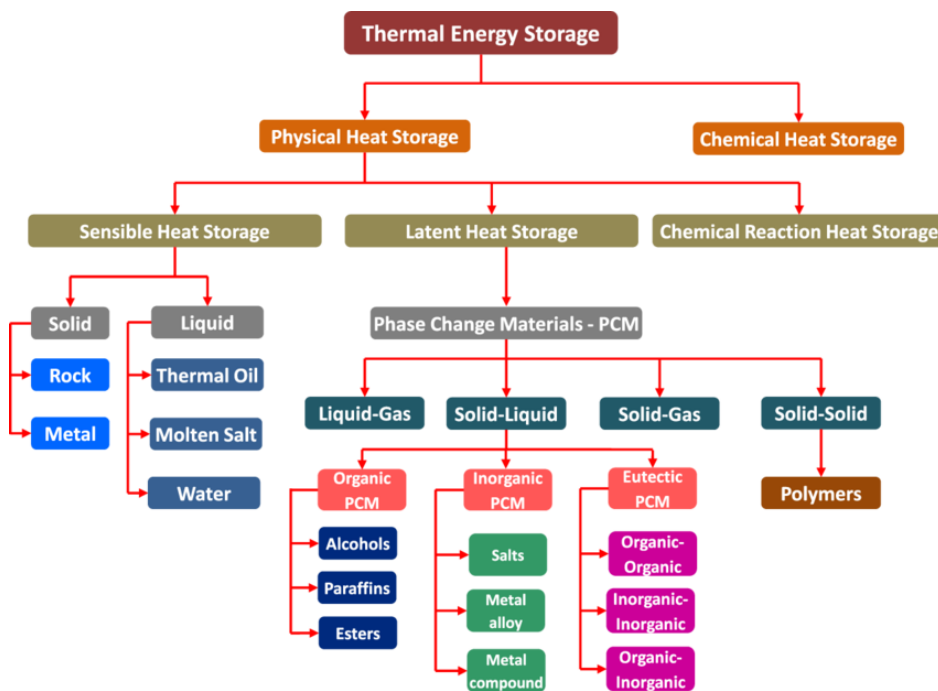


Figure 4: Overview of usual classification of thermal energy storage solution.2

1.3.1. Determining the suitability of TES to specific applications

In order to determine the appropriate type of TES to choose for a given application, Codema has graphed nine different TES technologies by their typical characteristics such as operating temperature, storage duration, land use requirement and cost. These graphs can be used as a quick reference to select the TES technology that best suits a given users needs.

Figure 5 outlines the typical temperature and storage duration ranges for the different forms of TES. The graph also includes typical temperature ranges for different applications such as building heat demands (space heating and hot water), process heating, and power generation. It should be noted that approximately 40% of process heat demand in Ireland will require less than 150°C⁵. Given the profile of large industrial heat users in Ireland (dairy, pharmaceutical, food and beverage industries, etc.) it is likely that a significant proportion of industrial heat demand in Ireland will be below 200°C (i.e. for evaporators, drying, sterilisation, CIPs systems, autoclaves, brewing etc.) but exact figures on this are not currently available. The minimum temperature for power generation is indicated as being 75°C for organic rankine cycle (ORC) engines, however, a temperature in excess of 120°C is preferred by industry to achieve reasonable efficiencies. This 120°C figure is the one that has been included in this graph. It is also worth noting that steam turbines will typically use steam in the 400°C - 600°C range⁶.

⁵ Based on figures from the SEAI national heat study - <https://www.seai.ie/sites/default/files/publications/Heating-and-Cooling-in-Ireland-Today.pdf>

⁶ Based on information from Wärtsilä, which aligns with figures from the BEIS CHP study (2021)

https://assets.publishing.service.gov.uk/media/602a7b6bd3bf7f031e1bdcdd/Part_2_CHP_Technologies_BEIS_v03.pdf

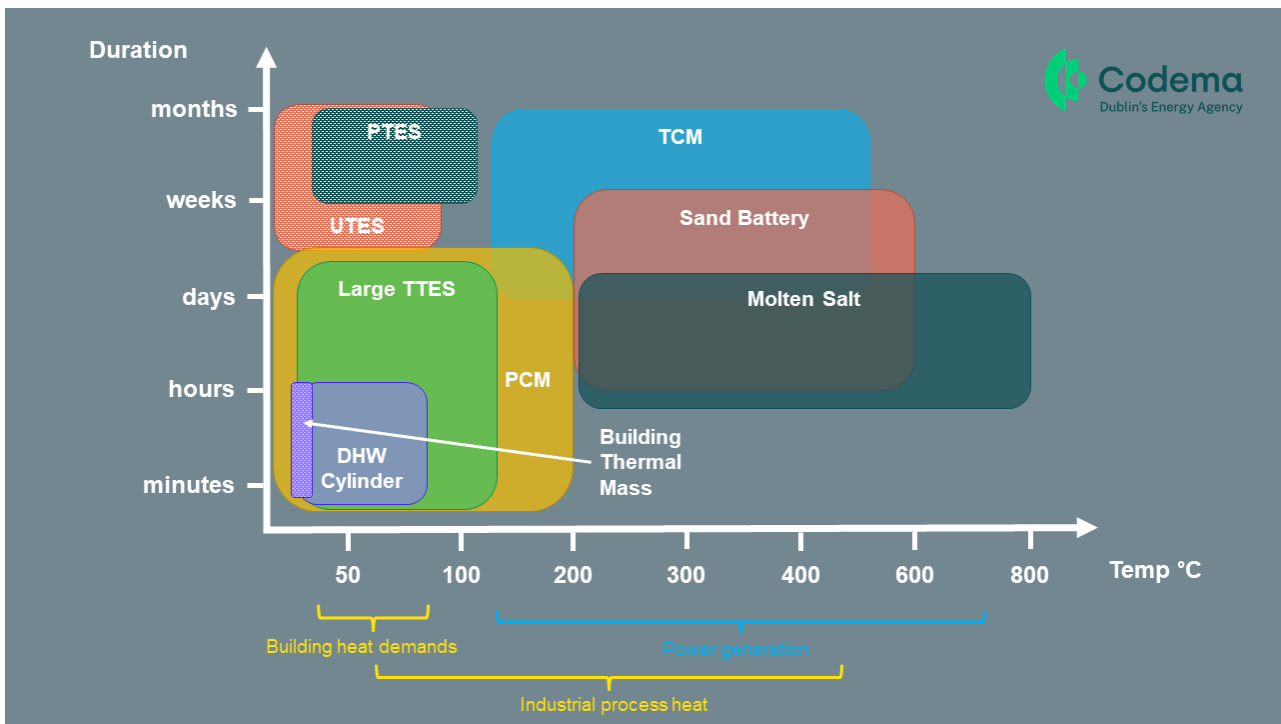


Figure 5: Typical temperature and duration ranges for thermal energy storage technologies

Figure 6 below outlines the typical cost and space requirements for the different forms of TES. It should be noted that the cost of the building thermal mass storage is considered zero, as this will already exist for the purpose of providing shelter to the building occupants. However, there may be a cost of upgrading controls that is not considered in this graph. There may be other forms of storage that already exist in a heating system, such as tank storage in an existing building or in an existing heat network, which could also be considered to have zero cost, but for the purpose of this graph it is assumed that these installations are new and require an upfront investment.

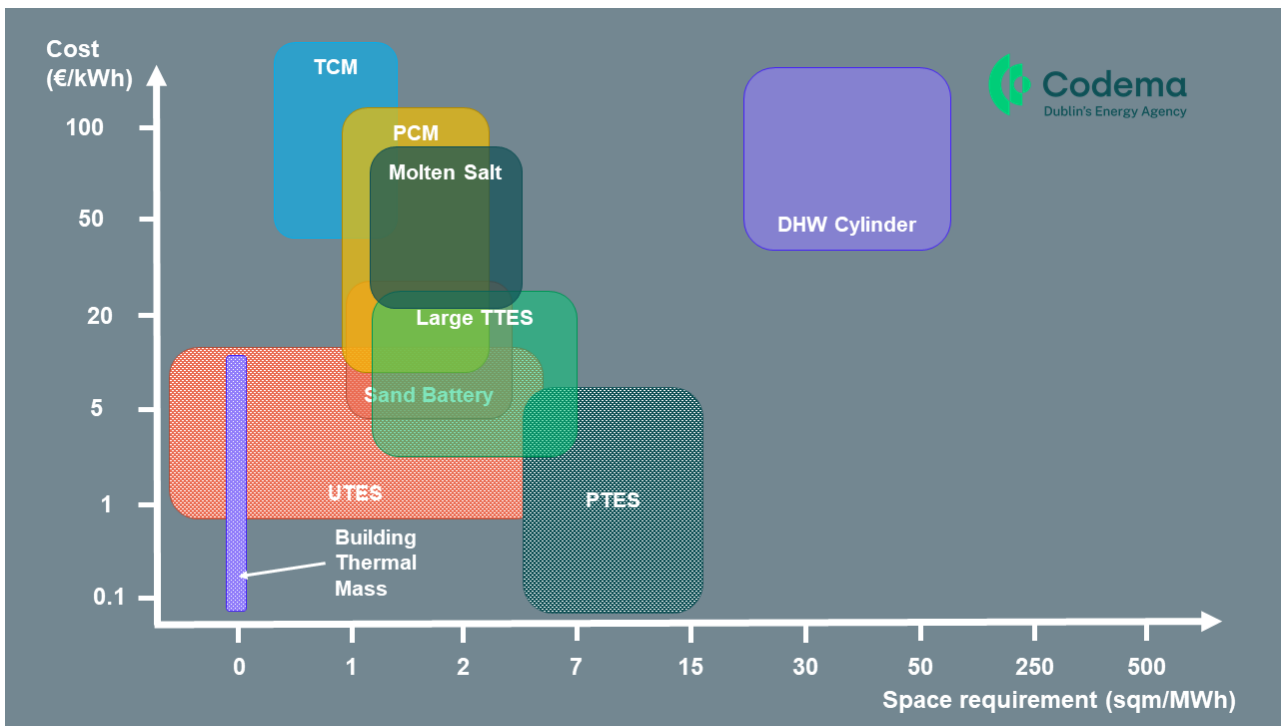


Figure 6: Typical cost and space requirement graph for thermal energy storage technologies

1.3.2. TES comparison table

The table below provides a comparison of the different forms of TES analysed as part of this project and includes a comparison with other forms of energy storage namely battery energy storage systems (most common technology for shorter duration storage) and hydrogen storage (less proven but often talked about in the context of long-duration or seasonal energy storage).

Table 1: Thermal energy storage comparison table (typical ranges)

TES Option	Temperature range (°C)	Typical cost range (€/kWh)	Typical duration range	Typical space requirement (m2/MWh)
Large-scale tank	35-120	3-35	mins-days	2-7
Domestic cylinder	35-85	100-400	mins-hours	20-100
Phase-change material	15-200	300-1,200	mins-days	1-2
Pit storage	35-90	0.1-10	weeks-months	5-15
Aquifer storage	15-90	1.3-5	weeks-months	negligible
Borehole	15-90	1-10	weeks-months	0.3-5 (during installation phase)
Molten salt	200-800	10-100	secs-days	2-4
Thermo-chemical material	150-550	20-80	days-months	0.2-1
Sand battery	200-600	5-20	hours-weeks	1-3
Hydrogen storage (for comparison)	N/A	11,000	hours-months	negligible (underground)
Battery storage (for comparison)	N/A	600-1,000	secs-days	35-45

A more detailed comparison of these technologies please contact Codema directly.

1.4. Resource Efficiency

An area that should also be considered is the relative resource efficiency of typical thermal storage (tank storage) when compared to other forms of storage like batteries. The figure below provides an indication of the overall breakdown of materials used in large-scale tank thermal energy storage and battery energy storage systems (Lithium Iron Phosphate - LFP). The overall weight of materials per MWh of storage capacity for the BESS system is approximately three times greater than that of the TTES (approximately 9tonnes/MWh for BESS compared with 3tonnes/MWh for the TTES⁷). It can be seen that the majority of the materials used for the BESS system are metals (steel, aluminium, copper) and rare earth minerals (lithium, graphite) which together make up 61% of the total weight of the BESS. The TTES consists predominantly of water, which makes up 94% of its final weight. The main material used in the TTES construction is steel which accounts for 4% of the final weight. It is worth noting that many BESS systems are modular and therefore will have a similar proportion of materials as they scale above the indicative 5MWh unit shown. The thermal energy storage tank will have a reducing proportion of materials as it increases in size due to the non-linear relationship between the volume of the tank and its surface area (you get proportionally more volume for a given increase in surface area). This is mitigated somewhat by the requirement to increase the thickness of steel for the tank if using similar height to diameter ratios so therefore larger tanks tend to have lower height to diameter ratio to smaller tanks.

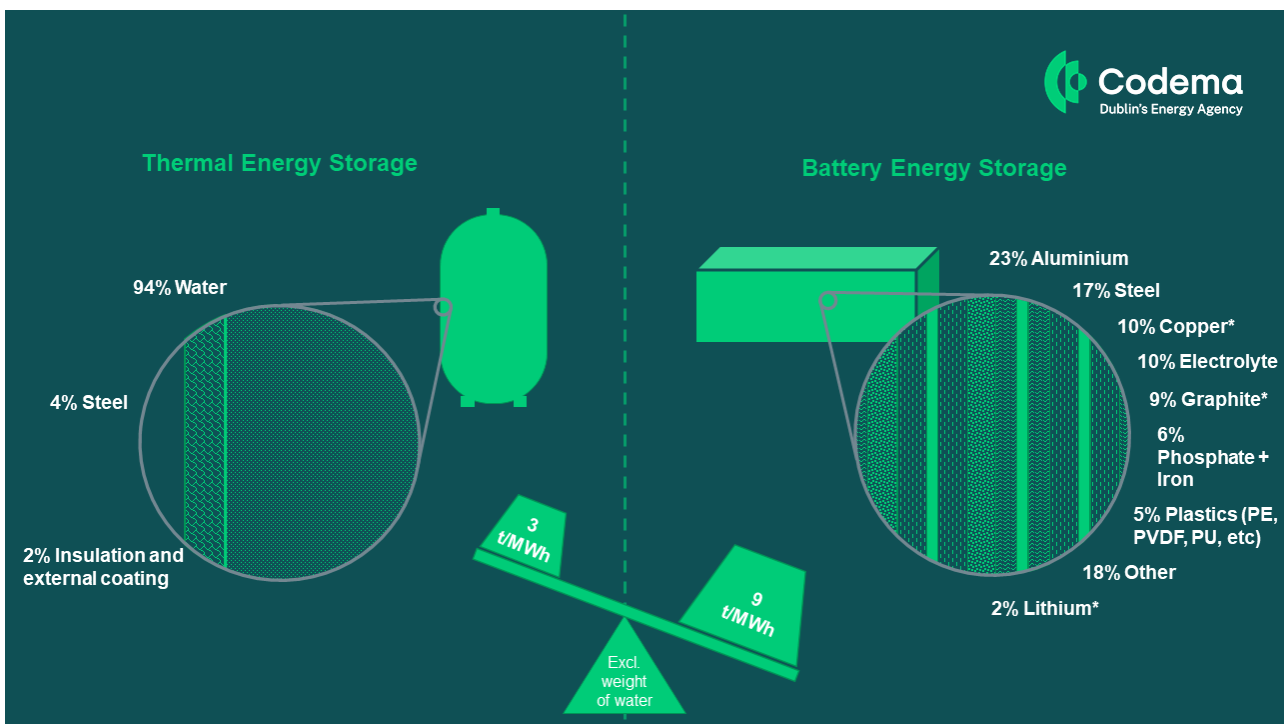


Figure 7: Resource efficiency comparison for large-scale energy storage (TTES and BESS @ 5MWh scale)

⁷ Excluding the weight of the water in the TTES which is not considered a construction material

2. Summary of Case Studies

The table below summarises the different case studies example used in that report.

Table 2: Case study summary table

ID	Project	Link	Area
CS1	Dublin, UCD Smurfit Business School Small commercial buffer tank	UCD Smurfit Business School buffer tank for Heat pump retrofit online article https://eurogas.ie/case-study-ucd-smurfit-business-school/	Ireland
CS2	County Kilkenny Residential buffer tank	Residential accumulator hot water tank (along with wood log boiler) Online article https://glas.ie/wp-content/uploads/2018/05/B-Dillon-Case-Study-3.pdf	Ireland
CS3	Cadaujac, France Underground thermal storage for centralised heating	Online article https://www.revolution-energetique.com/actus/voici-le-premier-stockage-souterrain-de-chaaleur-bas-carbone-en-france/	France
CS4	Thurrock, UK: Social housing heat batteries	Online website https://sunamp.com/case-studies/thurrock-residents-cut-costs-and-carbon/	UK
CS5	Kankaanpää: The First Commercial Sand Battery (8MWh)	Details available from Polar Night (Juha Niemi - Polar Night's Sales Manager - juha.niemi@pne.fi)	Finland
CS6	Pornainen: The First Large Scale Sand Battery (100MWh)	Details available from Polar Night (Juha Niemi - Polar Night's Sales Manager - juha.niemi@pne.fi)	Finland
CS7	Marstal, Denmark: Seasonal pit storage (2100m3) for DH using solar energy	Online Press release https://bankwatch.org/wp-content/uploads/2022/05/2022-05_Case-Study-Marstal_eng.pdf	Denmark
CS8	Meldorf, Germany: Pit thermal energy storage for DH (43000m3, 1500MWh)	Online article https://www.ramboll.com/projects/energy/germany-s-pit-thermal-energy-storage	EU Germany
CS9	Heat Smart Orkney (residential heat using curtailment)	Online article https://localenergy.scot/casestudy/heat-smart-orkney/	Scotland
CS10	Nevada, USA: The Crescent Dunes CSP project	Online article https://www.solarpaces.org/what-happened-with-crescent-dunes/ https://www.solarpaces.org/how-csp-thermal-energy-storage-works/	USA
CS11	Southampton, UK: Caldera's system	Online article https://www.iom3.org/resource/industrial-heat-cells-store-renewable-energy.html https://www.caldera.co.uk/	UK
CS12	Pixley, California:	Online website https://www.rondo.com/case-study/calgren-renewable-fuels	USA

	Rondo Heat battery at Calgren Renewable Fuels facility		
CS13	Gothenburg, Sweden: Multi-Family Building connected to DHN using FractLES technology	Online Website (Project 101096921 - THUMBS UP) https://www.thumbsupstorage.eu/lab-life/demonstrate/gothenburg-multi-family-building	Sweden
CS14	Valladolid, Spain: Single Family Building Pilot Site using the SortLES technology	Online Website (Project 101096921 - THUMBS UP) https://www.thumbsupstorage.eu/lab-life/demonstrate/valladolid-single-family-building	Spain

3. Sensible Thermal Store Case Studies

3.1. Tank Thermal Storage (TTES) Case Study

3.1.1. Brian Dillon, County Kilkenny, residential accumulator tank for space heating and hot water

Thermal Energy Storage Capacity	2,000L Hot water tank
Temperature range of thermal storage ⁸	40-90°C
Storage medium	Water
Type of heat store	Sensible
Use of Heat	Residential space heating and hot water
Link with Electrical Grid Network Flexibility	No grid application
Contact	Glas Energy



Figure 8: Glas Energy Case study: HDG Log Boiler system with 2000L buffer tank for Home Heating⁹

Glas Energy installed an HDG Navora log boiler and a 2,000-litre buffer tank in an outhouse near the main house. From September to early May, the boiler is usually fired every three days, increasing to every two days during colder weather. Logs are loaded onto a base of kindling and cardboard, and burned at high temperatures through a gasification process. This leaves only a small amount of charcoal and a thin layer of

⁸ Based on typical values for this type of installation rather than specific figures for this installation

⁹ Glas Energy, HDG Log Boiler for Home Heating Case study (published in 2018), <https://glas.ie/wp-content/uploads/2018/05/B-Dillon-Case-Study-3.pdf>

ash, which collects in a tray at the bottom. Keeping most of the charcoal in place helps to ignite the next fire. The ash tray is emptied onto a compost heap every few months. (Adapted from glas.ie website¹⁰)

3.1.2. UCD Smurfit Business School buffer tank for Heat pump retrofit

Thermal Energy Storage Capacity	1,500L
Temperature range of thermal storage ¹¹	40-90°C
Storage medium	Water
Type of heat store	sensible
Use of Heat	Space heating (of a restaurant)
Link with Electrical Grid Network Flexibility	Not particular grid application mentioned
Contact	PowerTherm Solutions/G&J Engineering

Designed by PowerTherm Solutions and installed by G & J Engineering Ltd., the system uses a Hidros LHA heat pump to heat the restaurant area. The heat pump feeds into a Cordivari multi-connection insulated buffer tank, supported by a high-efficiency gas-fired boiler as backup. The heat pump supplies around 80% of the restaurant's annual heating needs, with the boiler only kicking in when outdoor temperatures drop below 6°C and higher system temperatures are needed for comfort. The entire setup is managed by the existing Cylon BMS, with the heat pump connected via ModBus protocol. (Adapted from Euro Gas website¹²)

This 90kW heat pump replaced a 20-year-old gas fired sectional boiler and the Heat Pump project costed around €100,000.¹³

¹⁰ Glas Energy, HDG Log Boiler for Home Heating Case study (published in 2018), <https://glas.ie/wp-content/uploads/2018/05/B-Dillon-Case-Study-3.pdf>

¹¹ Based on typical values for this type of installation rather than specific figures for this installation

¹² Euro Gas, Case Study: UCD Smurfit Business School, <https://eurogas.ie/case-study-ucd-smurfit-business-school/>

¹³ SEAI, Case Study: University College Dublin on track to achieve 2020 Climate Action targets, <https://www.seai.ie/case-studies/ucd-climate-action-2>

3.2. Aquifer Thermal Storage (ATES) Case Study

3.2.1. ENGIE Group's new headquarters in La Garenne-Colombes (France) named "the Campus" using ATES

Thermal Energy Storage Capacity	Specific size not known (able to provide 1.9MW Heat)
Temperature range of thermal storage	80-90°C
Storage medium	water
Type of heat store	sensible
Use of Heat	Centralised heating (space heating and hot water)
Link with Electrical Grid Network Flexibility	Not specifically mentioned
Contact	Storengy

"The Campus", the future headquarters of ENGIE, features an energy hub designed to meet all heating and cooling needs using 100% local and renewable energy. Developed and operated by ENGIE teams, the hub combines several technologies: deep geothermal energy (ATES type), rooftop photovoltaic panels, biogas boilers, and electrical storage.

Storengy designed the heating and cooling systems using ATES (Aquifer Thermal Energy Storage) geothermal technology. Unlike conventional geothermal systems, ATES reverses water withdrawal and injection depending on the season. In winter, hot water is extracted, used for heating, then cooled and reinjected into a cold reservoir. Storengy's partner SANFOR drilled nine 90-meter-deep wells, accessible from the buildings' basements, delivering 1.9MW of heating and 1.6MW of cooling.

This 100% renewable geothermal solution will be supported by biogas boilers for heating and photovoltaic panels for cooling. It is also the first time Storengy is deploying its 'smart geothermal' solution on a project of this scale in France. (Adapted from ENGIE ¹⁴ and Think Geoenergy website ¹⁵).

¹⁴ ENGIE, "future Campus: 100% Renewable Energy" (article released in 2025), <https://www.engie.com/en/news/futur-campus-100-percent-renewable-energy>

¹⁵ Think Geoenergy, "ENGIE sets up aquifer geothermal energy storage for its new HQ" (article released in 2021), <https://www.engie.com/en/news/futur-campus-100-percent-renewable-energy>

3.3. Underground “Borehole” Thermal Energy Storage Case Study

3.3.1. AbSolar geothermal and solar thermal system with underground thermal storage

Thermal Energy Storage Capacity	10,000 m ³
Temperature range of thermal storage	80-90°C
Storage medium	water
Type of heat store	sensible
Use of Heat	District Heating
Link with Electrical Grid Network Flexibility	Not specifically mentioned Facilitate use of intermittent renewables electricity production through seasonal storage
Contact	AbSolar



Figure 9: Underground storage system combined with solar in Cadaujac, France¹⁶

In 2021, AbSolar delivered a heating system for a new neighbourhood with 67 homes. The system combines a solar thermal field, which pre-heats water using sunlight, and an underground storage system made up of 60 boreholes, each 30 meters deep. A heat pump is used to raise the water temperature as needed for space heating and hot water.¹⁶

¹⁶ Revolution Energetique, (article released in 2023), <https://www.revolution-energetique.com/actus/voici-le-premier-stockage-souterrain-de-chaleur-bas-carbone-en-france/>

3.4. Pit Thermal Storage (PTES) Case Study

3.4.1. Marstal, Denmark: Seasonal pit storage (75000m³) for DH using solar energy (and mixed energy system)

Thermal Energy Storage Capacity	75,000 m ³ pit thermal storage / 2100m ³ accumulation tank thermal storage
Temperature range of thermal storage	Maximum of 80-85°C during summer and down to 10°C in winter
Storage medium	Water
Type of heat store	Sensible
Use of Heat	Residential and commercial District Heating
Link with Electrical Grid Network Flexibility	Not specifically mentioned
Contact	Marstal Fjernvarme

This project uses 33,365 m² of solar thermal collectors, delivering around 28,000 MWh of thermal solar energy annually. The energy is stored in a 75,000 m³ pit seasonal storage and a 10,000 m² “pilot heat storage,” along with a 2,100 m² tank thermal storage. Solar collectors supply about 41% of the total energy demand based on the district heating output. The system also includes a 4 MW biomass boiler with a 750 kW Organic Rankine Cycle (ORC) unit, a 1.5 MWth electric heat pump, and backup bio-oil boilers.



Photo: Marstal solar plant with heat storages (source: Marstal Fjernvarme A.m.d.b)

Figure 10: Marstal solar plant with heat storages¹⁷

The Marstal solar heating plant is located on Aeroe, a renewable energy island south of Denmark. One of the world's largest and pioneering solar heating projects, it is known for its seasonal pit storage systems and the local community's strong support for renewable district heating.

Since 1994, Marstal District Heating (Marstal Fjernvarme) has been steadily shifting to 100% renewable energy. Today, about 50% of the heat comes from solar collectors, 40% from wood chips, and 2–3% from a heat pump. In 2001, with support from the Danish Energy Agency and the EU's Fifth Framework Programme (SUNSTORE 2), solar thermal covered up to 13% of the heat demand. By 2010, through the EU's Seventh Framework Programme (SUNSTORE 4), solar thermal was expanded to cover up to 50% of the demand. The total project budget was €15.1 million, with €6.1 million provided in EU grants and €0.4 million from partner contributions. (Adapted from CEE Bankwatch Network¹⁷)

¹⁷ CEE BankWatch Network, 2022, https://bankwatch.org/wp-content/uploads/2022/05/2022-05_Case-Study-Marstal_eng.pdf

3.4.2. Meldorf, Germany: Pit thermal energy storage for DH (43000m³, 1500MWh)

Thermal Energy Storage Capacity	1,500 MWh
Temperature range of thermal storage	Maximum of 90°C
Storage medium	Water
Type of heat store	Sensible
Use of Heat	Residential and commercial District Heating
Link with Electrical Grid Network Flexibility	Not specifically mentioned
Contact	WIMeG

WIMeG Wärmeinfrastruktur Meldorf GmbH & Co. KG (WIMeG) is developing a new district heating network to replace individual heating systems in about 55 residential and commercial buildings. The switch is expected to cut annual carbon emissions by 1,000 tonnes.

As part of the project, WIMeG is also building Germany's largest thermal pit storage, with a capacity of 43,000 m³ — about the size of 17 Olympic swimming pools. The storage can hold up to 1,500 MWh of heat during summer or low-demand periods, which is then redistributed when demand increases, helping to minimise waste and improve energy security.

The network will mainly use waste heat from a nearby printing plant, supported by biogas engines and peak-load gas boilers, with the option to add solar thermal energy in the future. The pit storage heats water up to 90°C using integrated heat sources. A floating, heat-insulating cover reduces heat loss, while the storage liner itself requires minimal thermal insulation. (Adapted from Ramboll website¹⁸)

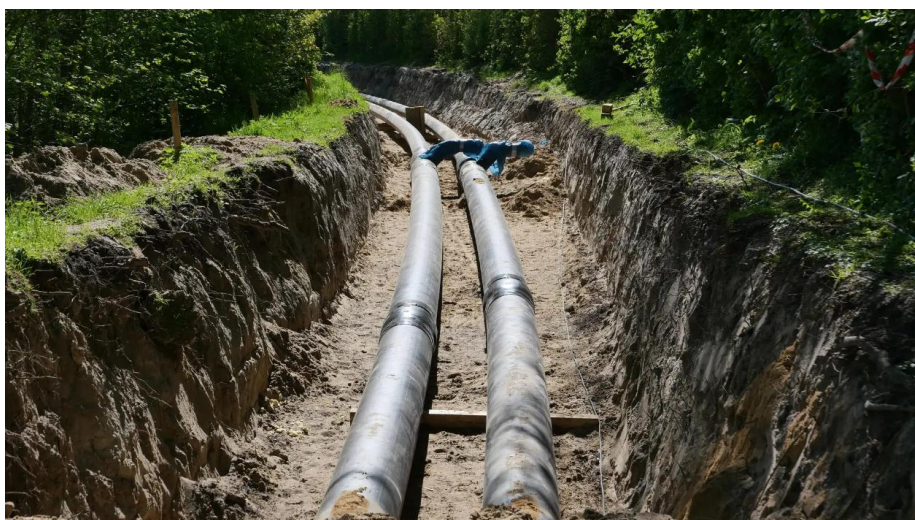


Figure 11: Image of district heating pipes in the town of Meldorf (fed with heat from Pit Storage), Schleswig-Holstein, Germany.

Ramboll's was appointed by WIMeG to provide planning services work on the Meldorf district heating system and the pit storage began in 2020. The pit storage was expected to be completed and ready for operation in early summer 2023, and the district heating system was expected to be operational by winter 2023.

The project does not mention explicit use of the system for Grid services application.

¹⁸ Ramboll projects, 2023, <https://www.ramboll.com/projects/energy/germany-s-pit-thermal-energy-storage>

3.5. Individual residential hot water tank case study

3.5.1. Heat Smart Orkney (residential heat using curtailment)

Thermal Energy Storage Capacity	108 electric heater and water immersion heater spread in 72 households (<i>approximately aggregated total of 576 kWh of hot water cylinder thermal storage¹⁹</i>)
Temperature range of thermal storage	From 10 to 60°C
Storage medium	Water
Type of heat store	Sensible
Use of Heat	Distributed residential space heating and hot water
Link with Electrical Grid Network Flexibility	Heating devices used for demand side management response to reduce curtailment
Contact	HSO Ltd

The Heat Smart Orkney (HSO) project was developed to reduce curtailment of the community-owned Rousay wind turbine, which in year 2016/2017 curtailed about 30% of its potential production (~0.7 GWh) and did not take advantage of £110,000 in potential local revenue. Funded by the Scottish Government's Local Energy Challenge Fund, HSO piloted a smart-grid system that controlled domestic heating devices to absorb excess energy during curtailment.

The project installed 108 electric heaters and water immersion heaters across 72 households in Orkney. During curtailment events, these devices were switched on, reducing curtailment and increasing turbine revenues. In 2018 and 2019, the project avoided 15 MWh and 3.3 MWh of marginal curtailment, respectively. Customer satisfaction remained high, with over 98% retention and about one in four households reporting lower fuel bills.

Now in its Legacy phase, HSO aims to expand to other generators on the Orkney grid. Financial models suggest break-even could be achieved with five turbines and 800 heating devices. Beyond its original goals, HSO helped address fuel poverty, strengthened ties with local grassroots organisations, and laid the groundwork for larger initiatives like the Smart Islands Energy Systems (SMILE) and Responsive Flexibility (ReFLEX) projects.

The project was led by the Rousay Egilsay & Wyre Development Trust, through its subsidiary HSO Ltd., alongside partners including REWIRED, Community Energy Scotland, VCharge (now Kaluza), Catalyst, and other Orkney-based development trusts. (Adapted from Local Energy Scotland blog ²⁰)

¹⁹ Considering 72 hot water cylinders of around 125L going from 10 to 65 °C

²⁰ Local Energy Scotland website, (final project reports released in 2020), <https://localenergy.scot/casestudy/heat-smart-orkney/>

3.6. “Ceramic store” Case Study

3.6.1. Caldera's Volcanic Rock Store Technology

Thermal Energy Storage Capacity	Each cell is 100kWh
Temperature range of thermal storage	Up to 204°C
Storage medium	Composite of recycled aluminium and volcanic rock
Type of heat store	sensible
Use of Heat	Demonstrator aiming for industrial heat use
Link with Electrical Grid Network Flexibility	A factory-assembled package that connects the Heat Cell to the site's MV power grid and controls charging. This includes an energy management system which dynamically responds to variable input power (e.g. from variable renewables) and/or output heat demand.
Contact	Caldera



Figure 12: Caldera's system pilot demonstrator, industrial-scale heat cells made from volcanic rock and scrap aluminium²¹

Caldera's technology stores renewable energy to deliver industrial heat on demand. The key components are heat cells, each containing a solid core that operates between 200°C and 500°C, surrounded by vacuum insulation for efficiency.

The company, Caldera, is partnering with the Manufacturing Technology Centre (part of the Advanced Manufacturing Catapult) to scale up production. While the full manufacturing process is confidential, the

²¹ Source online article (released on 11/09/2023): <https://www.iom3.org/resource/industrial-heat-cells-store-renewable-energy.html>

system involves melting recycled aluminium over volcanic rock. This design lowers costs while maintaining high thermal conductivity, as solid aluminium paths allow fast energy transfer.

The vacuum insulation system achieves high performance at a lower cost by using steam for heat extraction instead of hot air, avoiding heavy and expensive piping systems typically needed for air-based systems. Steam systems lose much less heat and require far less bulky insulation.

Although fossil fuels still have a higher energy density, Caldera's solution compares very well against other thermal storage technologies. It is best suited for sites with space for large ground-mounted solar arrays, often using nearby fields and private wire connections. The thermal storage units themselves are compact, about the size of a few shipping containers.

Caldera plans to offer complete systems with solar panels and thermal storage to provide 24/7 process heat. The first demonstrator will heat a 15,000-litre water tank using 100 kWh heat cells. Future versions will use 200 kWh cells to deliver steam on demand, scaling up to meet industrial needs. (Adapted from Institute of Materials, Mineral & Mining blog²¹)

3.6.2. Rondo Heat Battery at Calgren Renewable Fuels facility

Thermal Energy Storage Capacity	2 MWh
Temperature range of thermal storage	Up to 1,000°C
Storage medium	brick materials
Type of heat store	sensible
Use of Heat	Industrial heat
Link with Electrical Grid Network Flexibility	Charging from the grid but no specific application mentioned
Contact	Rondo



Figure 13: Rondo Heat Battery at Calgren Renewable Fuels facility²²

The 2 MWh Rondo Heat Battery (RHB) captures intermittent renewable electricity, stores it in brick materials at temperatures over 1,000°C, and supplies continuous industrial heat on demand.

Rondo is working with Calgren Renewable Fuels at their Pixley, California facility, where Calgren produces some of the world's lowest carbon intensity ethanol, biodiesel, and renewable natural gas (RNG).

Heat is delivered to Calgren through Rondo's Heat-as-a-Service (HaaS) model, offering energy at a cost per MMBtu lower than traditional gas-fired heat. This approach allows industrial users to access affordable, stable energy without needing upfront capital investment. (Adapted Rondo website²²)

²² Source online article (last checked on 03/04/2025): <https://www.rondo.com/case-study/calgren-renewable-fuels>

3.6.3. Polar Night Sand Battery Case Studies

Thermal Energy Storage Capacity	Kankaanpää: 8MWh / Porainen: 100MWH
Temperature range of thermal storage	For applications up to 400°C
Storage medium	Different type of available sand (for example local crushed soapstone)
Type of heat store	Sensible store
Use of Heat	Industrial and large-scale commercial
Link with Electrical Grid Network Flexibility	Sand battery technology complies with the technical requirements for grid balancing, The latest Sand Battery (100 MWh) is planned to be used for ancillary services and operated by Elisa, a Finnish telecommunications company.
Contact	Juha Niemi (Polar Night's Sales Manager) +358 45 783 950 33 juha.niemi@pne.fi

There are several demonstrations site of the Sand Battery technology developed by Polar Night Energy company. Even though there are yet no formal applications of the TES in grid services, the technology is charging by using self-produce or grid electricity (with possibility to take advantage of low SPOT prices), thus it makes possible to attend frequency containment or restoration reserve market and there is potential for leveraging additional revenue streams.

Kankaanpää: The First Commercial Sand Battery

Polar Night Energy constructed and operates the world's first commercial sand-based thermal energy storage for Vatajankoski Oy in Kankaanpää, Western Finland. This system had an energy storage capacity of 8MWh and a power capacity of 200kW.



Figure 14: Polar Night Energy Kankaanpää site

Pornainen: The First Large Scale Sand Battery

Loviisan Lämpö invested in Polar Night Energy's Sand Battery in Pornainen. This project is a large scale (100MWh energy storage capacity) Sand Battery project. The system has a power capacity of 1MW. The project aims to use the sand battery energy storage to reduce energy produced by combustion and eliminate the use of heating oil and expects to reduce CO2 emission by 70%.

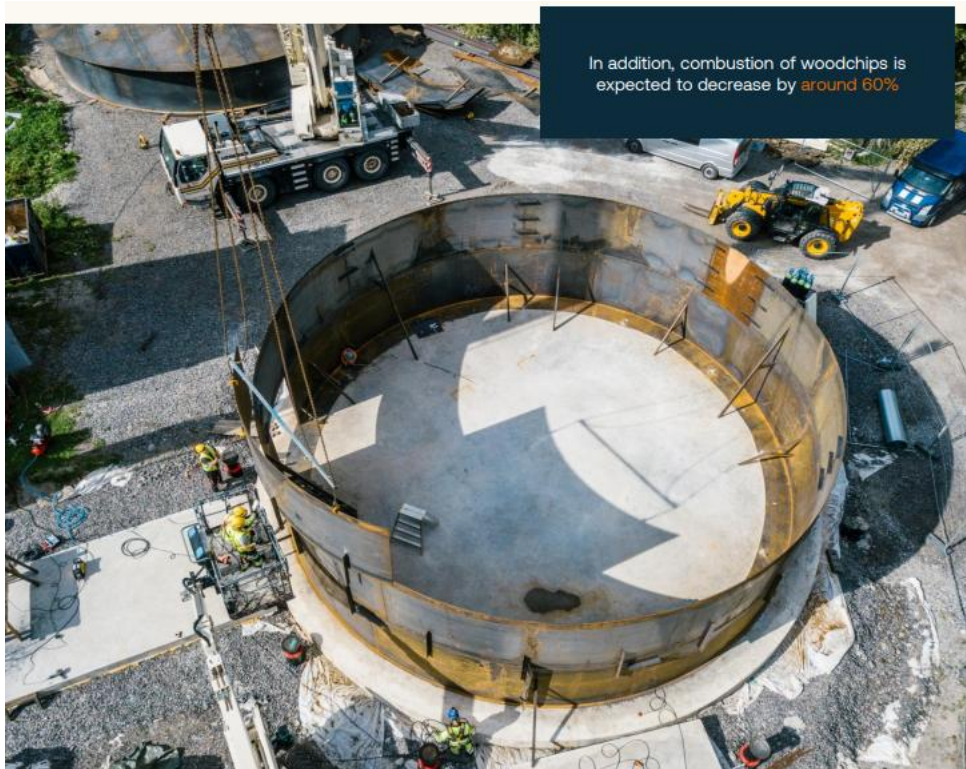


Figure 15: Construction of the Sand Battery (source: Polar Night)

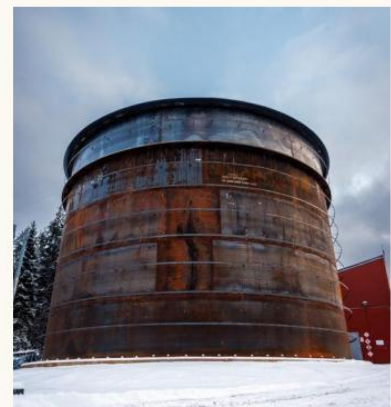
Pornainen



The storage unit was filled with 2,000 tons of crushed soapstone in October.



The roof and the upper wall section were lifted in place as a single unit.



The structure is finished and waiting for insulation and outside paneling.

4. Latent Store: Phase Change Material Case Studies

4.1. Molten Salt Case Study

4.1.1. The Crescent Dunes CSP project (Nevada, USA)

Thermal Energy Storage Capacity	10 hours heat storage at 110MW
Temperature range of thermal storage	400-565°C
Storage medium	Salt mix (sodium nitrate and potassium nitrate) (molten under liquid form)
Type of heat store	Latent
Use of Heat	Electricity production (steam turbine)
Link with Electrical Grid Network Flexibility	CSP plant use thermal storage to generate dispatchable electricity (110MW)
Contact	Cobra

The Crescent Dunes CSP plant in Nevada was the world's first full-scale tower concentrating solar power (CSP) project to include thermal energy storage. The plant uses a 10-hour molten salt storage system with a 110 MW capacity. Molten salt — a mix of sodium nitrate and potassium nitrate — is heated to around 565°C and stored in a large tank. The stored heat is used to generate steam, driving a turbine to produce electricity. The system can store enough solar energy to generate about 1,100 MWh per day, with molten salts losing only about 1°C of heat per day, making long-term storage possible.

Developed by SolarReserve, a RocketDyne-based startup, Crescent Dunes secured a power purchase agreement (PPA) with NV Energy to deliver dispatchable solar energy. However, as a first-of-its-kind project, it faced significant technical issues, leading to reduced output and a shutdown in 2020. This ultimately bankrupted SolarReserve and halted its future projects in Australia, South Africa, and Chile. The plant was restarted in mid-2021 by Cobra, the project's Engineering, Procurement, and Construction (EPC) contractor. (Adapted from SolarPACES website²³)

²³ SolarPACES website, "What happened with Crescent Dunes?" (Article released in August 2023), <https://www.solarpaces.org/what-happened-with-crescent-dunes/>



Like the first samples of other new energy technologies, the first full-scale CSP tower with thermal energy storage had a shaky start. Photo ©2015 Jamey Stillings

Figure 16 The Crescent Dunes CSP plant overview²³

One of the main advantages of molten salt thermal storage is its ability to store much more energy as heat compared to conventional electrical batteries charged by solar PV or grid electricity. During the day, the molten salt is kept as hot as possible, storing excess solar energy. Only the additional energy that cannot be stored is discharged and sold. Solar thermal storage becomes critical at night when PV panels no longer produce electricity and battery backups often cannot meet demand.

This technology — concentrated solar power (CSP) towers with molten salt — requires specialized equipment as its main value is when used in tandem with a steam turbine to create electricity on demand. After the molten salt is heated, it transfers its heat to water through a heat exchanger. The system then operates like a traditional steam plant using a standard Rankine cycle, which includes a reheater, economizer, and superheater. These components are essential to improve thermodynamic efficiency.²³

4.2. Residential Phase change material heat storage case study

4.2.1. Sunamp system for Thurrock social housing residents

Thermal Energy Storage Capacity	Not specifically mentioned
Temperature range of thermal storage	-30°C to around 118°C ²⁴
Storage medium	Plentigrade P58 phase change material
Type of heat store	Latent store
Use of Heat	Residential hot water
Link with Electrical Grid Network Flexibility	TES alimented by a heat pump, no specific flexibility uses mentioned
Contact	Sunamp



Figure 17 Example of residential Thermino heat battery installation²⁵

Thurrock Council and Kensa Contracting replaced old night storage heaters with ground source heat pumps and Thermino heat batteries in three tower blocks in Chadwell St Mary. The upgrade covered 273 social housing flats, aiming to provide a cheaper and more efficient heating solution for tenants, many of whom were struggling with energy bills exceeding £3,000 a year.

The new system had to be compact, easy to use, and minimally disruptive during installation. Boreholes drilled in the car park collect ambient ground heat, which is distributed through the buildings to small heat pumps installed in each flat, providing radiator heating. Hot water is supplied at mains pressure via compact Thermino heat batteries.

The project secured £2.3 million from Wave 1 of the Social Housing Decarbonisation Fund, becoming the largest ground source heat pump scheme to receive funding at that time in the UK.

(Adapted from Sunamp.com website)²⁶

²⁴ Potential range from the Thermino heat batteries

²⁵ Sunamp website, Case Studies (last checked 06/05/2025), <https://sunamp.com/case-studies/sunamp-transforms-a-brooklyn-studio-with-low-carbon-heating-and-hot-water-solution/>

²⁶ Sunamp website, Case Study : Cutting fuel poverty and carbon emissions for Thurrock social housing residents (last checked 08/04/2025), <https://sunamp.com/case-studies/thurrock-residents-cut-costs-and-carbon/>

4.2.2. Thumb Up project FractLES concept

Thermal Energy Storage Capacity	Individual modules of either 9kWh or 14kWh each (total validation & demonstration of 230 kWh)
Temperature range of thermal storage	14-20°C for cooling and 30-65°C for heating/DHW (directly charged by existing H&C facilities)
Storage medium	PCM derived from sustainable raw materials
Type of heat store	Latent
Use of Heat	Residential space heating/cooling and domestic hot water / Interconnections with District heating
Link with Electrical Grid Network Flexibility	The FractLES are mainly designed to be installed in H&C facilities mainly sourced by HPs, enhancing the Power-to-Heat (PtH) approach. It can also integrate own PtH solutions to boost the charging if necessary. These solutions bring inertia to the facilities, leveraging the availability of renewables and adding flexibility to the operation. The optimal operation and coordination of the installations will be supported by the CARTIF&RISE BEMS controlling strategies.
Contact	ThumbsUp Project Team: emilia.pisani.berglin@ri.se guillermo.andres-nieto@veolia.com

The Gothenburg pilot site of the ThumbsUp project will test the FractLES system latent thermal energy storage based on phase changing materials (PCM), from current information Codema could gather the pilot is planned but still in implementation phase. This technology aims to increase the energy efficiency and grid flexibility of buildings.

The pilot site is a multifamily building mainly occupied by students, with 29 flats and 34 residents across five floors, plus a rooftop and ventilation plant area. Flats are located on the north and south sides of a central stairwell, with service access from the stairwell. The building was purpose-built for testing new technologies, with all residents agreeing to participate in research activities. It is highly data-rich, with energy, occupancy, and weather monitoring from individual apartments up to the building's connections to the energy grids.

Current energy sources include a district heating network (DHN) connection with a 122kW heat exchanger, 14 kWp of solar PV on the roof and walls, two 9 kW air-source heat pumps (ASHPs), and borehole heat exchangers. Radiator heating uses a maximum flow temperature of 50°C, while the floor heating circuit operates between 35–40°C. On average (2018–2021), the building used 60 MWh of heat from the DHN and consumed 86 MWh of electricity annually.

The pilot will install five FractLES units for heating at the apartment level (9 kWh each, 45 kWh total storage) and four centralized FractLES units (14 kWh each, 56 kWh total storage) for DHW running alongside the DHN connection.

Operations will be optimized by RISE's Building Energy Management System (BEMS) strategies. WECOMP thermos-economic tool will be applied in the design phase of the validation and the GRADY tool will support optimizing the interaction between distributed thermal energy storages (TESs) and the DHN. (Adapted from Thumb Up project website²⁷)

²⁷ ThumbsUp project," Gothenburg Sweden: FractLES Pilot.", <https://www.thumbsupstorage.eu/lab-life/demonstrate/gothenburg-multi-family-building>

5. Thermo-chemical Heat Storage Case Studies

5.1. ThumbsUp project SorTES concept

Thermal Energy Storage Capacity	Storage modules of 20kWh each (total validation & demonstration of around 100 kWh)
Temperature range of thermal storage	10-50°C for either heating and cooling (directly charged by its own PtH technology)
Storage medium	Thermochemical Materials (TCM)
Type of heat store	Thermochemical
Use of Heat	Residential Space heating and cooling
Link with Electrical Grid Network Flexibility	The SorTES will be charged by integrated PtH solution to exploit onsite PV rooftop renewables as well as electricity from the grid, to increase the operation flexibility
Contact	ThumbsUp Project Team: emilia.pisani.berglin@ri.se guillermo.andres-nieto@veolia.com

The Valladolid site of the ThumbsUp project will notably intend on demonstrating thermochemical materials (TCM) sorption technology, from current information Codema gathered that the pilot is still in implementation phase. These materials are designed to be environmentally friendly and are derived from non-hazardous substances.

Constructed in 2021, this pilot project is a single-family home occupied year-round by two people. The two-floor building has a total area of around 165 m² and holds an A rating on the Energy Performance Certificate (EPC).

The house uses an air-to-water heat pump connected to a radiant floor system for both heating and cooling, and also provides domestic hot water (DHW). A rooftop solar PV system is installed. Annual energy demand is 1.3 MWh for heating, 1.8 MWh for cooling, and 2.1 MWh for DHW. Each room has a digital programmable thermostat that controls the temperature individually through the radiant floor circuit.

The project plans to install a SorTES (sorption-based Thermal Energy Storage) unit with a target capacity of 60 kWh to support heating and cooling needs. The SorTES will be charged using a power-to-heat (PtH) system powered by rooftop solar PV and grid electricity to enhance operational flexibility.

Additionally, one FractLES unit (9 kWh) will be installed for DHW. This short-duration storage unit will complement the long-duration SorTES and help balance daily energy demand. System optimization will be managed by CARTIF's Building Energy Management System (BEMS), and the WECOMP thermo-economic tool will guide the design phase (Adapted from ThumbsUp project website²⁸).

²⁸ ThumbsUp project," Valladolid, Spain: SorTES Pilot." <https://www.thumbsupstorage.eu/lab-life/demonstrate/valladolid-single-family-building>

5.2. RedoxBlox Case Study

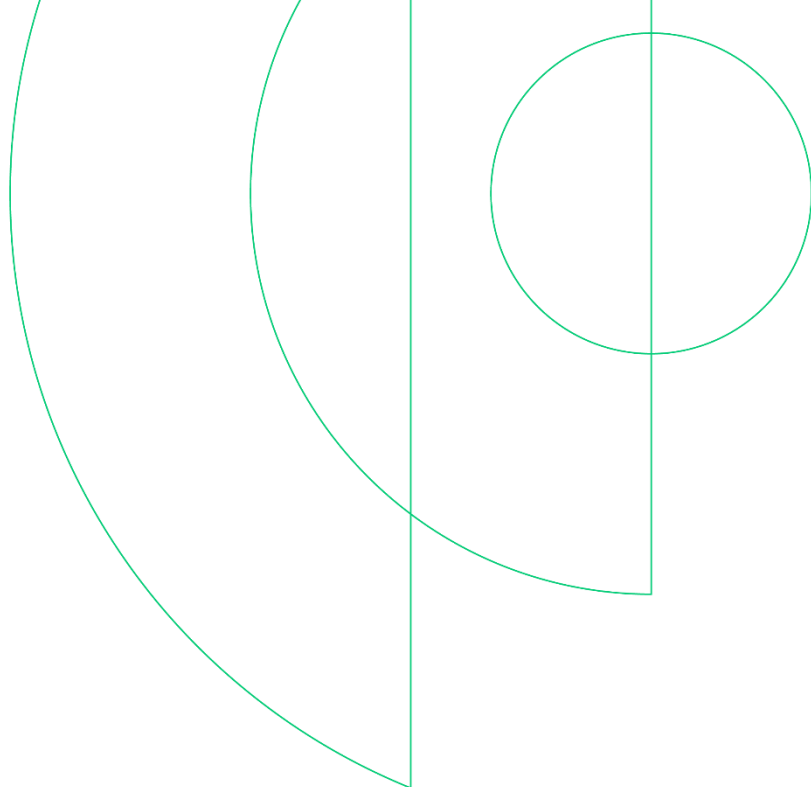
Thermal Energy Storage Capacity	Unknown
Temperature range of thermal storage	Up to 1,500°C
Storage medium	metal oxide pellets triggering a chemical reaction that releases oxygen and stores heat in the form of chemical energy
Type of heat store	thermochemical energy storage (TCES) (+sensible heat)
Use of Heat	Industrial Heat (Food & Dairy sector)
Link with Electrical Grid Network Flexibility	System controlled by VIOTAS (aggregator)' Demand Response platform
Contact	RedoxBlox

Arrabawn is introducing an innovative heat battery technology — the first of its kind in Ireland and in the global Food & Dairy sector.

The system, known as RedoxBlox, will have its electricity consumption managed by VIOTAS' Demand Response platform, ensuring it charges at optimal times when renewable energy generation on the grid is high. The RedoxBlox technology stores renewable electricity as thermochemical energy and releases it as heat when needed. Because it can deliver heat at very high temperatures, it offers a direct alternative to natural gas for industrial heat applications.

(Adapted from Viotas website²⁹)

²⁹ Viotas, Article: "VIOTAS Joins Forces in Pioneering Collaboration to Propel Sustainable Energy Solutions" (released in November 2023) <https://viotas.com/viotas-joins-forces-in-pioneering-collaboration-to-propel-sustainable-energy-solutions/>



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