Thermal Energy Storage

Brussels, September 2023

Thermal Energy Storage

Table of Contents

1. Introduction

This paper aims to shed light on the numerous benefits of thermal energy storage (TES) by providing an overview of technologies, inspiring projects, business cases, and revenue streams. Policy recommendations are also discussed.

In 2021, renewable energy made up 37% of the EU's electricity mix, and it is projected to reach 69% by 2030. As the European Union (EU) strives to achieve climate neutrality, address security of supply concerns, and combat high energy prices, renewable energy sources will progressively assume a more substantial role in the energy landscape.

The growing proportion of renewable energy in the existing power, heating, and cooling infrastructure presents a unique set of challenges. Operational variability, grid stabilisation, balancing, and demand response management emerge as crucial areas requiring attention. Consequently, it becomes imperative to explore effective strategies to tackle these challenges and ensure the seamless integration of renewable energy sources into the energy system.

Half of European energy consumption goes to heating and cooling, and around 89% of this demand is supplied by fossil fuels, most notably natural gas. Gas consumption shifted significantly since the invasion of Ukraine and the energy crisis that followed. However, the residential sector still accounts for most of its demand (50%), followed then by industrial use of gas and power which, according to the latest data, decreased by 20% since 2000.

Energy demand both in industry and domestic households, including buildings, typically follows a pattern of demand that can be burdensome for the energy grid during peak times and that may in some cases even cause energy supply interruptions. Thermal energy storage, alongside renewables, plays a key role in addressing these energy supply challenges while decarbonising the grid.

2. Technology Overview

Within the Clean Energy Package (CEP), the European Commission provided a definition for energy storage. This definition encompasses all types of energy storage currently available. For the purposes of this paper, a specific definition for thermal energy storage, based on definition of energy storage in the CEP, is proposed:

Thermal Energy Storage, as <u>one of the energy storage technologies</u>, refers to means of deferring the final use of thermal energy (or of electrical energy through thermal means) to a moment later than when it was generated, or the conversion of any form of energy into a form of energy which can be stored, the storing of such energy, and the subsequent reconversion of such energy into electrical or thermal energy.

Three different thermal energy storage principles can be observed: **sensible heat storage, latent heat storage, and thermochemical heat storage.** These technologies store energy at a wide spectrum of temperatures, for different temporal ranges, and are able to meet a variety of energy system needs.

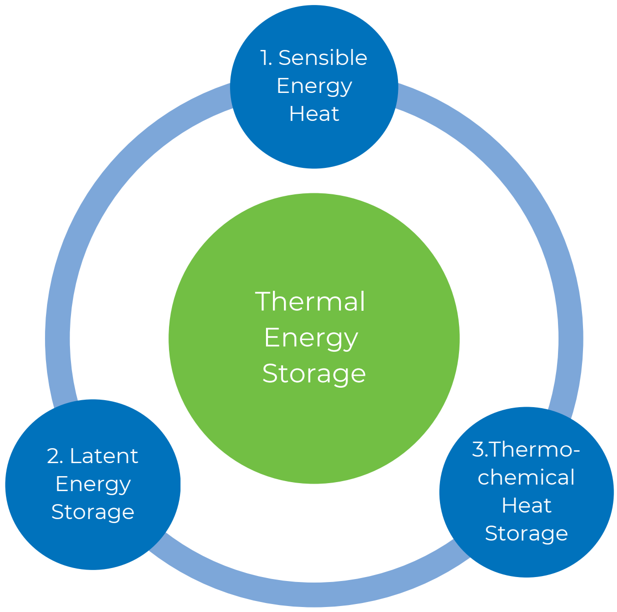


Figure 1: The major types of Thermal Energy Storage, EASE, 2023

1. Sensible heat storage (SHS) raises or lowers the temperature of a liquid or solid storage medium (e.g., water, sand, molten salts, graphite, rocks, with water being the cheapest option) in order to store and release thermal energy for applications of low to very high temperatures. This is the most common form of thermal energy storage and has found commercial success on residential and industrial scales. Energy storage temperature ranges from <0°C-2400°C for a duration that can range from minutes up to (in the case of low-temperature storage, eg. underground water storage) months.

2. Latent heat storage (LHS) uses a phase change material to absorb and store thermal energy at a constant temperature during the off-peak via melting and then releases the stored thermal energy during peak-demand time as it solidifies. This can store heat at temperatures ranging from <0°C-1600°C for a duration of hours to days.

3. Thermochemical heat storage (TCS) operates in two ways: chemical reactions and sorption processes. In the former, energy is stored as the heat of reaction of reversible reactions. The latter stores thermal energy either through adsorption (physical bonding) or absorption (uptake/dissolution of a material). TCS technologies can store thermal energy at temperatures ranging from <0°C-900°C, typically for a duration of hours to days, or potentially even up to months.

TES encompasses a broad variety of technical applications and multiple storage technologies:

Table 1: Thermal Energy Storage technologies and their use cases, EASE, 2023

Measure	Article	Description	Examples
1. Heat-to-heat	Heat → TES → Heat	In standard thermal storage, heat is stored and later released as heat.	Waste Heat recycling Storage for district heating
2. Heat-to-power	Heat → TES → Power	Heat is stored, converted and then released as electricity.	Waste heat Recovery
3. Power-to-heat	Power → (Conversion) → TES → Heat	Electricity is converted into heat, which is stored and later released as heat.	De-carbonisation of industrial process Domestic and district heat electrification
4. Power-to-heat-to-power	Power → (Conversion) → TES → (Conversion) → Power	Electricity is converted into heat, stored, and later converted back into electricity.	·Grid scale energy storage De-carbonisation of industrial energy and heat
5. Thermal-base-power-to-X	Power → (Conversion) → TES → (Conversion) → X	Electricity is converted to something else (X). The 'X' created is an energy carrier. Can also be used to describe processes like electrolysis for which thermal aspects are not essential for the deferral / storage / reconversion of energy (these processes are therefore excluded from the definition of TES and are not elaborated in this paper).	Domestic and district heat electrifica-tion

2.1. Storage Duration Use Case

Energy storage duration is primarily determined by the commercial requirements. Any thermal technology can have its storage duration extended based on overall system design and increased insulation. With that in mind, the following table provides an overview of the storage duration use case per type of the TES technology:

Table 2: Overview of current storage duration use case per type of Thermal Energy Storage technology, EASE elaboration of LDES Council report, 2023

TES Technologies according to their types	Storage duration use case			Current marketed power *
	Hours	Days	Week	MW
Most technologies able to serve intraday to multiday durations, with several able to serve up to months (e.g., water):				
Sensible Heat				
Graphite				
Ceramics, silica and sand				1-200
Molten Salts				1-300
Concrete				400
Rocks				>20
Steel				
Underground water				
Water				>100
Most technologies serve intraday to multiday durations:				
Latent Heat				
Microencapsulated metals				
Inorganic salts and eutectic mixtures				
Sodium				
Other liquid metals				
Molten aluminium alloy				0.1-300
Paraffin waxes, fatty acids				
Salt hydrates				
Salt-water mixtures				
Ice				
Liquid air				>100
Potential to serve intraday durations up to months:				
Thermochemical Heat				
Chemical Reaction Storage				
Absorption				

**The EASE Secretariat would like to highlight that the information within this table is based on preliminary research and is subject to further development.*

18 out of 20 TES technologies favour to store energy for hours which enables them to serve intraday to multiday durations. 17 out of 20 (85%) favour to store energy for days, ensuring multiday durations, while 5 out of 20 (25%) favour to store energy for weeks, some for months.

2.2. Technology Readiness Level

Technology readiness levels (TRL) are a measurement system used to assess the current maturity level of a particular technology. An overview of TES technologies with their TRL is presented in the table below:

Table 3: Overview of Thermal Energy Storage technologies with their Technology Readiness Levels, EASE elaboration of LDES Council report, 2023

TES Technologies according to their categories	Technology Readiness Level		
	1-3	4-6	7-9
Most technologies already commercially available with track record of pilots and use cases:			
Sensible Heat			
Graphite			
Ceramics, silica and sand			
Molten Salts			
Concrete			
Rocks			
Steel			
Underground water			
Water			
Large range of technical maturity, with some already commercially available and others in the R&D phase:			
Latent Heat			
Microencapsulated metals			
Inorganic salts and eutectic mixtures			
Sodium			
Other liquid metals			
Molten aluminium alloy			
Paraffin waxes, fatty acids			
Salt hydrates			
Salt-water mixtures			
Ice			
Liquid air			
Relatively nascent with most technologies in the R&D or pilot phase:			
Thermochemical Heat			
Chemical Reaction Storage			
Absorption			

1–3 include technologies up to experimental proof of concept; 4–6 include technologies up to demonstration in the relevant environment; 7–9 include technologies up to proof in operational environment.

Note that there are significant differences of maturity between some of the TRLs indicated in the table columns above, for example, there are strong differences between 7 and 9.

As can be seen from the table above, 11 out of 20 TES technologies (55%) are already commercially available with a track record of pilots and use cases. 8 of them (40%) are in the later phases of R&D where they are already proving themselves in the operational environment, while only one of them (5%) is considered to be in the pilot phase.

Given the overall high technology readiness level, there is no reason to delay TES deployment. The technology has already been proven in various applications that will be discussed in the next section of this paper. With the benefit of TES being clear, it is ready to be scaled up and deployed at a large scale.

2.3. Thermal Energy Storage Placement in the Energy System

TES can roughly be divided into *centralised systems* – where TES directly serves the grid or large-scale application – or *distributed systems* – where TES primarily serves an end-user in the energy system.

The difference between the two is the customer(s). In the *centralised system*, the customer is a TSO or a utility, whereas for the *distributed system*, the customers are industries/privates. Centralised applications can typically be applied in district heating and cooling systems, large industrial plants, combined heat and power plants, power generators and industrial-grade/utility-scale High Temperature Heat Pumps (HTHP). It is common for a centralised system to be used in a power-to-X scenario.

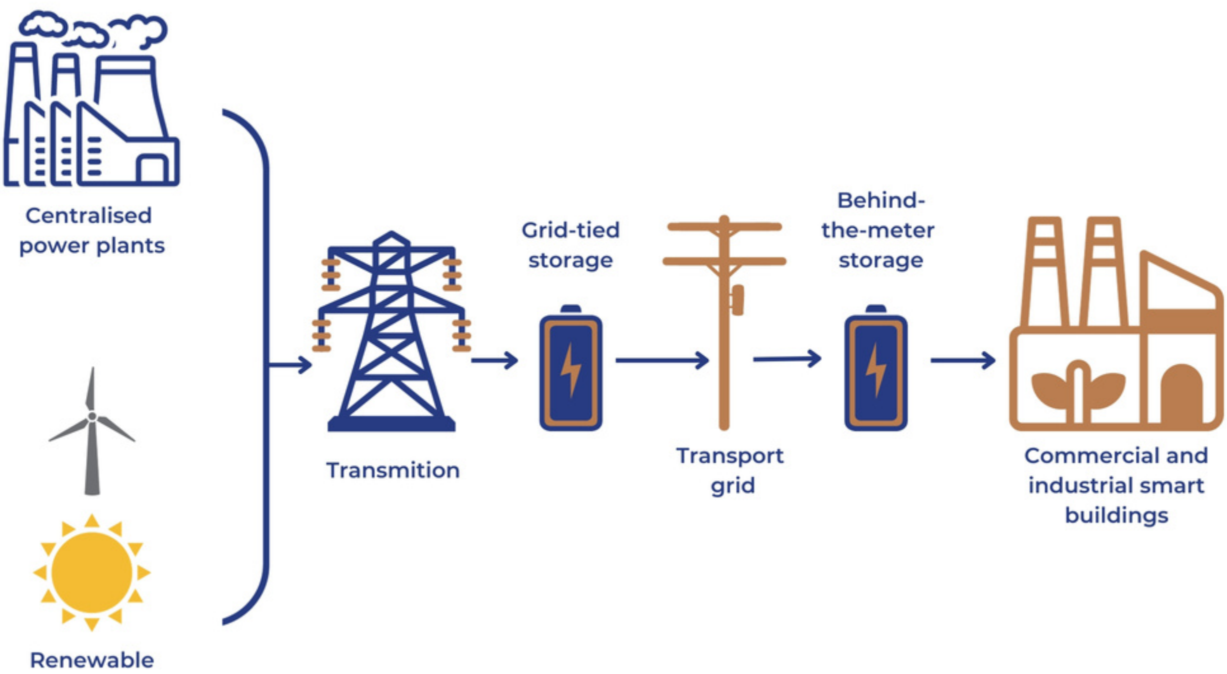


Figure 2: EASE elaboration on Sample system design and interconnection, The Pew Charitable Trusts: Energy Smart Technologies in the Evolving Power System, 2016

TES *distributed systems* are mostly applied in domestic, commercial and industrial buildings for water and space heating or cooling, or also in combination with heat pumps. Distributed systems have changed the way industrial heat is delivered by utilising a network of interconnected components, such as boilers, heat exchangers, and pipelines, to efficiently generate and distribute heat across large industrial facilities. Additionally, by integrating behind-the-meter renewables, distributed systems can also contribute to reducing carbon footprints and promoting environmental sustainability.

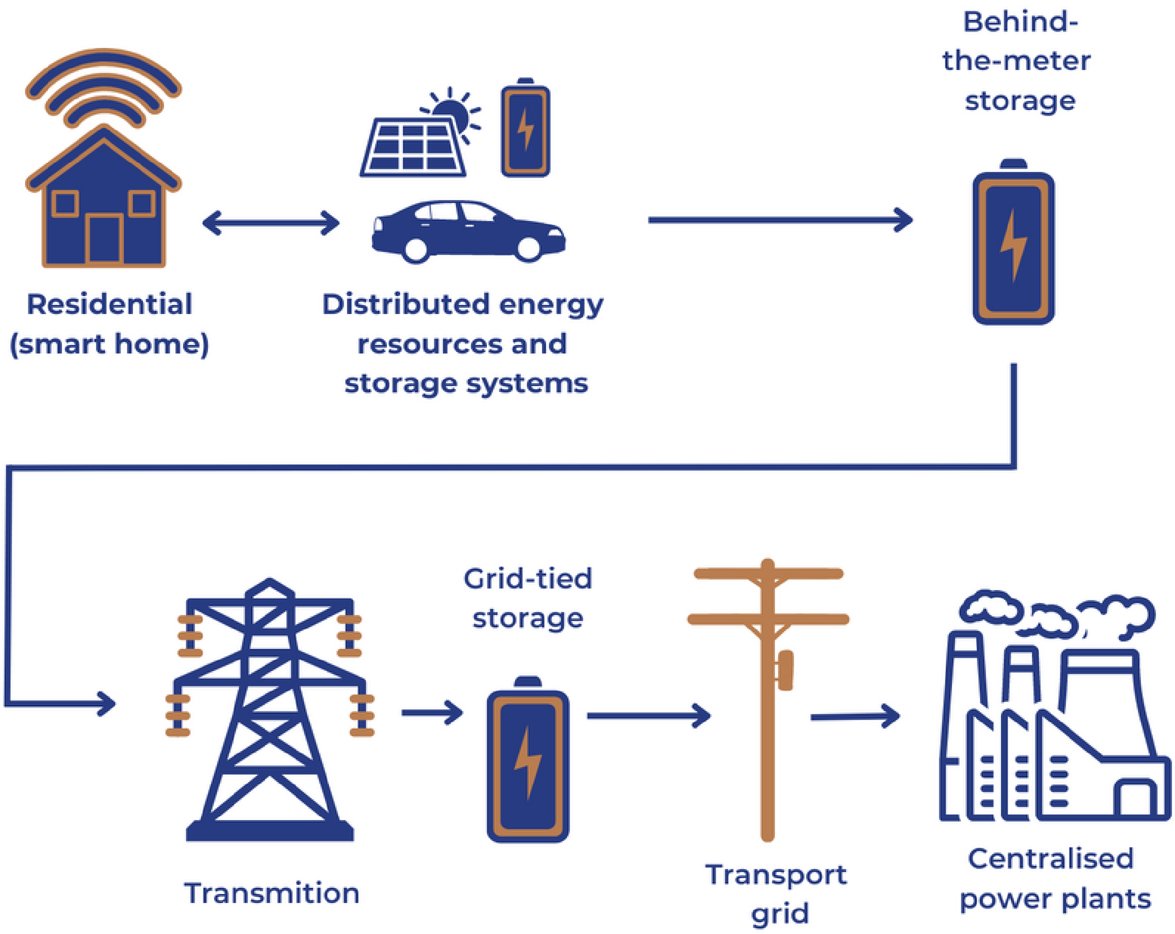


Figure 3: EASE elaboration on Sample system design and interconnection, The Pew Charitable Trusts: Energy Smart Technologies in the Evolving Power System, 2016

Both *centralised* and *distributed* thermal energy storage systems empower self-consumption or prosumers across the energy sector, including industrial, residential, community, commercial, and public prosumers.

3. The Added Value of Thermal Energy Storage

TES is uniquely positioned to contribute to electrification of heating and cooling systems while furthering renewable power generation by providing energy and heat flexibility. The table below provides an overview of services provided by TES within different markets:

Table 5: Overview of Thermal Energy Storage services and market participation, EASE, 2023

Market 1: Electricity[1]	**Service 1: RES Integration** ✔ **Accelerate Renewable Growth:** TES compensates for the intermittency of renewables, allowing for the energy transition to continue and even accelerate to meet the EU's renewable energy and climate targets. Certain TES can store excess renewable energy for hours and up to weeks and (for certain technologies such as sensible heat storage in underground water, without power output) even up to months, which can be an important tool to push renewable integration beyond 60%. TES can store excess renewable energy for hours and up to weeks, which would otherwise be curtailed. ✔ **Decrease Dependence on Fossil-Fuels generation:** in a situation with abundant excessive RES power generation, TES allows those energy systems to cut back their dependence on increasingly costly and volatile fossil fuel and EU carbon markets by replacing carbon-emitting fossil-fuel generation with stored renewable energy. ✔ **Reduce Curtailment:** Depending on the roundtrip efficiency, TES systems can firm the capacity of intermittent RES by storing excess energy during periods of high generation and delivering it when renewable generation is low or unavailable. ✔ **Reduce Grid Congestion:** Currently, the EU wastes enormous quantities of RES due to overproduction and grid congestion. Combining TES technologies with RES would provide a valuable addition to Europe's toolbox for decarbonisation solutions, supporting system efficiency through reduced energy curtailment.
	Service 2: Grid-Scale Flexibility ✔ **Security of Supply:** TES provides energy security (especially in longer duration applications) through storing grid-scale, renewable energy and optimising the use of home-grown energy. ✔ **Maximising Existing Grid Infrastructure:** TES can stabilise the grid and defer the need for maintenance on infrastructure, if operated in a grid-driven way (rather than market-driven). ✔ **Decrease Dependence on Fossil-Fuels Flexibility:** Flexibility is still extensively provided by fossil fuels, mostly gas turbines. TES technologies represent a green alternative.

[1] Note : Other storage and flexibility technologies exist and (similarly to TES) could also provide a non-neglectable contribution to the flexibility mix in providing these services to the electricity system.

	Service 3: Ancillary Services ✔ **Energy Arbitrage:** TES systems can participate in wholesale energy markets by buying electricity during periods of low demand and low prices, or even negative prices, and selling it back to the grid during periods of high demand and high prices. This practice, known as Energy Arbitrage, allows TES to benefit from price differentials. As a downside however, again, serious competition from other power storage technologies needs also to be considered here, not only for energy arbitrage but also for all ancillary services. ✔ **Frequency Services:** Certain TES can rapidly respond in seconds to grid fluctuations to keep the grid's frequency stable. ✔ **Load Following:** Through adjusting its output, TES can relieve local congestion when demand dips. ✔ **Stable Inertia:** participate in a variety of ancillary services to the grid, such as Frequency Containment Reserve (FCR), inertia and others. ✔ **Additional Revenue Streams:** TES assets can earn revenue by stacking ancillary services to their business model.
Market 2: Heating & Cooling	**Service 1: Decarbonising Industrial Processes** ✔ **Decrease Dependence on Fossil-Fuels:** TES could allow industry to cut back on use of volatile fossil-fuel commodity markets for their industrial processes and reduce overall production costs. ✔ **Customised Thermal Energy Needs:** Various heating capacities and utilities like steam, process air, and hot water are required for different industrial processes for which different TES technologies can be applied. ✔ **Optimising Electrified Heating and Cooling:** TES could allow for electrified industrial grade heating and cooling solutions to capitalise on off-peak pricing to reduce production costs. ✔ **Waste Heat Recovery:** TES can optimise thermal energy emitted by industrial processes to be used again in energy systems rather than being emitting as waste.
	Service 2: Decarbonisng Heating and Cooling ✔ **Decrease Dependence on Fossil-Fuels:** TES and electrification could allow for a cost-competitive elimination of fossil-fuel consumption for heating and cooling. ✔ **Single-Building Energy Storage Systems:** TES can be used behind-the-meter in buildings for heating and cooling alongside providing consumer energy management services such as end-user peak shaving, maximising prosumer participation, demand-side management, etc. ✔ **Secure District Heating & Cooling:** TES systems (Underground TES, tank, and pit storages) can be used to provide large-scale heat flexibility and security of supply on an hourly, daily, or seasonal basis in district applications. ✔ **Optimising Electrified Heating and Cooling:** TES could allow for electrified heating and cooling systems (heat pumps, electric heaters, etc.) to optimise their operational and cost performance through minimising overuse and capitalising on off-peak pricing. ✔ **Waste Heat Recovery:** TES could optimise thermal energy waste in certain residential and commercial applications by shifting it to be reused and reduce overall energy consumption.

Market 3: Combined/Post -Fossil Markets	**Service 1: Combined Heat and Power (CHP)** ✔ **Combined products:** CHP coupled with TES can allow for concurrent participation in both electricity and thermal energy markets, which can contribute to providing consumers access to unique, cleaner energy products. ✔ **Diversification and Stacking of Revenue:** CHP services enables a TES asset to stack revenues from multiple energy markets and adjust output based on the demand of multiple energy markets. Consequently, this diversifies their revenue streams and mitigates any overexposure to market shocks from a singular market.
	Service 2: Repurposing Stranded Assets ✔ **Post-Fossil Power Plants:** TES can be integrated with the steam cycle of decommissioned fossil power plants and breathes a second life to otherwise potentially stranded assets. ✔ **Just Transition in Regions:** The repurposing of decommissioned power plants enables for a just transition in regions traditionally dependent on fossil fuels into clean power regions. This keeps energy generation in these regions and curbs relocation of energy sources.
Market 4: Energy Efficiency	**Service 1: Boosting Energy Efficiency** ✔ **Cost Savings:** Through the storage of thermal energy (minus losses), especially waste heat, TES reduces the overall generation of thermal energy in the first place which makes for reduced costs across the energy system. ✔ **Cutting Back Carbon Costs:** TES could allow various industry sectors (food and beverages, pulp and paper, hard-to-abate etc.) to cut back dependence on an increasingly costly and volatile EU carbon market.

4. Business Cases

The list of projects and providers provided in this chapter is not exhaustive.

4.1. Residential, Commercial and District Heating

Thermal energy storage aids operational performance in urban areas for electrical grid demand shifting operations. This demonstration also investigated a new market option for electricity transmission system operators (TSOs) to benefit from day-ahead electricity trading and use low price benefits to sell renewable energy in form of heat in local district heating networks. This way, electrical grid peak demand can be lowered by shifting demand to nighttime when the demand is lower and within high supply time zones.

4.1.1 Decarbonisation of the Office Building in Turkey

The system has the benefit of direct application to old and historical buildings with a minor change in the building heating system. This enables the replacement of fossil-based boilers with thermal storage units. The system becomes economically feasible when the grid operators can directly involve heating schemes through thermal storage units as peak shifting products for the grid. Currently, the average daily price of electricity in Turkey is capped at 209.5 Euros/MW by the regulatory authority, yet average prices during the night drops down from 30 Euros/MW to 20 Euros/MW as wind power share increases in power generation. These lower renewable energy prices make the demonstration economically feasible and can help to decrease peak loads that are increasing due to the electrification of heating. One of the targets for the pilot is to investigate new revenue stream possibilities for heat trading by TSOs to their current electricity customers. This approach can contribute to the development of energy trading regulations by offering sectoral integration options.

Local TSO's office building, which acts as an innovation hub in İzmir city centre, will be used as a demonstration site. The area is highly dense with office buildings with peak electricity loads in daytime straining local gird sources. A solid phase 0.6 MWe thermal energy storage unit developed will be used for electrical grid and thermal grid integration, and act as a peak shifting product for the local grid. Utilisation of TES systems integrated to electrical grid to supply heat to district or local thermal grids also supports the Energy Efficiency and the Energy Performance of Buildings Directives. This is done by promoting the decarbonisation of heating and cooling in the building sector and supporting EU efforts on renovation and greening buildings.

İzmir city center

4.1.2. Reducing Wind Curtailment Through Sector Coupling Using TES in a District Heating Scheme in China

A collaborative project led to a successful commercial demonstration pilot to integrate TES into a district heating scheme using Composite Phase Change Materials (cPCMs) in the Chinese region of Xinjiang. The project was driven by the need to address the intermittency of renewables and network constraint challenges caused by a high penetration of renewable wind and combined heat and power district heating schemes. Local electricity demand is low in Xinjiang, and the majority of the renewable generation is utilised in geographically distant load centres. However, the low demand and network constraints meant that curtailment rates were as high as 40% in 2016. As a result, central and local government investigated routes to improve renewable utilisation rates. Heat decarbonisation was also on the government's agenda and support was provided through feed-in tariffs. There was also high volatility in electricity prices. A key part of their solution has been end-use coupling and converting excess renewables into heat that is stored using a thermal storage system. This is a good example of a technological solution being used to remedy a challenging regulatory environment. A 6 megawatt/36 megawatt hour (MWh) demonstration plant using high-temperature cPCMs has been operational since October 2016. This plant charges during off-peak hours, when the price of electricity is half of what it is during normal hours. Furthermore, it is estimated that over 80% of this electricity, or over 5 000 MWh per year, is wind generation that would otherwise have been curtailed. This facility has been successfully harnessing excess electricity from local wind generators, reducing wind curtailment, relieving network constraints and storing decarbonised heat. As a result of the success of the pilot, a further 20 plants have been constructed and are in operation across China.

4.1.3. Smart Refrigeration Providing Demand-Side Management Services at Commercial Retail Sites

Refrigeration aisle in supermarket

This project delivered smart refrigeration in retail sites to provide a peak-shaving service in the United States. An innovative American company is using PCMs to provide energy management solutions for supermarkets and commercial buildings with high refrigeration-based energy loads. Their product is a refrigeration battery that works by storing low-cost off-peak electricity in a frozen saltwater solution at night, then, during peak hours, when electricity and demand charges are highest, the system discharges to provide cooling. This significantly reduces peak load for the building. A cloud platform evaluates the energy use and electricity rates to optimise system operation and maximise savings. Indeed, the California Demand Response Auction Mechanism allows customers of the state's largest utilities to generate revenue from the power they can reliably offset during periods of high-grid demand. To date this product has been deployed twice at pilot scale for two major US supermarket chains.

4.2. Waste Heat Recovery with Thermal Energy Storage

Within various industry, more than 11.000 TWh a year is used for delivery of heat below 500°C. TES can be combined with waste heat recovery systems in industries where significant waste heat is generated. Waste heat recovery with thermal energy storage presents a compelling business case applicable to industries like manufacturing, petrochemicals, steel, pulp and paper and others. Manufacturing processes often involve the production, transformation, or treatment of materials which generates significant amounts of waste heat typically released into the atmosphere or unutilised water. By capturing and utilising waste heat, the industry can reduce its overall energy consumption and decrease its carbon intensity.

4.2.1. Steel Production and Recovery of Waste Heat in the Netherlands

Waste heat in the steel industry refers to the excess heat generated as a byproduct of various industrial processes. A project at the **steel production Ijmuiden** in the Netherlands demonstrates the potential to fully utilise the energy potential of the waste heat of the facility. A full-scale implementation throughout the facility shows impressive results: a 500 MWh TES can yield annual savings of 2.3 million GJ of natural gas (65 million Nm3) consumption and eliminate 130,000 tons of CO2 emissions, with a return of investment in less than three years.

TES systems need to be scalable to match the intensive energy demands of steel production processes. Additionally, integrating the storage systems into the existing infrastructure and processes without disrupting the production workflow is a technical challenge that requires careful planning and design.

Achieving decarbonisation requires international cooperation and a harmonisation of standards. Regulatory challenges include providing a stable policy framework and long-term planning to support the transition to decarbonisation. The decarbonisation of the steel industry could be improved and accelerated by investing in R&D of new technologies to minimise carbon emissions in steel production, including the exploration of alternative iron production methods and developing more efficient and sustainable TES and utilisation systems. This can be implemented by introducing supportive policies and financial incentives (which should however be technology-neutral and limited to situations of market failure, provide optimized societal value-for-money for the energy system, and be awarded through competitive process) to drive the adoption of low-carbon technologies in the steel industry such as carbon pricing mechanisms, tax credits for clean technologies, grants for research and development.

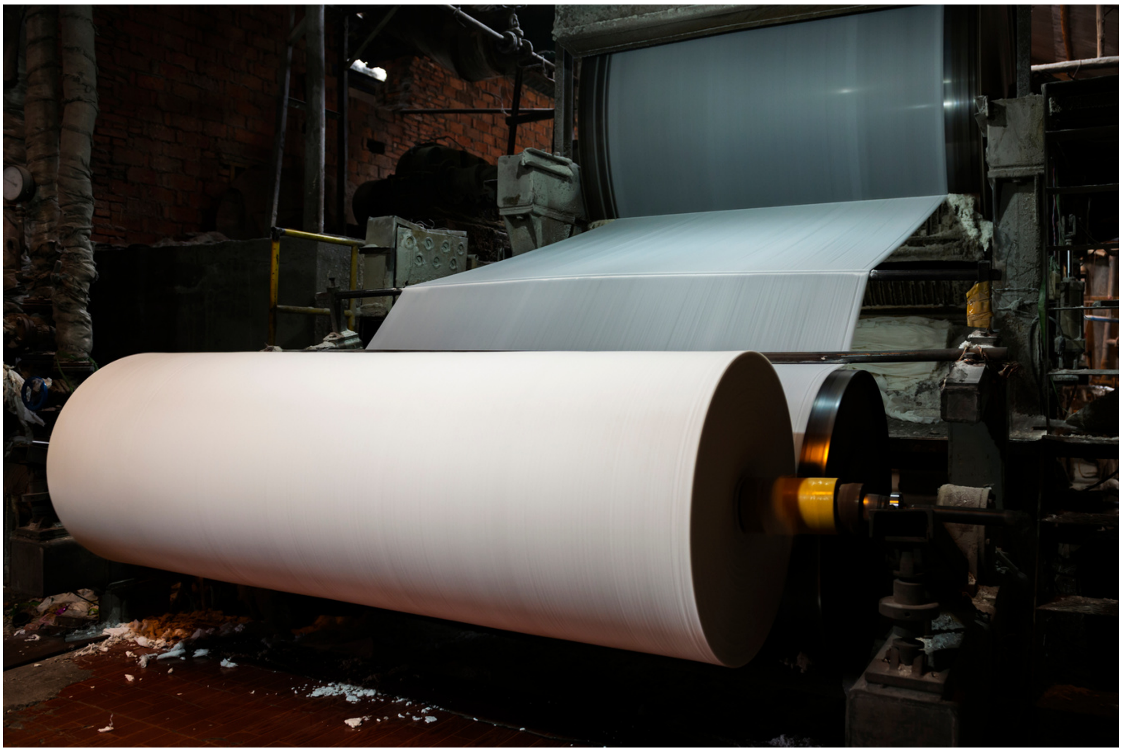
Steel production Ijmuiden

4.3. Decarbonisation of Medium Temperature Industrial Heat in Pulp and Paper Industry

The complete value of the pulp and paper industry in 2021 is assessed to be 351.53 billion U.S. dollars with expected growth. According to the International Energy Agency, within the industry, heat is used to process and dry materials with approximately 8% of the total heat demand, causing around 2% of global industry CO2 emissions. Today, natural gas CHP cycles or boilers produce most of the heat for their industrial processes. For industry decarbonisation, the heat must be electrified. The direct electrification of the industry, without a storage on the demand site, will lead to a direct exposure to the grid and electricity prices. Even with a favourable Power Purchase Agreement (PPA), congestions are possible on the grid in the peak hours which can cause electricity shortage and leave the industry exposed to potential production shut downs.

TES is offered to the customers as Heat-as-a-Service (HaaS), with no CapEx (capital expenditure) demand, but paid per MWh heat consumed. An off-grid solar PV plant will be installed and connected to the TES to further lower the price of electricity. In this case, the total heat demand is 30 GWh/year and through the electrification and decarbonisation of the customer, 6667 ton of CO2 emission can be avoided and save the customer up to 25% per MWh of heat compared to natural gas. By getting the energy needed for heat from an off-grid solution, the connection required to the grid is lowered with the cost of electricity. However, the industry cannot solely rely on an off-grid PV, as some of the present challenges to full electrification of the industry are the widespread taxation on using electricity to produce heat and the slow public funding processes. Additionally, limited know-how of the electricity market and the high uncertainty around future developments and regulations add to the challenge of decarbonizing the industry.

Incentives targeting the roll-out of TES may be put in place for mature and other TES technologies. An operational expense subsidy that would lower the electricity price if TES were placed on the demand side could give an additional upside to the business cases and accelerate the electrification of the industry. Subsidy schemes like this are already introduced in the Netherlands by the SDE++, and they could potentially be socioeconomically beneficial if replicated in other local contexts across the EU.



Paper factory

4.4. Agriculture

Heat serves various purposes in agricultural settings, encompassing livestock production, the drying of arable crops and other. Expanding operations to include offices, business centres, or leisure facilities, there is an opportunity to implement district heating systems. Yet, in order to fully capitalise on the advantages of renewable heat and reduce agricultural emissions, it is crucial to establish efficient means of transferring heat between different stages of the process.

4.4.1. Solar-Powered Green House Heating Scheme for Agricultural Industry Zone

Balıkesir Gönen Agricultural in Turkey is to be developed as a near zero emission zone. Unlike conventional agricultural heating, which is primarily drawn from fossil fuels, this zone aims to supply heat from renewables. West Turkey is rich with geothermal sources. The following challenges put a strain on efforts for expansions to the current infrastructure:

1. New geothermal wells cost at least €1.5 million with a 50% success rate to reach desired flow temperature and flow rates. Multiple operational wells are needed to ensure continuous thermal energy for fluctuations against environmental conditions.
2. Opposition from the local population against geothermal energy in west Turkey, where local geothermal sources contain up to 10% non-condensable gases. Incomplete and faulty applications have resulted in environmental damage and jeopardise the widely exported local products.

The project developer opted to add a 1MW TES unit developed. The new zone covers 800 hectares, and the system is coupled with PV panels planned for electricity supply for the industrial zone. Off-demand power generation will be stored as thermal energy up to 400 °C. In this case, thermal storage system supports local geothermal sources in following ways:

1. Eliminating drilling of new wells by increasing peak operational capacity
2. Support system during maintenance and operational emergencies

The storage system works behind-the-meter to comply with electricity market regulations. However, the main technical challenge still faced is the uninterrupted operational requirements, which without any skilled workforce to support remote operation conditions, can be quite difficult to overcome. Regardless of these, CapEx of the entire system is reduced by 45% by using thermal storage system compared to scenarios using a single geothermal source or natural gas. It is estimated that 128 tons of CO_2 emissions are prevented via the peak shaving operations of this TES application.

Agricultural zone in Turkey

4.5. Food and Beverages

Thermal energy storage plays a significant role in the food and beverages industry, enabling efficient and sustainable energy management. This industry relies heavily on refrigeration and heating processes for food preservation, processing, and storage. By implementing TES systems, excess heat generated during certain stages of production can be captured and stored for later use, reducing energy waste and optimizing energy consumption. During peak demand periods, stored thermal energy can be utilised to supplement heating or cooling requirements, ensuring consistent and controlled temperatures throughout the production and storage facilities. Additionally, TES offers flexibility by allowing food and beverage companies to take advantage of off-peak electricity rates for charging the thermal storage systems, further improving energy efficiency and cost-effectiveness.

4.5.1. Thermal Storage for Freight Containers

In 2018, academics based at the University of Birmingham (UK) Centre for Energy Storage collaborated with Chinese rail haulage maintenance and manufacturing company CRRC Shijiazhuang to demonstrate a Phase-Change-Material (PCM) based cooling system on board interchangeable road and rail units.

The system kept storage temperatures at the target of between 5°C and 12°C for up to 120 hours. The cold storage containers were transported 35 000 kilometres on road, and a further 1 000 kilometres on rails, across a range of climatic zones. The project team has noted that other haulage and transport companies have expressed an interest in the studied container. Storage temperatures are maintained more consistently in the new container than in mechanical alternatives, thus responding to the financial needs of logistics operators. Further, as the containers do not need a power supply, they can be more effectively transported between different transport types, such as rail to road in this case.

Rail Haulage

4.6. Decarbonisation of Power Grid Flexibility Services

The rapid integration of large RES capacities with their inherent variability creates large challenges for the power system marked by the built-in inertia of the fossil generation.

100MWe synchronous pumped heat electricity storage system to replace gas fired grid power © Malta

4.6.1. Adding Operational Flexibility to the Grid

The **Sun2Store** project develops, implements and operates an innovative utility-scale pumped-heat electricity LDES system with 100 MWe-net AC synchronous discharge power, 10 GWhe of solar electricity and over 10 hours of capacity that can store carbon-free variable solar power and convert it into a dispatchable, synchronous electricity on a daily basis. It will reduce greenhouse gasses emission by 1,777,311t CO2-eq (1,502,934 t CO2-eq for energy discharged from the storage plus 274,377 t CO2-eq for solar PV energy sent directly to the grid) and replace 780 million cubic meters of natural gas in the first 10-years of its operation. It can be charged and discharged 100% in unlimited cycles without degradation of the storage media.

Challenges associated with limited long-term revenue certainty and the need for multiple contractual arrangements to reflect value delivered by the TES assets affects the ability to attract adequate investments, especially during market nascency. To tackle these challenges, the following measures may be worthwhile to consider in the light of local grid contexts and energy system needs:

- Give LDES priority in the allocation of grid access at overbooked grid nodes
- Clarify the grid access process for storage assets in line with its dual function (power consumer and generator)
- Harmonise market incentives and connection rules for energy storage
- Attract investments by creating market mechanisms that secure long term revenue streams for LDES
- Create market mechanisms that secure long term charging power and cost for LDES assets, i.e. prioritising hybridisation with neighbouring and remote renewable generation plant

4.6.2. Thermal Energy Storage with Concentrating Solar Thermal (CST) Technologies in a Brewery

CST technologies use mirror configuration to reflect and concentrate the sun's direct normal irradiance (DNI) into a receiver to heat a high temperature fluid. This heat can be used to create steam, driving a turbine to generate electricity, or directly as heat purposed for heavy industries, known as Solar Heat for Industrial Processes (SHIP). Thanks to TES, CST production is possible at night and during cloudy periods, or at any time heat is required (within the limitation of the overall stored heat). TES makes CST a more flexible and dispatchable form of solar energy.

A 30 MW CST Plant in a brewery in Spain, covers 55% of the heat demand with the remaining 45% covered with biomass. © Protermosolar

The CST plant generates 28,7 GWh/y of steam which includes a TES solution (68MWh, 50% of total demand). The total budget of this case equates to €20 million, with €7 million of them with equity.

CST alone can struggle to participate in any flexibility and ancillary service to the system. With SHIP, there are two technical alternatives: CST paired together with TES and/or an electric heater coupled with TES. Challenges related to TES for SHIP mainly centre around finding new energy storage materials for commercial solutions with high temperature (>400°C) processes and meeting the space requirements (roof and ground).

Electricity wholesale markets do not provide sufficient investment signals, so regulatory mechanisms are needed to attract investment. Allowing all distributed energy resources, including energy storage, to participate in flexibility mechanisms, is also needed. Concerning SHIP, there is a lack of regulatory incentives for "Power to Heat" for ex. as a means to reduce curtailment, bankability, and moving from self-consumption to being able to supply larger shares of thermal demand of industry with SHIP.

Therefore, more technology dissemination and Capex incentives would aid TES roll-out which would ultimately accelerate the decarbonisation of our energy systems. However, any financial incentives should be technology-neutral and limited to situations of market failure, provide optimized societal value-for-money for the energy system (backed up by technology-neutral economic studies, such as cost-benefit analyses), and if possible be awarded through competitive process.

4.6.3. Thermal Hydro Energy Storage for PV Ultra Concentrated Technology

PV power can be used to charge thermal batteries in periods of grid curtailment. The thermal engine produces power for export to the grid when there is no solar power, giving the ability to generate 24-hours per day. Solar power is both converted into electricity and stored into heat form and later converted back to electricity in a Power-to-Heat-to_Power application. **RayGen's project** in Newbridge, Victoria, represents the world-first deployment of PV Ultra with additional heat storage installed. PV Ultra co-generates electricity and heat by using mirrors to focus sunlight onto a photovoltaic receiver on top of a tower containing highly efficient PV Ultra modules. Electricity is generated in the photovoltaic receiver and a closed-loop water cooling system captures and stores heat as a useful by-product. Thermal Hydro efficiently stores energy as a 90ºC temperature difference between two reservoirs. When required, firm power is dispatched through a thermally driven Organic Rankine Cycle (ORC) engine. Each PV Ultra receiver contains an array of PV Ultra modules that generate a total of 1MW electricity and 3MW heat. Main advantages of the technology include:

- Compared to standard PV solar PV Ultra is 4000x more energetically powerful (750 kW vs 0.18kW per m2) and has double the solar system efficiency (32% vs 15-17%)
- Long duration Energy Storage hours (10 hours vs 1-4 hours when compared with traditional battery storage)
- Overall round-trip efficiency (>70% vs <50% when compared with other ETES systems)
- It can provide black start, inertia and reactive power

Project at Carwarp, Australia with 4MWp of solar + 3MW of AC power from the heat engine connected to 50 MWh of thermal storage © SLB

Another project is expected to be in Yadnarie, Australia with 300MWp + 175 MWac with 2.1 GWh of thermal energy storage .

5. Policy Recommendations

State of Affairs

A low-carbon energy system requires adaptations to accommodate the changing patterns of energy production and consumption and increasing efforts to the decarbonisation of heat and cold. Energy storage will play a pivotal role in providing the required flexibility and offering balancing options to the integrated energy system. This holds true especially for thermal energy storage concepts, which have unique features and can be used to manage the variations in supply and demand at different scales. Alongside improving grid capacity and implementing storage on it, it is crucial to develop a regulatory framework which will recognise advancements already made and encourage further research and development of TES alongside other energy storage technologies.

5.1. Ensure Taxes and Surcharges on Energy Storage Reflect the Added Value to the Energy System

1. Abolish double taxation of energy storage projects so that the taxation system takes into account the unique services of energy storage and removes unnecessary market barriers within the European Commission's upcoming proposal for a revised Energy Taxation Directive.

2. TES should be guaranteed a level playing field in the EU by ensuring cost reflective grid charges in national regulation. Eliminating potential distorting surcharges would encourage this transition.

3. Establish energy storage as a new, fundamental pillar of the energy system to make unbundling rules more coherent, provide legal clarity, and address inconsistencies within the legislation. In other words, it is necessary to recognise that (thermal) energy storage does not fall under neither “generation” nor “consumption”, as it currently stands in most legal systems.

5.2. Untap Long-Term Investment and Revenue Streams

1. Develop a financial support mechanism to incentivise TES roll-out through providing subsidies for investments and long-term offtake agreements to foster viable business cases. TES manufacturers can, for example, trial lease-to-own propositions in cooperation with national, regional and local governments. Such schemes can improve the business case of TES and encourage customers to install TES without the risks and reservations associated with an upfront investment. Those incentives should be unbiased, targeted towards collectively beneficial use cases that are not yet sufficiently encouraged by the market, optimize energy system value, and be allocated competitively.

2. Provide incentives for the recovery of waste heat towards the aim of increasing energy efficiency of power plants, industries, buildings, district heating and cooling by facilitating cooperation between industries, heating companies, utilities, and citizens. Waste heat recovery could recycle large amounts of energy for the energy system and will aid in reducing waste in the EU's heating and cooling sector. Those incentives should be unbiased, targeted towards collectively beneficial use cases that are not yet sufficiently encouraged by the market, optimize energy system value, and be allocated competitively.

3. Unlock investment signals for storage with longer durations in low-carbon system to deal with increasing renewables' penetration and more frequent grid constraints. At the moment, market conditions are not yet able to incetivise thermal energy storage ability to shift energy for long periods of time.

4. Decarbonise capacity remuneration mechanisms: thermal energy storage can help to ensure security of supply - it may be crucial especially when looking at the long duration energy shifting perspective. Current legislation should be reformed progressively to ensure capacity markets are climate-aligned while also continuing to ensure security of supply. More detailed propositions on how to decarbonise capacity mechanisms can be found in the policy paper on the electricity market design revision, available on EASE's website.

5. Reduce curtailment by reforming market conditions so that Europe harnesses energy storage wherever it can effectively help to limit thrown-away energy and strengthening the EU's cap on renewable curtailment. Furthermore, energy storage, especially thermal energy storage, can provide the shifting of energy for long durations and should be considered in the replacement of fossil-fuel peakers as a more secure, cost-effective and (if charged with power from low-carbon sources) emission-free alternative.

5.3. Adapt Grid Connection Process to (Thermal) Energy Storage

1. Accelerate the grid connection process by elaborating specific, EU level requirements. In general, EU network codes do not sufficiently address energy storage facilities, which results in unequal treatment across Member States, particularly when it comes to requirements for electricity grid connection. The current situation stifles competition and hinders energy storage facilities by prolonging deployment time by months/years.

5.4. Provide Investors with Long-Term Vision and Strategy

1. Reassess the EU Heating and Cooling Strategy to align with the climate and energy security imperatives. The EU Heating and Cooling Strategy does not reflect current objectives of the EU Green Deal and REPowerEU package. Renewable and clean heating technologies in buildings and industry must be incentivised through financial and regulatory instruments for the uptake of renewable and waste heat sources and efficient heating technologies. These measures must be streamlined through other EU legislature and further developed with member states, local authorities and stakeholders.

2. Require Member states to set indicative national objectives for energy storage, to be reflected in their National Energy and Climate plans. Such objectives should be technology neutral and look at different timeframes, i.e. energy storage needs from seconds to seasons, as well as needs due to interannual variations.

5.5. Improve Planning and Functioning of the Energy System

1. Map-out key sites for energy storage development to address its potential in accelerating energy transition plans. Mapping the key sites would highlight potential development opportunities and provide long-term incentive for investment.

2. Provide option to Member States to set RES curtailment caps in order to reach 2030 renewable energy targets. Market-based dispatch should be prioritised, though curtailment will still play an essential role in a socio-economically optimised system. More detailed propositions be found in the policy paper on the electricity market design revision, available on EASE's website.

5.6. Accelerate Maturity and Manufacturing of Thermal Energy Storage Technologies.

1. Further encourage EU-level R&D of TES technologies to bring more advanced solutions to the market and accelerate the already-decreasing cost of longer duration energy storage. In general, public and private sector have limited access to new technologies, unless the initiative is led by national, regional or local government. R&D can reduce the gap between novelty and accessibility by mainstreaming new technologies and making them more available to general use.

2. Strengthen the European manufacturing of energy storage technologies. While from a R&D perspective Europe plays a key role in thermal energy storage, in terms of manufacturing significant room for improvement exists.

3. Increase data accessibility for projects and technological advancements of TES in private and public sectors. Available access to information on TES technologies improves their visibility and highlights the improvement of existing processes would encourage industries to deploy resources in production. The accessibility of technological data would have a positive impact on their cost and make them more accessible to a wider range of public.

Several pieces of legislation and files are currently under discussion at the European Union level. There is therefore an opportunity to address the policy recommendations listed above - the following files are particularly relevant for thermal energy storage:

1. Ensure energy storage plays a key role in the Net-Zero Industrial Act (NZIA). As proposed by the European Commission, energy storage should be considered a strategic net-zero technology in the NZIA. This is key to access e.g., faster permitting, workforce reskilling, and regulatory sandboxes.

2. Revise assumptions on storage potential in the Ten-Year Network Development Plan (TYNDP) to better address the role of energy storage facilities. It is important to fully integrate the characteristics and potential benefits of energy storage, and not to overlook the role of TES. The role of energy storage should be further investigated in the context of sector integration and cross-border connections. Distribution Network Development Plans should also take this into consideration.

3. Improve the Electricity Market Design to unlock energy storage as an essential catalyst of the climate-neutral energy system of the future by considering the unique services of energy storage and untapping long-term investment and revenue streams, such as capacity and grid ancillary services, for storage. More information on this can be found in a policy paper on the electricity market design revision found on EASE's website.

6. Conclusion

As Europe transitions away from fossil-fuels to an energy system dominated by affordable, renewable and intermittent energy, TES can help bridge the current transitional energy system to the carbon-neutral energy system of the future. EASE estimates that the EU will need to reach approx. 200 GW of energy storage by 2030 (existing and new-built storage combined), and 600 GW (of which over two-thirds concern energy shifting technologies, i.e. power-to-X-to-power) by 2050 to meet its renewable energy targets. Additionally, once an energy system reaches >60% renewable penetration, longer duration energy storage may be increasingly necessary to maintain security of supply and TES is a key solution providing longer durations of flexibility. Further economic studies on TES use cases will be highly useful to allow policymakers to establish supportive regulatory frameworks wherever these use cases offer socioeconomic added value in addressing the needs of the energy system.

Decarbonising the generation of thermal energy for heating and cooling is a particular challenge of the energy transition that TES is uniquely positioned to help overcome. It can address gaps in efficiency in electrification, helping to make the reduction of the carbon-intensity of hard-to-abate sectors more accessible. Various TES technologies are mature enough right now - with more in the pipeline - to already provide heat flexibility for industry and electrical flexibility to the grid. Further, certain TES can also empower consumers to provide services to both thermal and electrical energy systems alongside with decarbonisation.

Thermal energy storage technologies will continue to grow as **integral solutions in providing energy and heat flexibility** to a European energy system defined by an ever-growing mix of intermittent, renewable energy. Furthermore, even though it may face challenges in terms of roundtrip efficiency and competition from other storage/flexibility solutions, in many cases TES can help **reduce the EU's reliance on fossil-fuels and boost energy security** by storing home-grown renewable energy, some of which would otherwise be curtailed. TES is **a key solution in providing large-scale and longer duration energy storage to facilitate the energy transition for decades to come.** TES solutions may contribute to tackle emissions in some of Europe's highest emitting and hardest-to-abate sectors and deserve a more pronounced consideration in EU policy. **In order for the EU to achieve its climate-neutrality targets and for REPowerEU to have long-term success in addressing the energy crisis, long-term solutions, like TES, need to be better capitalised upon.**

7. References

[1] Eurostat, Renewable Energy Statistics, 2023, available at : https://ec.europa.eu/eurostat/statistics explained/index.php?title=Renewable_energy_statistics

[2] Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: State of the Energy Union, 2022, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022DC0547

[3] ACER: Gas factsheet, 2022, available at: https://www.acer.europa.eu/gas-factsheet

[4] LDES Council: Net-zero heat: Long Duration Energy Storage to accelerate energy system decarbonization, McKinsey & Company, 2022, available at: https://www.mckinsey.com/capabilities/sustainability/our-insights/net-zero-heat-long-duration-energy-storage-to-accelerate-energy-system-decarbonization

[5] UK: Flexibility for low carbon electric heating The role of smart thermal storage in providing flexible, low carbon electric heating, 2022, available at: https://static1.squarespace.com/static/61af158225618e1511f3323f/t/6348080d3e4c696e22f6b8ca/1665665039164/Benefits+of+heat+flexibility_Thermal+Storage+UK_October+2022.pdf

[6] EU (2019) Directive 2019/944 of the EU parliament and the council on common rules for the internal market for electricity. Article 2, Paragraph (59), available at : https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32019L0944

[7] EASE: Energy Storage Technologies, 2023, available at: https://ease-storage.eu/energy-storage/technologies/

[8]Sample system design and interconnection, The Pew Charitable Trusts: Energy Smart Technologies in the Evolving Power System, 2016, available at: https://www.pewtrusts.org/-/media/assets/2016/02/the_smart_grid_how_energy_technology_is_evolving_print.pdf

[9] European Energy Research Alliance's Joint Programme on Energy Efficiency in Industrial Processes: Industrial Thermal Energy Storage – Supporting the transition to decarbonise industry, 2023, available at: https://d2m9e9.n3cdn1.secureserver.net/wp-content/uploads/2022/12/DU-WP-Ind-TES-web.pdf

[10] EASE: Ancillary Services - Energy Storage Applications Forms, 2021, available at: https://ease-storage.eu/wp-content/uploads/2021/08/Ancillary-Services.pdf

[11] EnTEC: Study on the performance of support for electricity from renewable sources granted by means of tendering procedures in the Union, 2022, available at: https://op.europa.eu/en/publication-detail/-/publication/e04f3bb2-649f-11ed-92ed-01aa75ed71a1/language-en

[12] Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0210.01.ENG

[13] Statista: Market size of paper and pulp industry worldwide from 2021 to 2029, available at: https://www.statista.com/statistics/1073451/global-market-value-pulp-and-paper/

[14] International Energy Agency: Pulp and Paper, 2022, available at: https://www.iea.org/reports/pulp-and-paper

[15] Netherlands Enterprise Agency: Stimulation of sustainable energy production and climate transition (SDE++), available at: https://english.rvo.nl/subsidies-programmes/sde

[16] IRENA: Innovation outlook – Thermal Energy Storage, 2020, available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Innovation_Outlook_TES_2020.pdf?rev=6950b7b9792344b5ab28d58e18209926

[17] EASE: Energy Storage Targets 2030 and 2050, available at: https://ease-storage.eu/publication/energy-storage-targets-2030-and-2050/

Notes

***

About EASE:

The European Association for Storage of Energy (EASE) is the leading member - supported association representing organisations active across the entire energy storage value chain. EASE supports the deployment of energy storage to further the cost-effective transition to a resilient, carbon-neutral, and secure energy system. Together, EASE members have significant expertise across all major storage technologies and applications. This allows us to generate new ideas and policy recommendations that are essential to build a regulatory framework that is supportive of storage.

For more information please visit www.ease-storage.eu

***

***

Contact: Margareta Rončević | Junior Policy Officer | m.roncevic@ease-storage.eu

European Association
for Storage of Energy

Avenue Adolphe Lacomblé 59/8
1030 Brussels | Belgium
Tel: +32 2 743 29 82
@EASE_ES

www.ease-storage.eu
info@ease-storage.eu