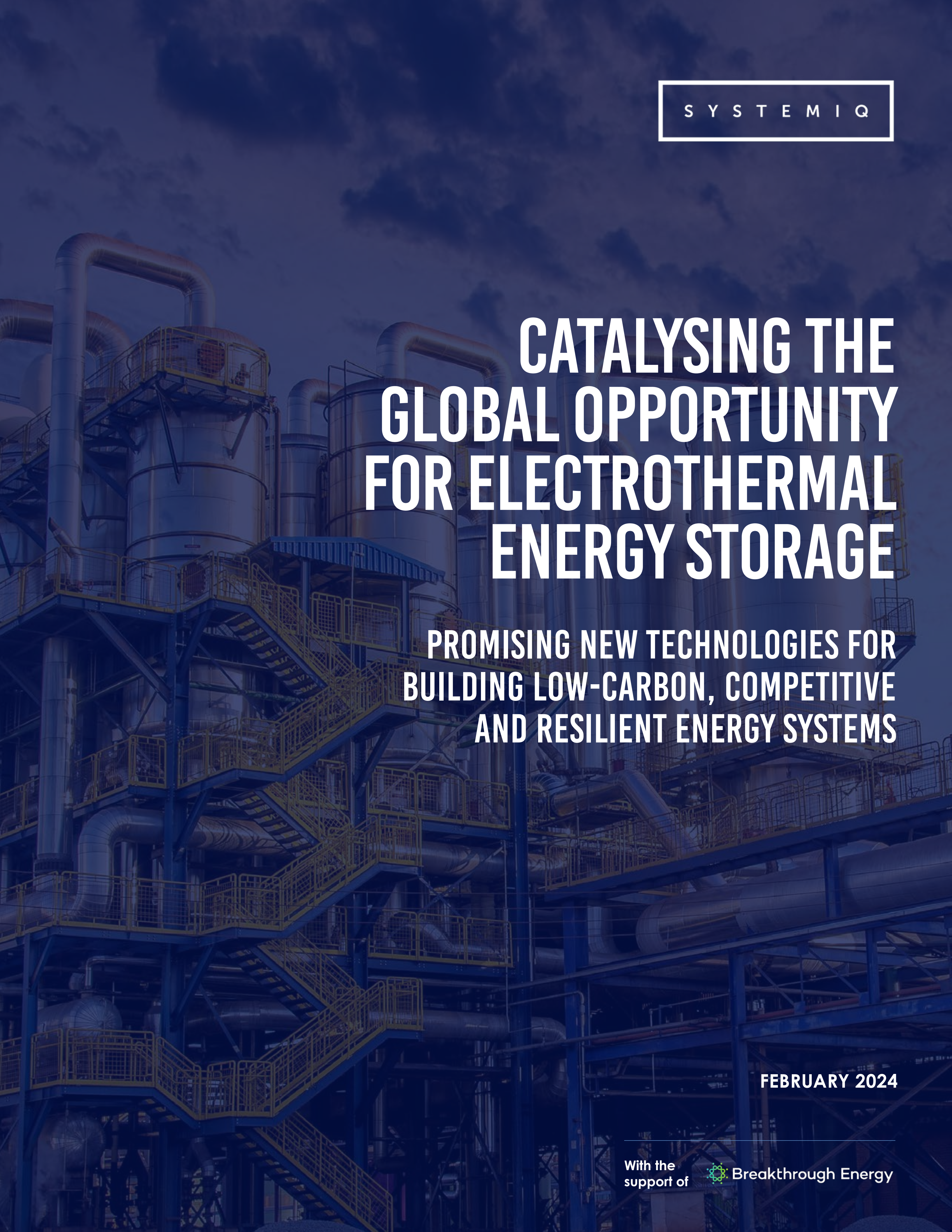

SYSTEMIQ

CATALYSING THE GLOBAL OPPORTUNITY FOR ELECTROTHERMAL ENERGY STORAGE

PROMISING NEW TECHNOLOGIES FOR BUILDING LOW-CARBON, COMPETITIVE AND RESILIENT ENERGY SYSTEMS

FEBRUARY 2024

With the support of Breakthrough Energy

PREFACE

The pace of the energy transition is picking up against a background of geopolitical uncertainty and commodity market volatility. Transitioning away from fossil fuels was agreed upon by nearly 200 countries for the first time at the 2023 United Nations Climate Change Conference in Dubai. Clean electrification of economies around the world has never been more attractive, with volatile fossil fuel prices and wind and solar volumes increasing exponentially over the past few years.

This transition is further aided by the expansion of the solution space: new electricity-based technologies are quickly maturing. One of the emerging technologies is electrothermal energy storage (ETES), which integrates electrification of heat with heat storage and could be a solution for decarbonising heat.

The majority of industrial heat is currently fossil based. Electrifying heat allows the substitution of gas, coal and oil with (preferably zero-carbon) electricity. This substitution has the dual benefits of improving energy security and independence, as well as reducing greenhouse gas emissions. Although there are other technologies that can electrify heat, such as heat pumps or electric boilers, ETES technologies have a third benefit of providing energy storage. This provides the unique ability to use electricity generation by intermittent renewables (solar, wind) to fulfil the large-scale and continuous heat demand that is typical for an industrial site. Additionally, ETES can do so with very high efficiency and at relatively low investment costs.

ETES technologies are already competitive with fossil fuel and decarbonisation solutions in specific use cases, for example when directly coupled to renewables in some locations, or because of environmental constraints. However, ETES is an emerging technology and there are still barriers to be overcome before a tipping point in ETES adoption is reached and it becomes competitive in the majority of cases. A new technology can reach a tipping point when it becomes more competitive than the conventional technology in three dimensions: affordability, attractiveness and accessibility. Historical examples indicate that when a tipping point is reached for a new technology, its adoption switches from a linear to an exponential pace as consumers, producers and investors decisively embrace it.

In this report, the potential impact of and market size for ETES technologies in 2030 and beyond are assessed in the first chapter. Then, the market, regulatory and policy gaps that need to be closed in order to help ETES technologies compete on a level playing field and unlock their benefits are identified. Finally, the enablers are identified that must be in place to reach a tipping point in ETES.

Alongside the main report that you are reading now, there are seven appendices with action plans for Denmark, France, Germany, the Netherlands, Spain, the United Kingdom and the United States (which focusses on the Electric Reliability Council of Texas [ERCOT]). These short pullouts are intended to succinctly communicate the ETES opportunity and actions required to scale up deployment in each country. They can be found on the following website, together with up-to-date contact information: **https://systemiq.info/etes**.

This report is intended to provide clear guidance, especially for policymakers and grid operators, on what actions are required to catalyse a tipping point for this promising new technology.

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This report was developed between November 2023 and February 2024 by Systemiq with the support of Breakthrough Energy. The Systemiq team consisted of **Min Guan**, **Stephannie Ditmar Lins**, **Hannah Maral**, **Lukas Marthaler**, **Sophie Slot** and **Abindra Soemali** and was led by **Eveline Speelman** and **Maaike Witteveen.** The Breakthrough Energy team consisted of **Pénélope Le Menestrel**, **Abigail Regitsky**, **Julia Reinaud** and **Alberto Toril**.

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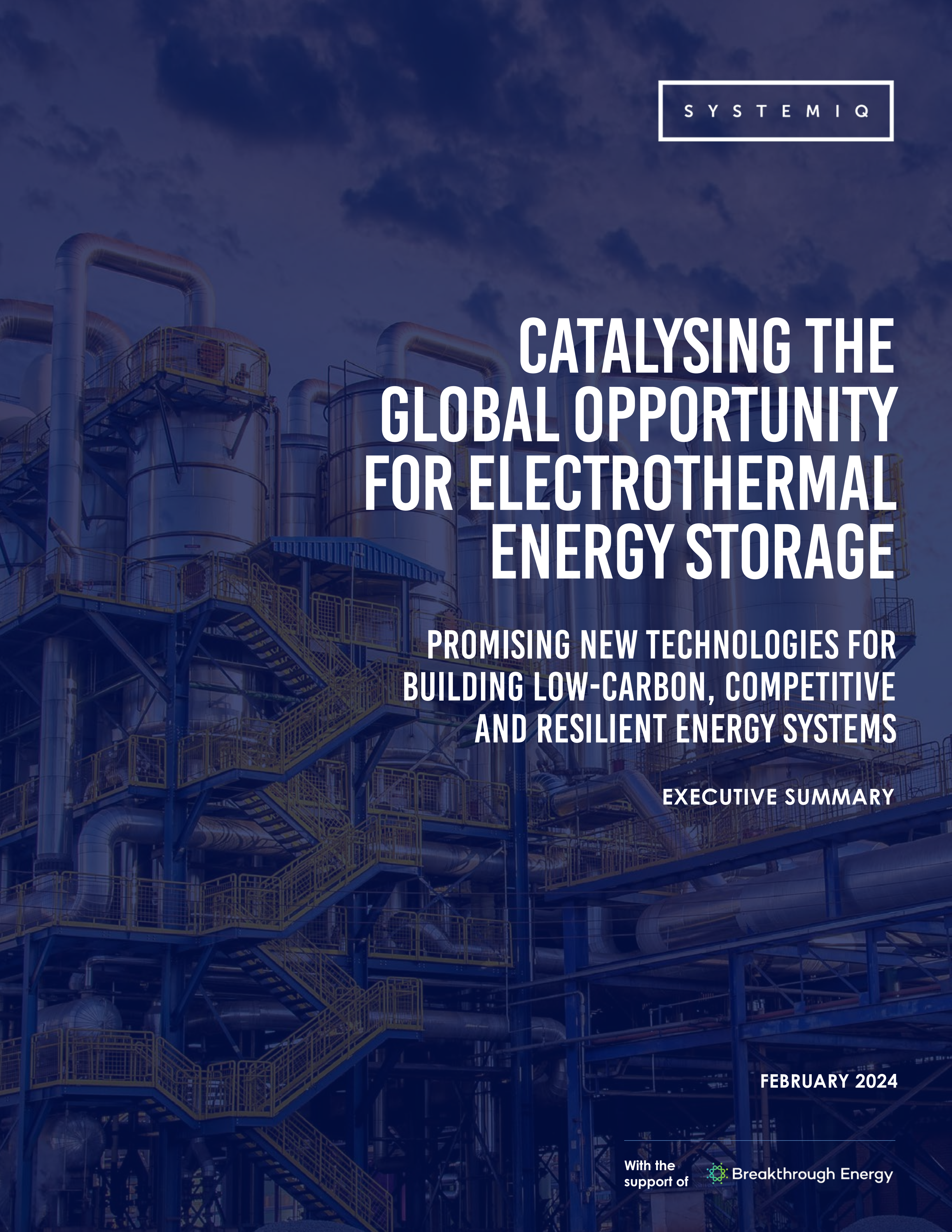
TABLE OF CONTENTS



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EXECUTIVE SUMMARY

FEBRUARY 2024

With the support of Breakthrough Energy

1 Decarbonisation of industrial heat is necessary to avoid the worst impacts of climate change and solutions are available today.

To ensure that global temperature rise stays well below 2°C, as countries pledged to in the Paris Agreement, reaching net-zero greenhouse gas (GHG) emissions by mid-century is critical. Industrial heat generation is a large contributor to the total GHG emissions today. Heat is a very important contributor. In 2019, heat accounted for 50% of energy end use and 40% of global carbon dioxide (CO_2) emissions.[1] About 50% of all heat produced is used for industrial processes, which leads to almost 20% (6 gigatonnes) of global CO_2 emissions.[2] These are emissions from boilers or furnaces in which fossil fuels, such as gas, oil or coal are combusted to create heat.

Decarbonisation of industrial heat is critical to reach net zero and it is technologically possible, even though there are still barriers to overcome in economic competitiveness and technology readiness, particularly for high-temperature processes (above 400°C).

Commercially available technologies to electrify industrial heat today are heat pumps, electric boilers and, for some applications, electric furnaces. This report focusses on electrothermal energy storage (ETES), emerging commercial technologies, which are promising systems to contribute to decarbonising industrial heat.

2 ETES technologies are commercially available and electrify industrial heat processes with the additional ability to store energy in the form of heat.

ETES technologies use electricity to produce heat and then store it in a heat storage medium such as bricks. Systems can charge when electricity is cheapest, which is typically when there is excess renewable electricity production. The stored heat can then be used to generate a continuous flow of heat on demand. Models commercially available today can deliver heat up to 400°C, typically as hot water or steam. As such, ETES can replace fossil fuel–based industrial boilers. Figure ES1 demonstrates how different types of ETES technologies work.

ETES technologies are widely applicable as virtually all industrial sectors have at least some processes requiring heat in these temperature ranges. In some sectors ETES could cover all heat demand, such as in the food and beverage manufacturing and paper and pulp sectors. These sectors typically require temperatures up to 400°C. ETES systems that provide higher-temperature heat up to 1,500°C are under development and are targeting rollout by 2030. Heat for processes such as biorefining (up to 600°C), steel preheating (up to 700°C) and clinker preheating (up to 900°C) could then be addressed by an ETES system.

ETES is especially relevant for industrial sites and other processes that require heat continuously and want to use energy from wind or solar instead of from fossil fuels to fulfil their energy needs. ETES can also be configured to generate power from the stored heat, alongside steam.

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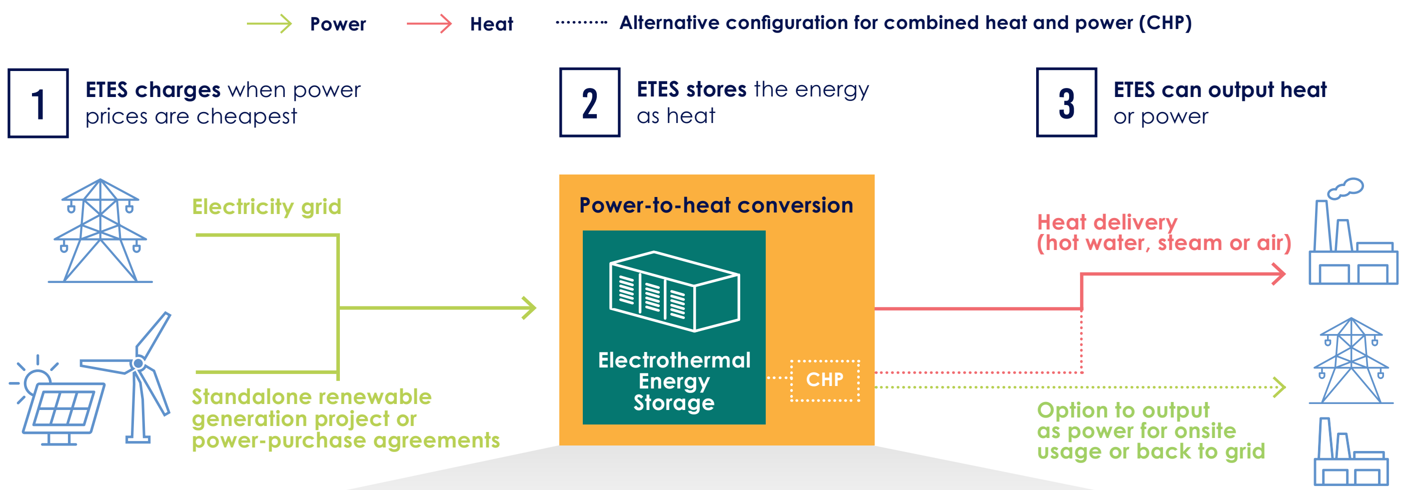
1 "Renewables 2019, Heat," IEA, 2019.

2 "Energy System Overview, Industry," IEA, 2023; and "Decarbonization of Industrial Sectors: The Next Frontier", McKinsey 2018.

Figure ES1 How different types of ETES technologies work



Landscape of ETES technology types and providers

	SENSIBLE HEAT	LATENT HEAT	THERMOCHEMICAL HEAT
How it works	Increases temperature of a solid or liquid medium	Changing material phase	Endothermic and exothermic chemical reactions
Temperature range	<0 to 700°C *In progress to reach more than 1,500°C*	*In progress to reach 1,600°C*	*In progress to reach 900°C*
Storage duration	Intra day to days (or months at lower temperatures)	Intra day to days	Intra day to months
TRL	Commercially available	R&D to commercial available	Nascent
Providers (non exhaustive)	Antora, Build to Zero, Brenmiller, Electrified Thermal Solutions, EnergyNest, Echogen, Kraftblock, Kyoto, Magaldi, Malta, Rondo, Storworks, 1414°	Azelio, MGA Thermal, TORC, Thermophoton, 1414°	redoxblox, SaltX

Source: Company websites; *Net-zero heat: Long Duration Energy Storage to accelerate energy system decarbonization*, LDES Council, 2023.

3 ETES could reduce the equivalent of up to ~40% of 2022 global gas use and the equivalent of up to 14% of global energy-related greenhouse gas (GHG) emissions by mid-century.

The electrification of industrial heat reduces a country's dependence on fossil fuels and enables decarbonisation. In regions that rely on the import of fossil fuels, energy independence and resilience will also improve.

Commercially available ETES systems today are mostly applicable to industrial processes that use hot water or steam for heating. These are most common in the food and beverage, chemicals, textiles and paper and pulp sectors. With these applications, it is estimated that by 2030 ETES has the potential to electrify the equivalent of ~8% of current global gas use. This translates into abating the equivalent of up to ~2% of global energy-related GHG emissions.

Besides these applications, ETES technology development is anticipated to unlock higher-temperature industrial applications such as clinker preheating and steel direct reduced iron (DRI) preheating. On top of that, ETES applications will expand to cover emerging demand for new energy-related processes, such as green chemicals and sustainable aviation fuel, that will grow with advancement of the energy transition.

Finally, nonindustrial markets such as district heating (that can already be addressed today, as is currently trialled in Denmark) and direct air carbon capture (a market that could develop after 2030) could be an additional opportunity for ETES. These additional applications could grow the addressable market by almost 2.5 times. By mid-century, ETES could displace the equivalent of ~30%–40% of current global gas use and abate up to 14% of today's energy-related GHG emissions.

4 ETES can help balance electricity demand and supply, reducing the need for grid expansion and supporting the expansion of renewable electricity generation.

As electricity systems rely more and more on variable sources of wind and solar power, matching this variable supply with flexible demand and/or storage increasingly becomes a prerequisite. ETES can help reduce electricity demand peaks (by up to 6%–30%) compared with other industrial electrification technologies in the countries analysed. This reduces the costs of grid expansion because electricity grids are typically sized to accommodate peak demand.

ETES can also help the power system by using (excess) renewable electricity at times of high solar and wind generation, therefore reducing curtailment levels in the power system. This way, ETES is estimated to enable an average of ~2.6× its own capacity in renewable generation capacity to come online. This means, in addition to its own electricity use (many ETES technologies can generate electricity in addition to heat), ETES is estimated to enable an average extra 1.6 megawatts (MW) of variable renewable power generation to come online.

5 ETES can provide flexible electricity demand for industrial heat that is relatively energy efficient and requires lower investment while using widely available materials.

Allowing for flexible electricity demand will be a crucial feature of industrial electrification. The high efficiency of ETES (90%–95% from grid electricity to heat) and comparatively lower investment costs (the capital expenditure per kilowatt of grid-scale battery systems can be more than double the capital expenditure required for ETES) make them more cost effective than adding battery storage to electric boilers and in some cases even to heat pumps. ETES value chains can be local. ETES technologies rely on widely available materials, such as bricks, and do not require the scarce minerals that batteries need. These benefits can be unlocked today with actions from market players, technology providers, industrial users, regulators and grid operators.

6 ETES has benefits over other electrification of heat technologies in temperature reach, ease of installation and storage capability.

ETES is expected to be part of the technology mix used to generate low-carbon industrial heat. Heat from hydrogen is not yet commercially available and is expected to be considerably more expensive than ETES due to the energy losses in the hydrogen production process. Heat pumps are more energy efficient converting electricity to heat than ETES (200%–300% efficiency for a heat pump versus 90%–95% for ETES) and thereby typically more cost-competitive than ETES. However, heat pumps can require extensive on-site changes, and heat pumps cannot reach temperatures above 200°C yet — while more than half of industrial heat demand is for temperatures above 200°C.[3] Electric boilers can provide the same temperatures as ETES-based boilers can reach today. Future electric furnaces are expected to be able to reach similar temperature levels (above 1,000°C) as future ETES systems as both technologies develop further. However, the inflexible baseload demand of heat pumps, e-boilers and e-furnaces requires additional investment — either in the electricity network or in on-site storage — to translate intermittent electricity from renewables into continuous electricity.

3 "Industrial Heat Demand by Temperature Range," IEA, 2018.

Financial support to close a cost gap with fossil fuel–based heating is better spent on ETES than on hydrogen-based technologies. ETES technologies are more cost-competitive per tonne of carbon abated than green hydrogen–based technologies for applicable industrial processes. ETES can be (close to) cost-competitive with gas boilers today, whereas heat from hydrogen boilers can be three to five times more expensive than gas boilers.

7 In most regions, ETES faces barriers in affordability and accessibility compared with gas boilers.

Natural gas boilers are the incumbent industrial heating technology in Europe and the United States. While some hurdles remain, ETES is projected to be generally competitive with natural gas boilers by 2030 in Spain. In all regions that were analysed, ETES may be competitive when optimised for a specific site (e.g., bespoke grid fee agreement and power purchase agreement or on-site generation). However, in Denmark, France, Germany, the Netherlands, the United Kingdom and the Texas ERCOT region in the United States, the levelised cost of heat (LCOH) of ETES is higher than that of natural gas boilers. This is because in these regions electricity grid fees and taxes are higher than grid fees for natural gas, and wholesale electricity is more expensive than natural gas per unit of energy.

ETES is also less accessible compared with natural gas boilers due to electricity grid congestion, which can lead to waiting times of up to 10 years in some regions. Without any changes to regulations, the benefits of ETES are unlikely to be unlocked due to the barriers above. However, with realistic, targeted actions, regions can remove the barriers to at scale deployment.

8 Policymakers and grid operators can act now by removing barriers and accelerate a tipping point in the uptake of ETES.

Policymakers and grid operators are crucial stakeholders in shaping the market conditions for ETES. The regulation of electricity markets and industry decarbonisation has a significant impact on the affordability and accessibility of ETES. Based on the regions studied for this report (Denmark, France, Germany, the Netherlands, the United Kingdom, Spain and the Texas ERCOT region in the United States), the most important actions are:

- **Reform grid fees, taxes and discounts to incentivise grid power usage during least-used periods.** The cheapest grid costs should be for usage that is least cost to the grid (i.e., flexible or off-peak usage), but this often not the case today. Grids are planned to serve peak load. Therefore, grid costs (fees, taxes and levies) and associated discounts could be aligned with how much usage profiles add to the peak load.
- **Introduce criteria to fast-track grid connection for flexible demand technologies.** Flexible demand could reduce grid congestion issues and avoid grid expansion costs. However, there is currently a long wait time (of up to 10 years in some regions) to be connected to the grid. Some regions are proposing prioritising renewables and electricity storage connections. Even though ETES may even reduce grid congestion (depending on charging schedule), it has not yet been considered for prioritisation.
- **Ensure that ETES is eligible for industrial decarbonisation, energy storage and flexible demand support schemes.** ETES being a relatively new technology means it is often not included in support schemes. Doing so would not only enhance energy security and reduce industrial emissions, but also benefit the decarbonisation of the wider electricity and energy systems. Even today the affordability gap can be closed without subsidies in certain countries and setups. Subsidies put in place today will provide business case certainty for cost effective decarbonisation of heat to be implemented by 2030. Most business cases made today will include the LCOH around 2030 and beyond. Analysis shows that dedicated subsidies are not required in 2030 in the countries analysed if other levers are actioned.

9 Technology providers can act now by increasing awareness of ETES, and by working with industry users to ensure the optimal configuration of the ETES asset for the specifics of the site.

Technology companies and industrial users also play a critical role in raising the awareness of ETES and ensuring that ETES is factored into future site plans. Key actions are:

- **Technology companies can continue to raise awareness of ETES benefits** through continued stakeholder engagement.
- **Technology companies can tailor their product offering** to promising market segments, which can include combined product offerings with utilities and grid operators to provide charging optimisation and grid connection.
- **Industrial users can evaluate ETES technologies for heat provision on their sites** and put in place an action plan for sites where it makes economic sense. Larger industrial hubs can explore the possibility of combined heat provision for the entire hub. As part of this they can work with technology providers to ensure their ETES setup is optimised for the specific site characteristics, such as local grid congestion charges, governmental support schemes, operating hours and grid fee structure.
- **Industrial manufacturers can explore whether there is an appetite for a green premium for their products to cover any cost increase from using ETES,** which could be incentivised by regulations or corporate commitments to a lower product carbon footprint.

This executive summary is an extract from the report *Catalysing the Global Opportunity for Electrothermal Energy Storage: Promising New Technologies for Building Low-Carbon, Competitive and Resilient Energy Systems.* The full report can be found at **https://systemiq.info/etes**.

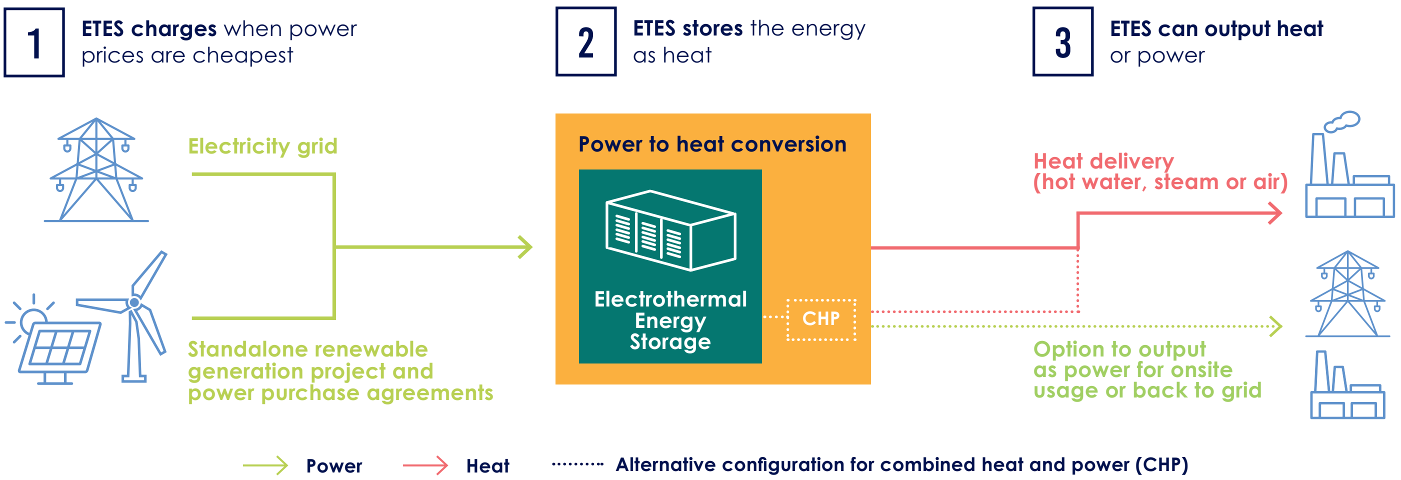
This report was developed by Systemiq with the support of Breakthrough Energy.

ETES TECHNOLOGIES AT A GLANCE

ETES is an emerging class of technologies — with early deployments at full scale underway today — that provides continuous decarbonised heat to large-scale users such as industrial sites. Today, commercially available ETES units can reach up to 400°C output temperatures.[4] With ongoing technology developments, ETES technology providers expect that temperatures up to 1,500°C can be commercially available in the near future.

Uniquely, ETES provides heat by converting electricity into heat and storing the heat, for example, by heating up bricks or concrete. That heat is then released to be delivered, often via hot water or steam, into industrial sites such as paper mills or dairy processing factories. Typically, only 6–12 hours per day of charging with electricity is required for a continuous 24-hour, heat supply. The charging and heat delivery can be turned on and off at will. A schematic can be found in Figure 1.

Figure 1 **How ETES technology works**



For industrial users, ETES's storage capability provides clear benefits when an (almost) continuous supply of heat is required, such as at most industrial sites or district heating providers. Electricity prices fluctuate throughout the day because these prices are a function of electricity demand and, increasingly, variable electricity supply from solar and wind. With ETES, these users can take advantage of the periods when there is a cheap, abundant supply of renewable electricity and use it to serve their continuous heat demand.

4 The current upper range of ETES pilot installation output temperatures is 700°C. The current upper range of ETES is based on sensible heat, which is the focus of this report. See the next page for more details. Hot air temperature ranges to above 1,000°C are currently in research and development (R&D).

For utilities and grid operators, ETES units provide flexible electricity demand at scale. That is attractive because ETES can be charged at times when there is more electricity generated than demand. Through the flexible charging of ETES, its demand can be rebalanced to better match the variable supply of solar and wind. This way, ETES is estimated to enable on average ~2.6× its own thermal capacity in renewable generation capacity to come online. This means in addition to its own electricity use, ETES is estimated to enable an average extra 1.6 MW of variable renewable power generation to come online.[5]

In contrast to other electric heating equipment that is not flexible, such as e-boilers and heat pumps, ETES can reduce grid congestion and provide real-time grid balancing. When the grid is at peak capacity with other electricity demand, the charging can be turned off. This reduces both the need for alternative — and less efficient when it comes to providing heat demand — storage technologies such as batteries or pumped hydroelectricity storage, and the need to increase the electricity grid capacity.

For governments with decarbonisation or energy independence objectives, ETES reduces demand for fossil fuels such as natural gas or coal. It directly avoids the need for fossil fuel–based boilers and it can facilitate greater deployment of intermittent renewables such as solar photovoltaics and wind in the electricity system. These are expanded on in Chapter 1.

There are currently more than 40 technology providers for ETES, with the majority of those providing sensible heat (e.g., storing the energy in bricks, lava rocks, concrete or molten salt) and a few providing latent heat (e.g., switching between liquid and gaseous carbon dioxide) at commercial readiness. An overview of the technology landscape is in Figure 2. This report focusses on the technologies that use sensible heat because these technologies are the most mature. ETES is in the early commercial phase (Technology Readiness Level [TRL] 7) with the first units installed and operational and many providers able to commercially offer solutions today.

Figure 2 Landscape of ETES technology types and providers

	SENSIBLE HEAT	LATENT HEAT	THERMOCHEMICAL HEAT
How it works	Increases temperature of a solid or liquid medium	Changing material phase	Endothermic and exothermic chemical reactions
Temperature range	<0 to 700°C *In progress to reach 1,500+°C*	*In progress to reach 1,600°C*	*In progress to reach 900°C*
Storage duration	Intra day to days (or months at lower temperatures)	Intra day to days	Intra day to months
TRL	Commercially available	R&D to commercial available	Nascent
Providers (non exhaustive)	ANTORA, BUILD TO ZERO, BRENMILLER, Electrified Thermal Solutions, ENERGYNEST, ECHOGEN power systems, KRAFTBLOCK, KYOTO, MAGALDI, MALTA, RONDO, STORWORKS, 1414°	AZELIO, MGA THERMAL, TORC, THERMOPHOTON, 1414°	redoxblox, SaltX Technology

Source: Company websites; *Net-zero heat: Long Duration Energy Storage to accelerate energy system decarbonization*, LDES Council, 2023.

5 Jesse Jenkins and Sam van der Jagt, "Understanding the Role and Design Space of Demand Sinks in Low-Carbon Power Systems," 2021, published in ResearchSquare. See Technical Appendix for assumptions behind the 2.6× factor.

CHAPTER 1

THE IMPACT AND MARKET OF ETES

1.1 DEPLOYMENT OF ETES CAN HAVE A POSITIVE IMPACT ON INDUSTRIAL COMPANIES AND SOCIETY BY INCREASING ENERGY SECURITY, RESILIENCY AND REDUCING EMISSIONS

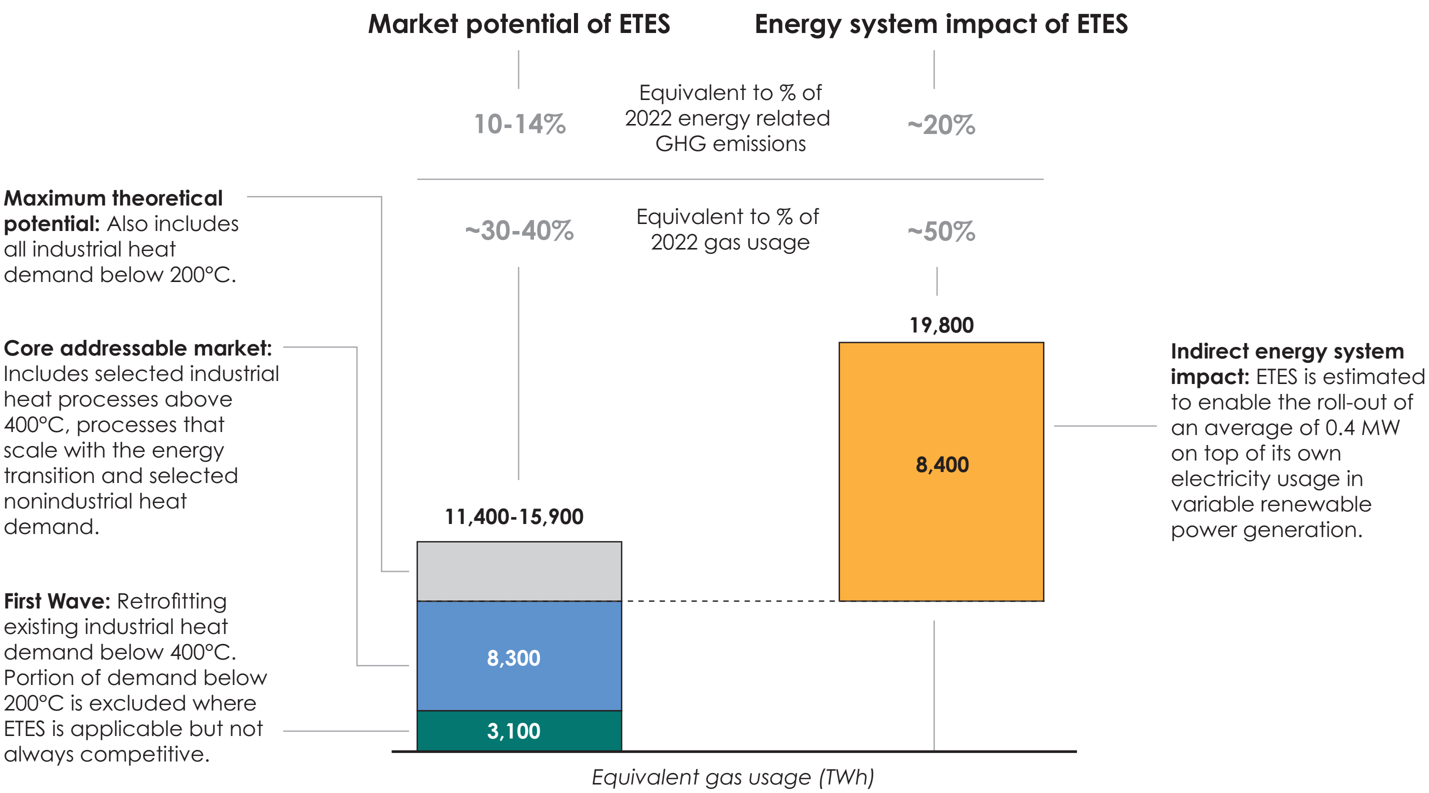
ETES is a commercially available technology that electrifies industrial heat processes with the additional ability to store energy in the form of heat. The estimated global market potential for ETES by 2050 is equivalent to up to ~30%–40% of today's global natural gas consumption and up to 10%–14% of today's total energy-related GHG emissions.[6] Commercially available ETES units today can typically provide heat for processes up to 400°C. It is therefore expected that the first wave of applications before 2030 will be mostly in that temperature range.

6 Energy-related GHG emissions are GHG emissions from the burning of fossil fuels (so they exclude emissions from the use of fossil fuel as feedstock and land use changes).

In addition to the direct impact of ETES on the energy system by electrification of heat, analysis shows that ETES could enable the rollout of additional variable renewable power generation.[7] This implies that through the avoidance of gas power plant generation, by mid-century an estimated average of ~19,800 terawatt hours (TWh)/year of renewables can be facilitated by ETES alone. This is equal to 70% of today's global electricity system (~28,000 TWh[8]).

The energy system impact of ETES can therefore be significantly larger than the market potential suggests. An overview of the market potential and the energy system impact of ETES can be found in Figure 3.

Figure 3 Global estimated market potential and energy system impact of ETES



An overview of the processes included in the market potential and calculation of the energy system impact can be found in Figure 5 and the Technical Appendix (downloadable from https://systemiq.info/etes).

Source: UNFCCC data set (2021) — except for Australia (2019), International Aluminum Institute, World Steel Association, Eurostat, EuraTEX, USGS, Petrochemical Europe; Mind the Gap report by ETC, Fossil Fuel Role in Energy Transition report by ETC, EU heat profile is derived from EU Joint Research Center; US Heat Profile is derived from Energy Innovations' Decarbonizing Low-Temperature Industrial Heat in the U.S.; Understanding the Role and Design Space of Demand Sinks in Low-carbon Power Systems (Jenkins, 2021)

Deploying ETES to electrify heat has several benefits for a country or region. It can increase energy independence and reduce GHG emissions. On top of that, ETES can support wider decarbonisation of the energy system.

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7 Energy system impact is estimated from Jesse Jenkins and Sam van der Jagt's paper "Understanding the Role and Design Space of Demand Sinks in Low-Carbon Power Systems," published in 2021 in ResearchSquare. Their research estimates that 0.9–1.9 MW of renewable generation comes online for every 1 MW of ETES thermal load. This implies that beyond the first megawatt required to serve the new ETES load, there could be on average an additional 0.4 MW of renewables to come online. With a six-hour charging schedule and 24-hour discharge schedule, for every 1 MW thermal ETES demand there is an additional ~1.6 MW of renewable capacity to come online. We convert this to megawatt hours of gas displaced in a year using a 60% gas generation efficiency factor. See the Technical Appendix for calculation.

8 "Energy Statistics Data Browser," IEA, 2023.

Energy independence: ETES can reduce an equivalent of up to 8% of the current natural gas consumption by 2030, and up to 30%–40% by mid-century. Electrifying heat with ETES technologies decreases a country's reliance on fossil fuels. This reduces the reliance on imported gas, which historically has seen large price volatility and availability restrictions during geopolitical events. When the indirect energy system impact is included, ETES can avoid fossil fuel consumption that is the equivalent of up to ~50% of 2022 gas usage. For a specific country, the impact can vary. The analysis shows that ETES can reduce dependence on fossil fuels by an equivalent of 15% to more than 60% of a country's current natural gas consumption by mid-century.[9]

Emissions abatement: ETES can directly reduce the equivalent of up to 2% of energy-related GHG emissions by 2030, and up to 10%–14% globally by 2050. ETES not only directly reduces energy-related GHGs by replacing fossil fuels, but it also contributes significantly to the reduction of power systems' GHG emissions by providing demand flexibility. Analysis shows that ETES can facilitate abatement of 15%–30% of a country's current energy-related emissions when including indirect power system impact.

1.2 ETES CAN SUPPORT THE TRANSITION TO A NET-ZERO ENERGY SYSTEM BY OPTIMISING AND BALANCING THE BROADER ELECTRICITY SYSTEM

ETES provides additional benefits to the energy system besides decarbonisation and energy security. Its ability to charge flexibly can help optimise and balance the broader electricity system. The scale-up of intermittent renewables combined with the projected increase in electrification makes managing electricity supply and demand more challenging. Substantial investments will be required to build out the electricity grid and develop more sophisticated mechanisms to time-match electricity generation and demand. ETES can support the electricity system in three main ways, which are shown in Figure 4.

9 Based on the analysis of the addressable market in the seven focus countries: Denmark, France, Germany, the Netherlands, Spain, the United Kingdom and the ERCOT region in the United States. In countries where coal is the dominant source of industrial heat, ETES would replace coal consumption.

First, ETES can ensure less electricity is wasted. It can provide load shifting compared with electrified heat technologies without storage (e-boilers, heat pumps). In practice, load shifting with ETES means that a continuous heat demand does not imply a continuous electricity demand. Instead, the electricity demand can be shifted to times when electricity generation would otherwise be curtailed, meaning that renewable electricity generation would be actively reduced because there was no demand with which to match it. Flexible demand or energy storage, such as ETES, can avoid the need for curtailment.

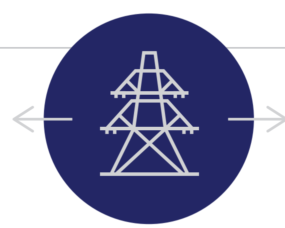
Second, ETES can avoid some of the growth in peak electricity demand and thereby reduce the need to expand the electricity grid and reduce associated costs. The load shifting that avoids curtailment at times of peak production by switching to charging mode can also reduce peak electricity demand by switching off charging at times when there is high demand in the electricity system. Analysis suggests demand peaks can be reduced by up to 6%–30%[10] if ETES units are installed instead of e-boilers. Because the electricity grid is dimensioned on the peak capacity, this is a strong reduction in the investments needed to expand the grid. This benefit is being recognised broadly: The European Commission has announced a new peak-shaving product aimed at reducing electricity demand during peak hours, to which ETES could contribute.

Third, ETES systems can output power in addition to heat. Such a combined heat and power (CHP) setup uses high-pressure steam from the storage unit to generate electricity with a turbine. The residual hot water or (lower-pressure, lower-temperature) steam that remains after the turbine is then used in the industrial process. Typically, both the electricity and heat will be used on-site. There is also the option to feed the electricity back onto the grid, in the same way as electric vehicle-to-grid, flexible buildings or other storage technologies. ETES could therefore be utilised not only as flexible demand, but also as flexible generation by the electricity system operator. This setup can only be implemented alongside low- to medium-temperature and pressure heat demand.[11] Because the round-trip efficiency of this setup can be up to as high as 95%, ETES with CHP output could help reduce grid congestion pressure. This setup has the most benefits where the power output is directly used by the industrial site to avoid even higher grid power costs.

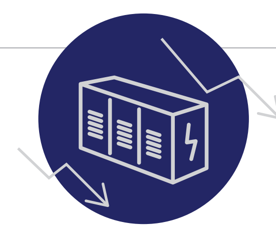
Figure 4 Benefits of ETES to the electricity grid

How ETES can support the transition to a net-zero energy system

ETES can enable faster renewables deployment through creating headroom on grids for renewable power beyond its own charging needs



ETES could avoid overbuild of the power grid by reducing peak demand and the associated costs



ETES can reduce the need for dedicated grid storage by providing balancing and capacity services

Source: Jenkins and Van der Jagt, Understanding the Role and Design Space of Demand Sinks in Low-carbon Power Systems, 2021; Net-Zero Heat, LDES Council, 20XX, and Driving to Net Zero Industry through Long Duration Energy Storage, LDES Council, 2023

10 Estimated by calculating additional demand from grid-connected e-boilers and the 2030 first wave addressable market.

11 Combined heat and power generates electricity and heat by heat cascading. First, the high-pressure, high-temperature steam generates electricity through a turbine. The resulting lower-pressure, lower-temperature heat is used in the process.

1.3 ETES PROVIDES FLEXIBILITY IN THE POWER SYSTEM AT RELATIVELY LOW COST AND COMPARES FAVOURABLY TO OTHER TYPES OF LONG-DURATION ENERGY STORAGE

In principle, the three benefits for the power system described above can also be provided by other electricity storage technologies, such as compressed air or pumped storage. However, the main advantages of ETES are that the cost per unit of storage is lower than other technologies, such as electrochemical batteries, for long-duration energy storage purposes, and the system maintains very high energy efficiency of about 90%–95% from grid electricity to heat output.[12] A cost comparison between ETES technologies and other types of storage can be found in the Technical Appendix.

At least some of the capital cost for an ETES asset can be paid for by the decarbonising industrial heat business case. Therefore, the benefit to the power system is (partially) a bonus similar to electric vehicle batteries. As such, it provides flexibility in the power system at relatively low cost, whilst maintaining a continuous heat supply for industry.[13] According to analyses, an ETES system has a lower cost of heat delivered compared with an e-boiler with a lithium-ion battery storage system.[14]

1.4 THE POTENTIAL MARKET FOR ETES IS HIGHLY DEPENDENT ON THE DETAILED TEMPERATURE NEEDS OF INDUSTRIAL PROCESSES

The market potential for ETES is mostly driven by the temperature requirements of the individual industrial processes and the relative competitiveness of the options available to provide that temperature. On an industrial site, multiple processes, such as drying or distillation that have different temperature requirements, can take place at the same time. A bottom-up assessment of industrial processes indicates that the applicability of ETES differs significantly between sectors.

12 As mentioned earlier, this efficiency is only when heat is the output. The round-trip efficiency of electricity from the grid to the storage unit back to electricity is ~45%.

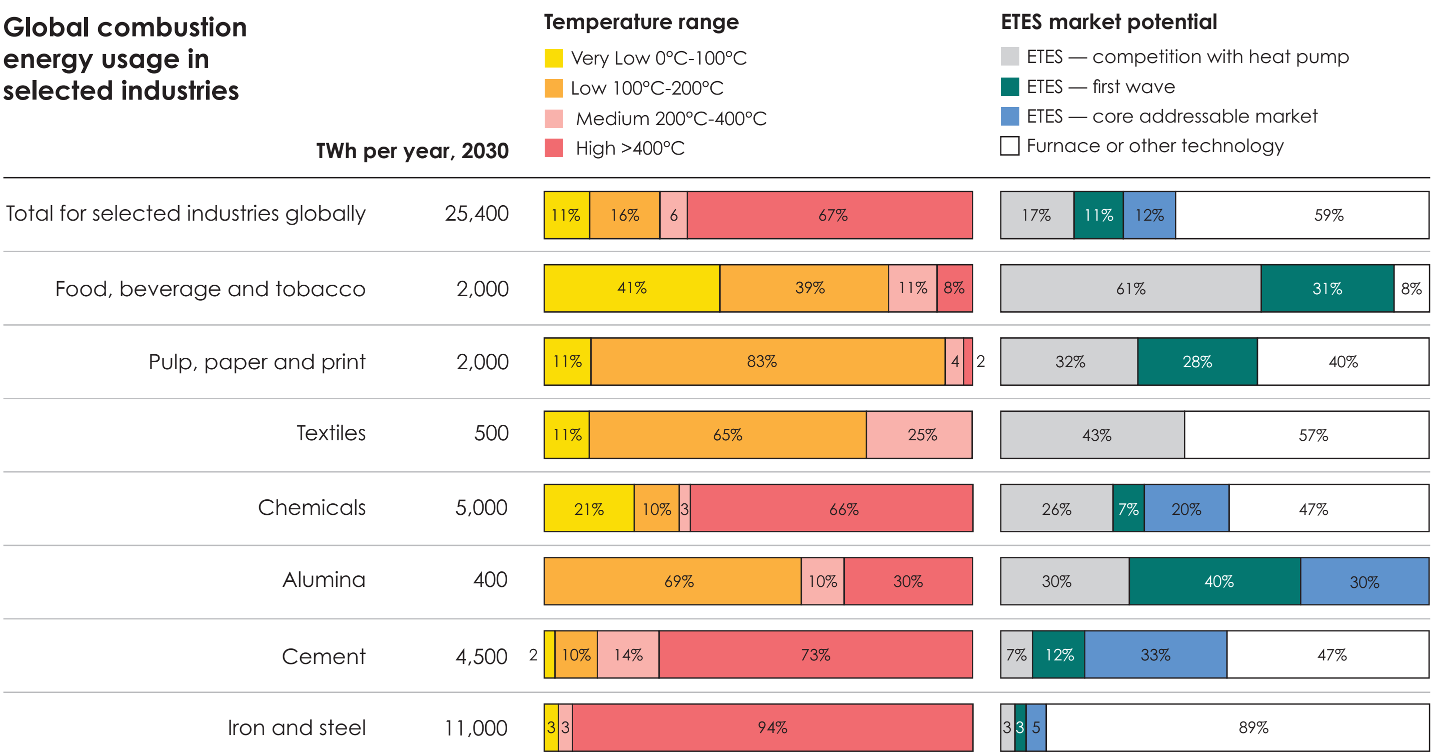
13 *Driving to Net Zero Industry Through Long Duration Energy Storage*, LDES Council, 2023.

14 See the Technical Appendix for detailed analysis. It should be noted that the commercially available storage duration of batteries currently does not reach the storage duration of an ETES system.

ETES technologies can provide a larger share of the heat required in the food and beverage sector, which almost exclusively requires temperatures below 400°C in processes such as baking and pasteurisation. In this sector, ETES technologies have competition from heat pumps as alternatives to provide heat below 200°C.[15] In contrast, the iron and steel sector and cement sector require much higher temperatures, of over 1,600°C in cement kilns for the calcination of limestone and in steel blast furnaces. Given where ETES technologies stand today, they can provide heat for preheating of the air and feedstock and for drying processes, which is a small share of the total energy needs in the iron and steel and cement sectors.

Furthermore, the applicability of ETES can depend on the specific processes occurring within a sector. In the chemicals sector, for example, natural gas is used today to provide heat for the hydrogen production process called steam methane reforming. That process will mostly decarbonise by switching the production to electrolysis, rather than replacing the natural gas furnace with an ETES unit. In the paper and pulp sector for the focus countries in the report, 40%–45% of energy is provided by bio-based feedstock residue. That share of energy is unlikely to be electrified for decarbonisation purposes because it is already low carbon. The overview of heat grades and applicability of ETES is visualised in Figure 5.[16]

Figure 5 Overview of market segments in our global market sizing estimate



Note: Only considers energy usage from fuel combustion, not emissions from process, power sector and transportation energy consumption.
Source: UNFCCC data set (2021), except for Australia (2019); International Aluminum Institute; World Steel Association; Eurostat; EuraTEX; USGS; Petrochemical Europe; EU heat profile is derived from EU Joint Research Center; US heat profile is derived from Decarbonizing Low-Temperature Industrial Heat in the U.S., Energy Innovations, 2023

15 More details on the competitiveness of ETES versus heat pumps can be found in the next chapter and the Technical Appendix.

16 For each of the focus countries, the potential market for ETES was sized bottom-up by considering the applicability of technology to key processes within each sector. The sizing was then extrapolated towards a global perspective by taking global numbers for sectors where ETES is technically attributable to all processes. For sectors where only some processes are included, scale up is done by volume of product produced instead and assumes that the energy intensity per product stays constant.

1.5 THE FIRST WAVE OF EARLY ETES MARKET POTENTIAL IS EXPECTED TO BE MORE THAN 3,000 TWH IN INDUSTRIAL PROCESSES THAT REQUIRE HEAT BELOW 400°C

The deployment of ETES will likely be phased. By 2030, the first wave of ETES is anticipated to be applied at industrial processes with a heat demand up to 400°C.[17] Today, these industrial processes typically use steam to transfer heat from a fossil fuel boiler. These boilers are often positioned just outside the factory building. ETES could be deployed here as a relatively simple replacement of the existing boiler because ETES technologies are currently engineered to provide steam as well. The existing industrial process is therefore not impacted.

Processes heated by steam are prominent in sectors like food and beverage, pulp and paper and textiles. In other industrial sectors, such as alumina, chemicals or biorefining, most processes require higher temperatures. In these sectors, ETES can be deployed for only a part of the heat demand, for example, for bauxite digestion in the alumina process. The global potential for this first wave is estimated to be 3,100 TWh, covering 2% of global energy-related GHG emissions and 8% of gas use in terms of direct on-site impact. The total system impact of this first wave of applications can be up to 1.7 times these numbers if the role of ETES in enabling variable renewables is included.

1.6 THE TOTAL MARKET POTENTIAL OF ETES COULD GROW TO UP TO 11,400–15,900 TWH (10%–14% OF 2022 ENERGY-RELATED GHG EMISSIONS) BY MID-CENTURY AND INCLUDES PROCESSES WITH HIGHER TEMPERATURE NEEDS, NEW INDUSTRIAL PROCESSES THAT SCALE WITH THE ENERGY TRANSITION AND NONINDUSTRIAL HEAT DEMAND

As ETES technologies develop, higher-temperature processes come in sight. The process temperatures in hard-to-abate sectors (chemicals, alumina, cement, refining, iron and steel) are mostly above 400°C. Heat for these higher-temperature processes is typically supplied in furnaces via hot air rather than steam. The development of ETES technologies with a higher temperature output will expand the processes suitable for ETES to include calcination in alumina, a larger share of the preheating in cement production and biorefining in chemicals. The global market potential for ETES in existing higher-temperature industrial processes is estimated.

New industrial processes will emerge as the energy transition unfolds. These can be new and growing markets for ETES. Some of these new processes directly replace existing ones, such as DRI preheating in the steel sector and biorefining in the chemicals sector. Another example is sustainable aviation fuel production, where ETES can provide heat in the Fischer-Tropsch process, which is an important step in electric fuel production.[18] ETES can also provide the heat to separate captured carbon dioxide from the capture medium in direct air capture. The global potential for new industrial processes is estimated to be 4,000 TWh, which is the equivalent of 3% of today's global energy-related GHG emissions and 10% of today's gas use by 2050.

Beyond direct industrial applications, thermal energy storage can also be used to electrify district heating networks, with large-scale working projects in Germany and Denmark.[19] In addition, ETES is seen as a retrofit possibility for coal plants, to turn strategically positioned thermal plants into grid flexibility assets with long-duration storage capacity. The global potential for this segment is estimated to be 1,300 TWh, which translates to 2% of global energy-related GHG emissions and 3% of gas use by 2050.

17 The likely sweet spot for ETES is to serve heat demands between 200°C and 400°C because heat pumps can reach up to 200°C at a higher efficiency.

18 Another industrial process that might be addressable by ETES is the production of alternative or substitute cementitious materials (ACM/SCM), which are projected to replace 10% of clinkers in the cement industry by 2050. ACM/SCM can reduce 400 TWh of heat demand from clinker production, but this is not included in the calculation due to uncertainty about which ACM/SCM option will be the main substitute for clinkers. From Fossil Fuels in Transition, Energy Transition Commission (2023).

19 For example, the ETES company Kyoto Energy is trialling technology to be used for district heating.

A DEEP DIVE ON THE FIRST WAVE SECTORS

In the **food and beverage sector**, steam is used for processes such as cooking, pasteurisation and distilling, which require temperatures below 400°C.

Paper, pulp and print processes are in the same temperature range as the food, beverage and tobacco sector (below 400°C), but ETES applicability is slightly less given that biomass from feedstock residues makes up a large share 40%–45% of energy consumption in the paper and pulp industry today and that is unlikely to be replaced.

Textiles facilities tend to use low-temperature heat (below 100°C) for drying, washing and pressing on a continuous basis. There is relatively little textile industry compared with the other segments in the countries that are the focus of this report.

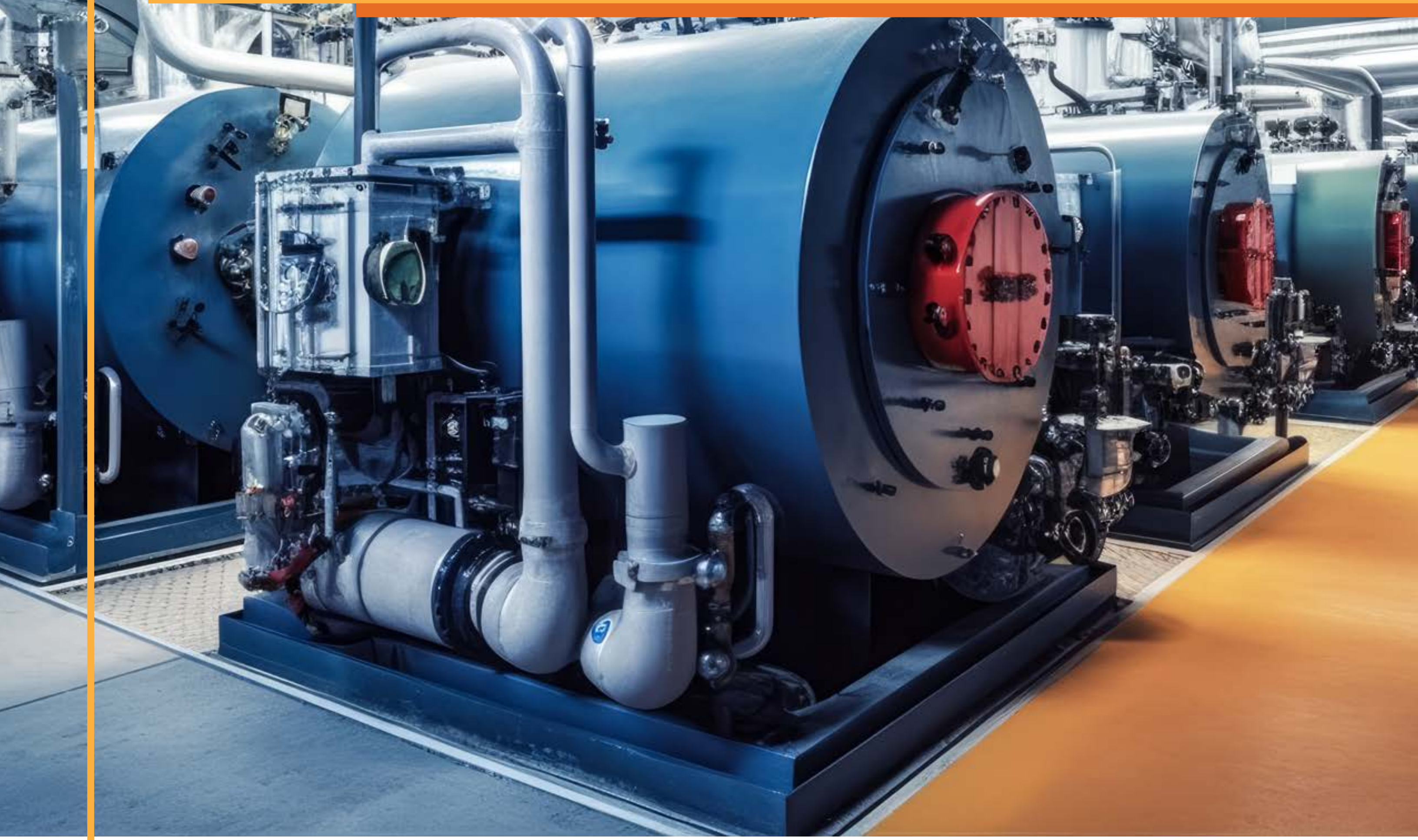
Alumina refining takes place in four steps, with ETES applicable in the first wave for the first step, digestion. In the digestion step, bauxite is finely ground in mills, then mixed with a recycled caustic soda solution and steam in digester vessels operating at high temperature (up to 280°C) and high pressure.

In all these applications, heat pumps and electric boilers are alternative technology choices, depending on the temperatures required. The trade-offs are described in the next chapter of this report.[20]

20 This was accounted for in the market sizing by excluding the heat demand up to 100°C, and only including half of the heat demand between 100°C and 200°C for the first wave and core addressable market.

CHAPTER 2

OPPORTUNITIES AND BARRIERS OF THE SCALE-UP OF ETES



2.1 A TIPPING POINT FOR ETES CAN BE REACHED THROUGH CLOSING GAPS IN AFFORDABILITY AND ACCESSIBILITY

Historical examples indicate that the uptake of a new technology typically follows an S-curve, as is visualised in Figure 6. According to the tipping point theory, the exponential uptake of a new technology will start when the technology is more affordable, attractive and accessible than the conventional alternative.[21]

To reach a tipping point, ETES should be more competitive than fossil fuel alternatives. And to capture a significant share of the market potential, ETES should be more competitive than other alternatives to provide zero-carbon heat. Compared with fossil fuel alternatives to provide industrial steam, ETES scores well on **attractiveness**. It reduces GHG emissions and air pollution and is relatively easy to add into an existing process and holds benefits for power systems. However, on **affordability** and **accessibility** ETES still has a gap to close.

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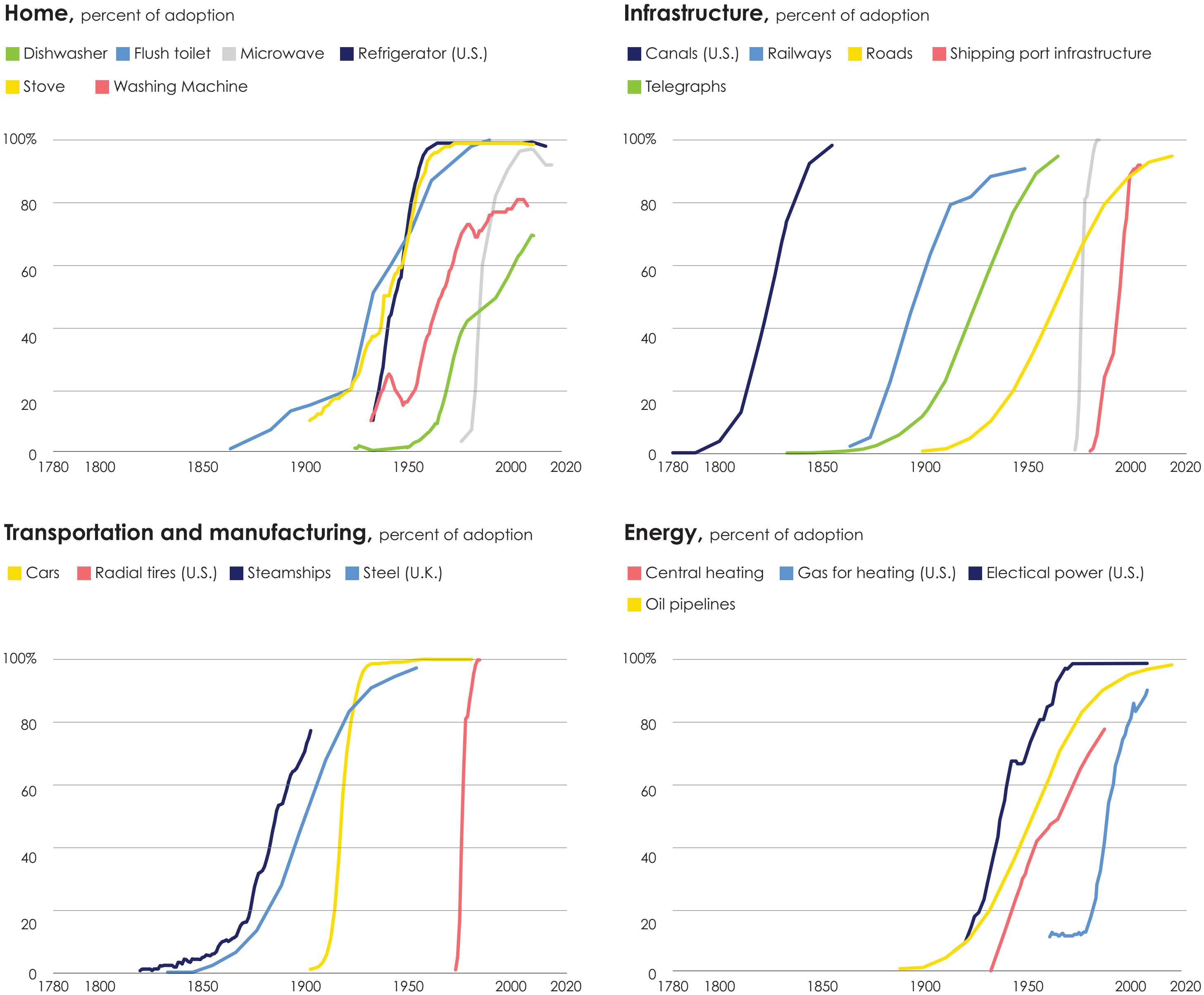
15 *The Breakthrough Effect*, Systemiq 2023

Figure 6 Historial tipping points

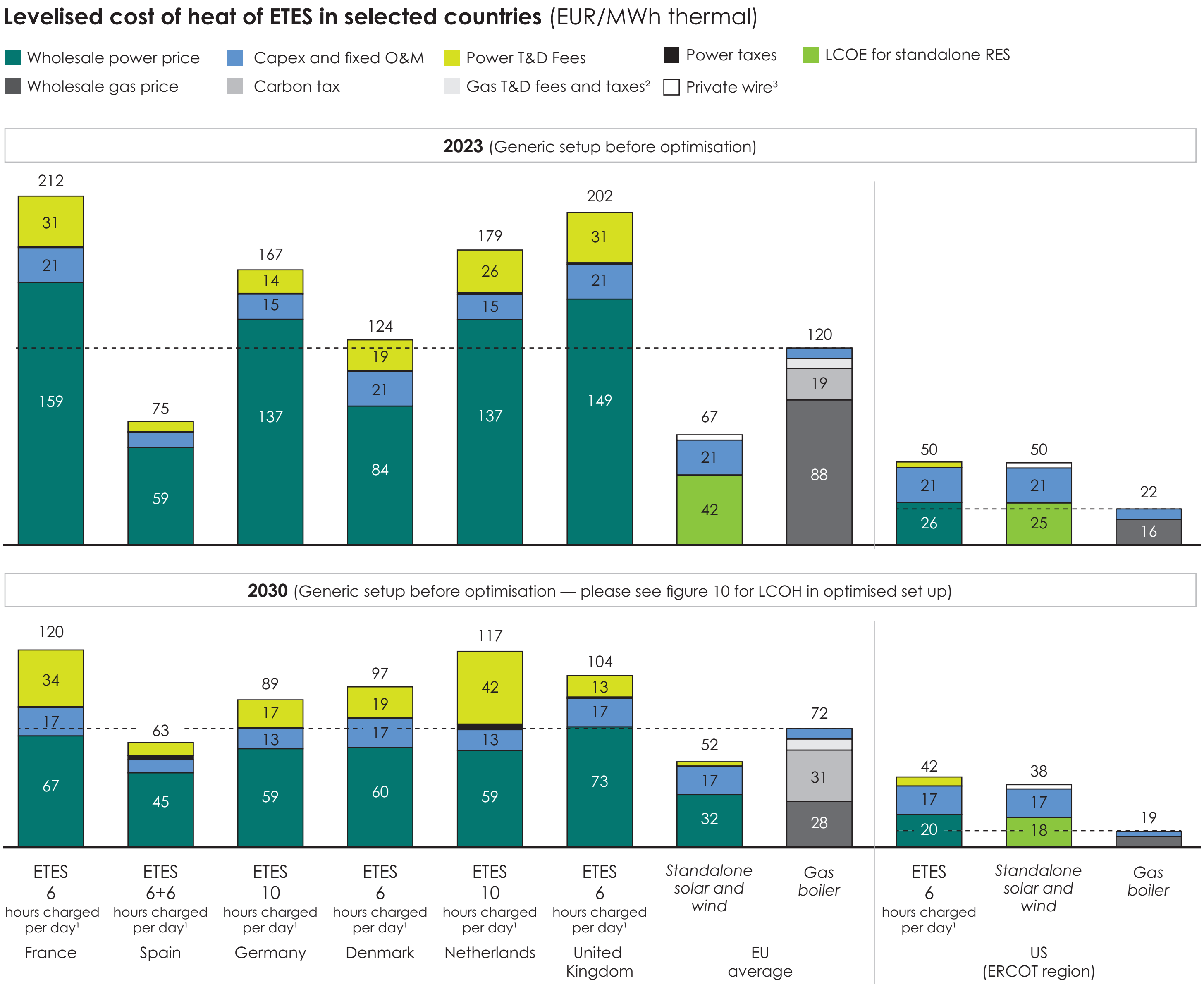


2.2 AFFORDABILITY: ALTHOUGH ETES ALLOWS INDUSTRIAL COMPANIES TO ACCESS THE LOWEST POWER PRICES, GRID FEES AND TAXES AND THE CAPITAL COST MAKES HEAT FROM ETES GENERALLY LESS AFFORDABLE THAN HEAT FROM A GAS BOILER

To compare the costs from different heating technologies, the levelised cost of heat (LCOH) can be used. The LCOH combines the different aspects that contribute to the heating costs. The main contributors to the LCOH of ETES are power prices, grid fees and the capital costs of the ETES unit. Figure 7 provides an overview of the LCOH in the focus countries. The LCOH below are generalised, it is worth nothing that for specific sites there are optimisation levers available (for example negotiating PPA contracts or optimising charging schedules) that can significantly reduce LCOH. Please see box on case studies later in this chapter, the levers in Chapter 3 and the country action plans for more details. From the analysis on focus countries it is apparent that the affordability gap can be closed today with realistic actions from market players, technology providers, industrial users, policy makers and grid operators.

In the countries that were analysed, there is significant variation in grid-based power prices during the day. Historically, the difference between the average 24-hour power price and the lowest-cost six hours was 13%–45%.[22] ETES technologies allow companies to capture these lowest power prices and use these limited number of charging hours per day to provide continuous 24-hour heat. In all focus countries, electricity prices in the six lowest-cost hours were higher than wholesale gas prices per unit of energy.[23]

Figure 7 Generalised LCOH in 2023 and 2030 in selected countries



¹ Commercially available solid state thermal energy storage, 6- to 12-hour charge and 24-hour discharge; wholesale power price is for the least expensive 6 to 12 hours
² Private wire estimated at 15% of CAPEX
³ Private wire estimated at 15% of capital expenditures
Note: Does not include current subsidies schemes, changes in T&D fees, taxes, and balancing costs; power prices are based on CCC projections for a decarbonised grid
Source: P2H Cost Calculator (2022) — Agora, IRENA Remap 2030, TNO Technology Fact sheet (2015), Thermal Energy Storage (2023) — RTC, Industrial Thermal Batteries (2023) — LDES, Prospects for LDES in Germany (2022) — Aurora, Expert interviews, TSO And DSO websites, 2022 Entso-E Power Prices, EEX Future Prices, MPP Power and Feedstock Projections (2020), Climate Change Committee — Deep-Decarbonization Pathways for UK Industry, Nord Pool, Cornwall Insight GB Power Market Outlook to 2030 Q2 2023

22 Based on 2022 Day-Ahead prices from European Network of Transmission System Operators for Electricity (ENTSO-E), the lowest-cost six hours were 55%–87% of the average day-ahead price.

23 Based on the hourly price data, these lowest-cost hours are in some regions 60%–80% more expensive per unit of energy than the natural gas wholesale price.

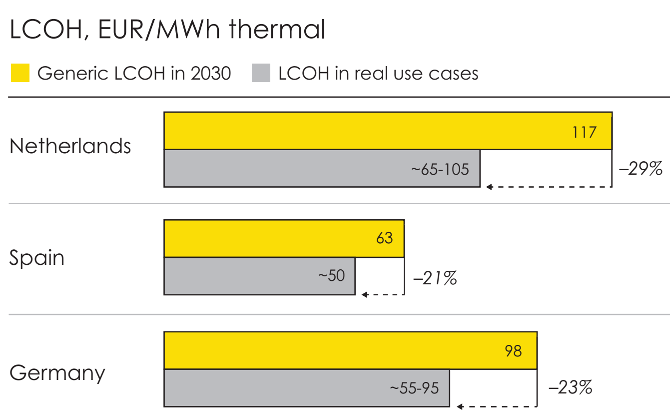
Grid fees are a major contributor to the price difference between ETES and gas boilers. Electricity grid fees could be up to six times higher than gas grid fees in 2023, increasing to up to 12 times higher by 2030 under current grid fee structures. Often this is due to the legacy design of grid tariffs and market mechanisms, which were suitable for a dispatchable system based on fossil fuel–based electricity generation assets. In some countries, like Germany, grid fee levels are negotiable. Many of the countries that were analysed are now in the process of approving updated grid fee structures to ensure that flexibility in the electricity system is fairly incentivised. For example, the Netherlands and Denmark have introduced discounted grid fees for interruptible connections.

As can be seen in Figure 7 (previous page), in certain countries, like Spain, the electricity price difference and the grid fee structure are such that ETES is competitive with gas boilers in 2030. For example, Spain uses time-variable grid fees, which allow ETES to charge at times with low fees. In other countries that were analysed, ETES assets that use grid-based electricity are less affordable than natural gas boilers under the current grid fee structures, though countries are starting to look at changes as noted above. However, in specific project circumstances, ETES can already be more affordable than a gas boiler today by optimising the charging schedule, backup heat source, direct connection to renewables and so on, for specific local and industrial site characteristics (see Box below).

OPTIMISING ETES: CASE STUDIES

Technology providers have shared anonymised real-world examples of how ETES is applied. It is found that optimising the setup of an ETES can result in up to a ~50% reduction in LCOH compared with a generalised setup. These levels can be reached for assets that are — at least partially — connected to the grid. Levers for optimisation include — but are not limited to — negotiation of grid fees, negotiation for power supply contract and backup from gas boilers to avoid charging at times with very high power prices.

Levelised cost of heat of different technologies in real case studies in selected countries, 2030



Country	Generic LCOH in 2030	LCOH in real use cases	Change	Applications	Process temperature range	Power supply
Netherlands	117	~65-105	–29%	Chemicals	180-200°C	Grid connected, grid with solar and backup gas boiler
Spain	63	~50	–21%	Chemicals, pulp and paper, pharma	160-230°C	Grid connected, power purchase agreement, grid connected with power purchase agreement
Germany	98	~55-95	–23%	Pulp and paper, manufacturing	150-210°C	Grid with solar and backup gas boiler, grid connected with backup gas boiler

Source: Technology providers

2.3 OPTIMISING THE SITE- AND LOCATION-SPECIFIC SETUP OF THE ETES ASSET CAN REDUCE THE LCOH

Technology providers and industrial sites can optimise the deployment of the ETES asset based on site specifics, such as the operating schedule and the location. On a case-by-case basis, optimising the charging pattern and size of the installation can lower the cost of heat by up to ~30% compared to the general analysis in this report (see Box on previous page).

Linking ETES to renewable electricity generated on-site or using a private wire to connect to a renewable energy source nearby results in the lowest cost of heat because it allows the circumvention of grid fees and gives access to low-cost power. This private wire option can reduce the LCOH by about 25%–75% depending on the region and renewable energy source, as is shown in Figure 7. This setup is not able to fulfil all heat demand with ETES without a backup grid connection or energy supply. There will be days in the year when the renewable power asset cannot produce enough to charge the ETES.

As discussed earlier, an ETES asset can be engineered to generate both heat and power in a CHP setup. This could lower the overall cost of energy for a site in locations where the electricity price fluctuation is high. In the countries assessed, the CHP option reduced the cost of heat by about 3%–11%, but in instances with high grid fees, it increased the price of heat by 1%–8%.[24] The cost advantage that CHP brings by displacing electricity purchased from the grid, increases as electricity price volatility increases and/or if electricity is obtained directly from renewable energy generation assets, as direct generation is often cheaper than wholesale electricity purchased.

2.4 OPTIMISING THE ETES SETUP TO GENERATE ADDITIONAL REVENUE STREAMS FROM GRID SERVICES

ETES' heat-generated revenue can be supplemented with additional revenue streams from grid services. An ETES system without CHP power output is able to participate in demand-side response and ancillary services (up and down reserve markets), given the ability to flexibly charge.[25] An ETES set up in CHP mode enables it to participate in power market revenue streams of balancing services and capacity markets.[26]

Using ETES in these markets can provide a hedge against power price uncertainty. Whenever electricity prices and thus the cost of delivering heat are high, revenues from balancing markets are also likely to be high due to tightness in operating the power system. It is worth noting that participation in some markets will prevent bidding in others. For instance, participation in secondary reserve, which helps keep the grid frequency stable, would prevent participation in wholesale intraday markets.

Indicative revenue estimates from actual cases indicate value captured across balancing markets and ancillary services could lower LCOH by ~20–40 EUR/MWh, reducing the cost of heat by 20%–60%.[27] Actual values will vary according to market and trading strategy. It is worth noting that optimising for ancillary services will impact on the cost of electricity used to charge the ETES system, and that there is uncertainty risk to revenues, as ancillary services contracts are short term or market based so cannot be locked in.

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24 Due to the need for ETES to continue heat supply 24/7, an ETES + CHP configuration requires a larger grid connection. An overview can be found in the Technical Appendix.

25 For example, the United Kingdom has a well-functioning flexibility market in place through which ETES could generate additional revenues.

26 Out of the countries analysed in this report, France, Germany, Italy and the United Kingdom have (various designs of) a capacity market in place. Of these, the United Kingdom's capacity market is the most mature. Spain is currently designing a capacity market.

27 Case studies suggest that ancillary service revenues could be in the range of EUR 20,000–40,000 per installed megawatt hour (MWh) per annum. For an installed capacity of [100] MWh, this would translate to [EUR ~2,000,000 to ~4,000,000] per annum, lowering the LCOH by ~20–40 EUR/MWh. The Texas region of the United States is not included for percentage range.

In addition to grid services, ETES as a storage asset can also be used to take intraday trading positions and capture a share of the price movements in the electricity wholesale market (arbitrage), similar to energy generation and flexibility assets including pumped hydro. Across the regions assessed, ETES assets were already eligible to participate across existing grid service markets.

ETES IN ITALY

Although Italy is not a focus country in this report, there is a growing interest in ETES there. ETES may be cost-competitive with incumbent gas boilers by 2030, taking into account available subsidies.[28] Industrial companies, mainly in the food and beverage and pulp and paper sectors, are already exploring the benefits ETES could bring to their sites with first deployments expected to be driven mainly by companies' individual decarbonisation targets.

Several factors for the interest in ETES in Italy are:

1. **Very low power prices** stemming from the increased development of renewables, especially in the central and southern parts of Italy where high levels of north-south transmission grid congestion occur, because expanding the grid is challenging. ETES is a way to capture this value.

2. **Government capital expenditure incentives**, consisting of innovation tax credits, region-specific incentives and incentives to support Energy Communities. In total, capital expenditure incentives can reduce the levelised cost of storage by ~40%–50%, providing strong support for the ETES business case.[29]

3. **Government operational expenditure incentives**, through support for Energy Communities and potential additional revenues from energy efficiency certificates and grid services. In total, operational expenditure incentives can reduce the LCOH by ~15 EUR/MWh thermal.[30]

However, extensive bureaucratic processes can be a barrier for companies to access these incentives. If incentive processes can be simplified, the case for ETES in Italy could be strong.

2.5 ACCESSIBILITY: ETES IS LESS ACCESSIBLE THAN CONVENTIONAL BOILERS DUE TO GRID CONNECTION QUEUES

ETES is expected to be accessible from a supply chain perspective. There are a significant number of technology providers, the technologies do not make use of scarce materials and assets can be produced locally.

However, grid-connected ETES scores worse than conventional boilers on accessibility due to the requirement for sizeable grid connections in — in some cases heavily — congested grids. Grid

28 Based on ETES with dedicated solar photovoltaic and including capital expenditure and operational expenditure incentives.

29 Capital expenditure incentives include the ZES tax credit (2024), the Industry 5.0 tax credit (2024), the Energy Community benefit (on thermal storage capital expenditures) and the innovation fund.

30 Operational expenditure incentives include the Energy Community benefit and potential revenues from white certificates and grid services.

connection queues can push back the ability for a site to increase its electrical connection by up to 10 years. In countries where the grid is congested, such as France, the Netherlands, Spain and the United Kingdom, this issue is not unique to ETES but also touches the connection of new power generation assets and demand from new residential neighbourhoods.

Some countries such as Spain and the United Kingdom are in the process of amending connection queues to give preference to the connection of renewables and storage. Other countries such as Denmark and the Netherlands are in the process of approving interruptible grid connections in locations where these benefit the grid.[31]

ETES systems could bypass congested electricity grids altogether through a private wire setup (in regions that allow this) that connects directly to renewable electricity production, although a backup such as a gas boiler or grid connection is required to ensure continuous heat supply when there is less renewable energy production than needed to charge the ETES.[32] By keeping a gas boiler as backup, the operational risk associated with the installation of the new ETES technologies is reduced.

2.6 ETES COMPLEMENTS OTHER INDUSTRIAL HEATING TECHNOLOGIES SUCH AS HEAT PUMPS AND ELECTRIC BOILERS

There are more technologies to decarbonise heat besides ETES. Alternatives are electric boilers, heat pumps and hydrogen-based heat.

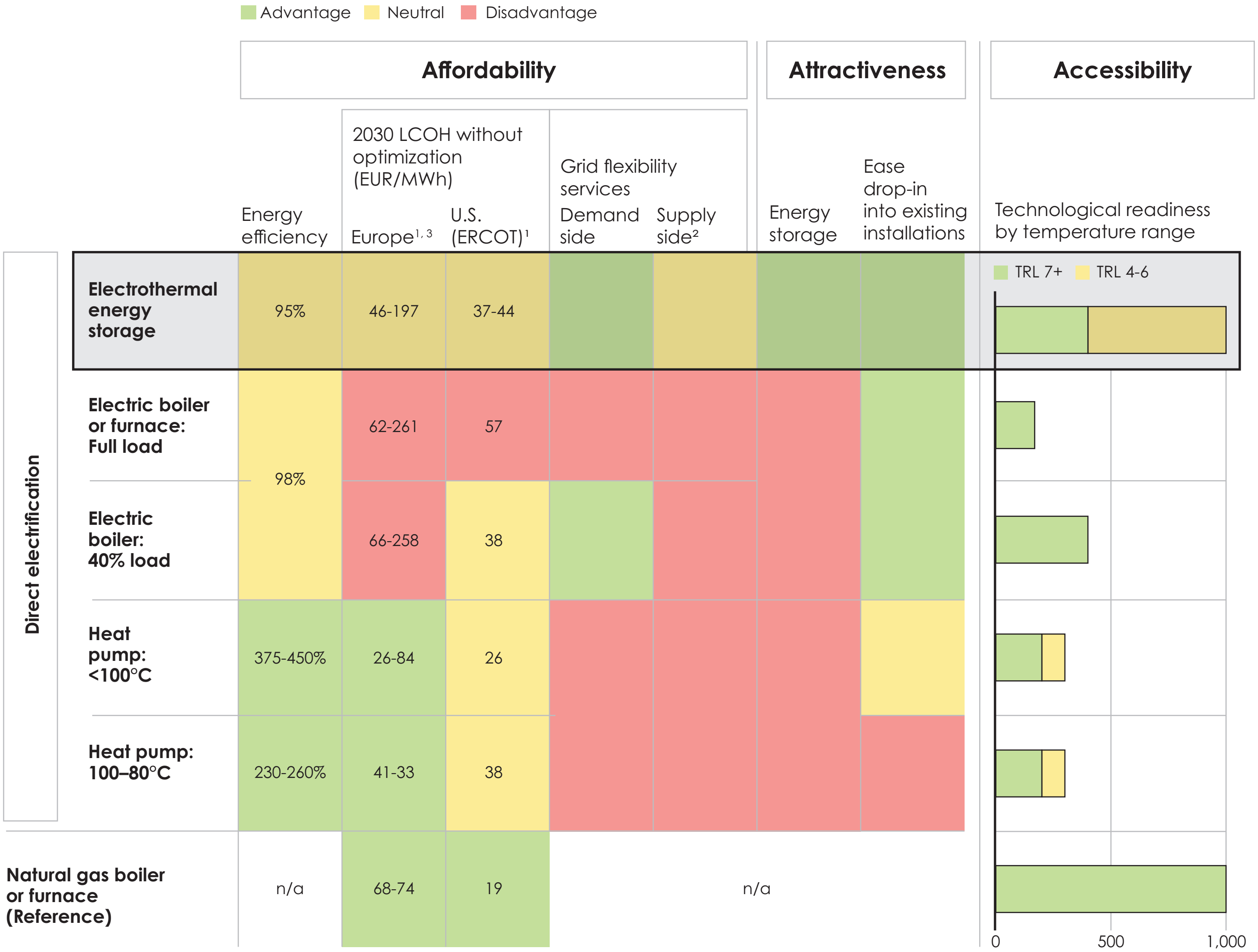
A natural gas boiler or furnace can be replaced by a hydrogen boiler or hydrogen furnace. These would provide zero-carbon heat if the hydrogen is produced without carbon emissions. The cost per unit of energy of hydrogen makes this option unaffordable. Hydrogen is an expensive fuel because of the many steps and inefficiencies in its production and costs associated with transport and storage. The lack of green hydrogen production makes this option inaccessible as well. It is expected that hydrogen will play a marginal role in providing industrial heat.

Electrifying heat with heat pumps and electric boilers or furnaces is expected to play a significant role alongside ETES in the decarbonisation of industrial heat. Figure 8 highlights the key differences between these technologies. Regardless of choice of electrification technology, many customers will elect to keep their gas boilers and operate these as a backup heat source to minimise risk whilst transitioning towards electrified heat.

31 Another option to accelerate ETES grid connection is when interruptible or non-firm grid access contracts are available: using a special contract, grid operators are allowed to interrupt grid connections during peak times in exchange for a discount on grid fees. ETES can use the grid connection when capacity is available.

32 Although developing renewables alongside ETES could lead to increased project risk and timelines, ETES could be sited with existing renewables facing curtailment and absorb otherwise curtailed power. However, for ETES to produce heat continuously, a backup heat or electricity supply is required for days when there is not enough electricity produced by the renewable asset.

Figure 8 Key differences between ETES, heat pump and e-boiler technologies



[1] Assumptions for all technologies: 10 MW capacity for thermal discharge 95% capacity factor (except for e-boilers at 40%); 25-year lifetime for the calculation of annualized capital expenditures 8.5% cost of capital

[2] Is technically capable of participating in ancillary, capacity and balancing mechanism services

[3] ETES lower bound uses stand-alone wind/solar

Source: P2H Cost Calculator (2022) — Agora, IRENA Remap 2030, TNO Technology Fact sheet (2015), Thermal Energy Storage (2023) — RTC, Industrial Thermal Batteries (2023) — LDES, Prospects for LDES in Germany (2022) — Aurora

2.7 HEAT PUMPS ARE MORE ECONOMICAL FOR LOWER TEMPERATURE RANGES, BUT CAN INCREASE SYSTEM COMPLEXITY AND DO NOT OFFER SIZEABLE ENERGY STORAGE CAPABILITIES

Heat pumps are often the most economical option to provide low-temperature heat, due to theoretically high efficiencies of 300%–400%, compared with a round-trip efficiency of 90%–95% of ETES. The higher efficiency often more than compensates for the higher investment costs that come with the procurement and installation of a heat pump. However, heat pumps are limited by their operating temperature range. Today they operate up to 120°C and there is an expectation that this could increase to about 200°C. The electricity demand of heat pumps is lower than that of ETES, but the absence of sizeable storage makes that electricity demand less flexible.

In higher temperature ranges (in the 100°C–200°C region), heat pump operating efficiencies can drop to 200%–300% and the system's complexity can increase. Higher-temperature heat pumps need a heat input that is 50°C–80°C below the required temperature to operate efficiently. This is not always available, or only with extensive retrofitting changes to the (steam) pipe system on-site. Conversations with technology providers indicated that only a small amount of customisation is required to retrofit compatible processes with ETES.

2.8 ELECTRIC BOILERS AND FURNACES CAN REPLACE FOSSIL FUEL–FIRED BOILERS AND FURNACES, BUT REQUIRE A HIGH AND CONTINUOUS ELECTRICITY DEMAND

Electric boilers are a one-for-one replacement for existing fossil fuel–fired boilers. Electric furnaces can replace existing fossil fuel–fired furnaces in theory but require dedicated technology development for higher-temperature processes (800°C–1,650°C[33]) such as steam cracking in the chemicals sector. Electric boilers and furnaces require continuous electricity to provide continuous heat because storage is not integrated. These assets have relatively high operating costs because they lack the advantages of storage and a high energy efficiency. If electric boilers are operated in a hybrid setup next to a gas boiler, they can operate as a flexible load. In these setups, typically only up to 40% decarbonisation is achieved and scaling up to 100% operational hours is costly due to the baseload power demand. Overall, electric boilers and furnaces require a smaller grid connection than ETES, which leads to lower grid fees in most grid fee structures today.

2.9 COMPARED TO HEAT PUMPS AND E-BOILERS, ETES HAS SEVERAL ADVANTAGES WHEN CATERING TO MEDIUM- TO HIGH-TEMPERATURE HEAT PROCESSES

The main advantages are:

- **Commercial high temperature range**, available today up to 400°C with potential to increase above 1,500°C (currently under development)
- **Ability to lower operating costs**, as a flexible demand asset that is able to consume the cheapest electricity prices and capture benefits from electricity system services (which can be done by running in CHP setup)
- **The ease of retrofit** in place of conventional steam production for industrial processes, which make up the majority of low- to medium-temperature processes.

33 Temperature for steel blast furnaces from British Steel website and for steam cracking from Linde website.

CHAPTER 3

ACTIONS FOR A TIPPING POINT IN ETES

3.1 COUNTRY-SPECIFIC ACTIONS ARE REQUIRED TO OVERCOME AFFORDABILITY AND ACCESSIBILITY BARRIERS

Previous chapters discussed the benefits of ETES technologies and their role in decarbonising industry and energy systems. ETES has a role to play not only in driving energy independence and decarbonisation, but also in enabling a faster scale-up of variable renewables generation, which is the foundation of future energy systems. There are, however, barriers in affordability and accessibility for ETES to reach a tipping point.

Today's electricity policy, regulatory and market mechanisms were designed with a very different electricity generation and demand system in mind. To reap the benefits of a scale-up of ETES, unintended system disincentives need to be reformed, and ETES needs to be eligible for decarbonisation incentive schemes. Changing today's electricity grid fees and market mechanisms are the most critical levers to ensure ETES can compete on equal footing.

An overview of the enablers required for a tipping point in ETES is shown in Figure 9. All countries that are analysed have gaps, but they are not the same in each country. The mechanisms that would enable ETES (such as subsidy schemes and grid codes) are different in each country.

Figure 9 Assessment and key enablers that policymakers and grid operators can action to reach a tipping point for ETES and their status in countries analysed

Priority enablers | In place | In progress | Not in place | Not relevant

	Enabler	Netherlands	Spain	Germany	United Kingdom	France	Denmark	TEXAS US
Affordability	Electricity market design gives right signals to incentivise flexible assets to come into the system	In place	In place	In place	In place	In progress	In place	In place
Affordability	**Grid costs charging structure reflects congestion alleviation benefits**	In progress	Not in place	Not in place	Not in place	Not in place	In progress	In progress
Affordability	Thermal energy storage can participate in balancing mechanism, capacity markets and ancillary market services	In place	In progress	In progress	In place	In progress	In progress	In progress
Affordability	**Thermal energy storage is eligible for (net-zero) subsidies**	In progress	In progress	In progress	Not in place	Not in place	Not in place	In progress
Attractiveness	Industrial users have the access and capability to optimise in the wholesale price market	In place	In place	In place	In place	In place	In place	In progress
Attractiveness	Industrial users are familiar with thermal energy storage technology	In progress	In progress	In place	In place	In place	In place	In place
Attractiveness	Public procurement requirements are in place for industrial products with low embedded carbon	In place	In place	In progress	Not in place	In progress	In place	In place
Accessibility	Companies are able to deploy private wires as needed between renewables generation and industrial sites	In place	In place	In place	In place	Not in place	In place	In place
Accessibility	**Companies are readily able to connect and access grid capacity required**	Not in place	Not in place	In progress	Not in place	Not in place	In progress	In progress
Accessibility	**Decarbonisation technology connections are prioritized during supply chain delays — US only**	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not in place

Source: Source: Systemiq analysis based on government websites, press search, Aurora reports and RTE reports

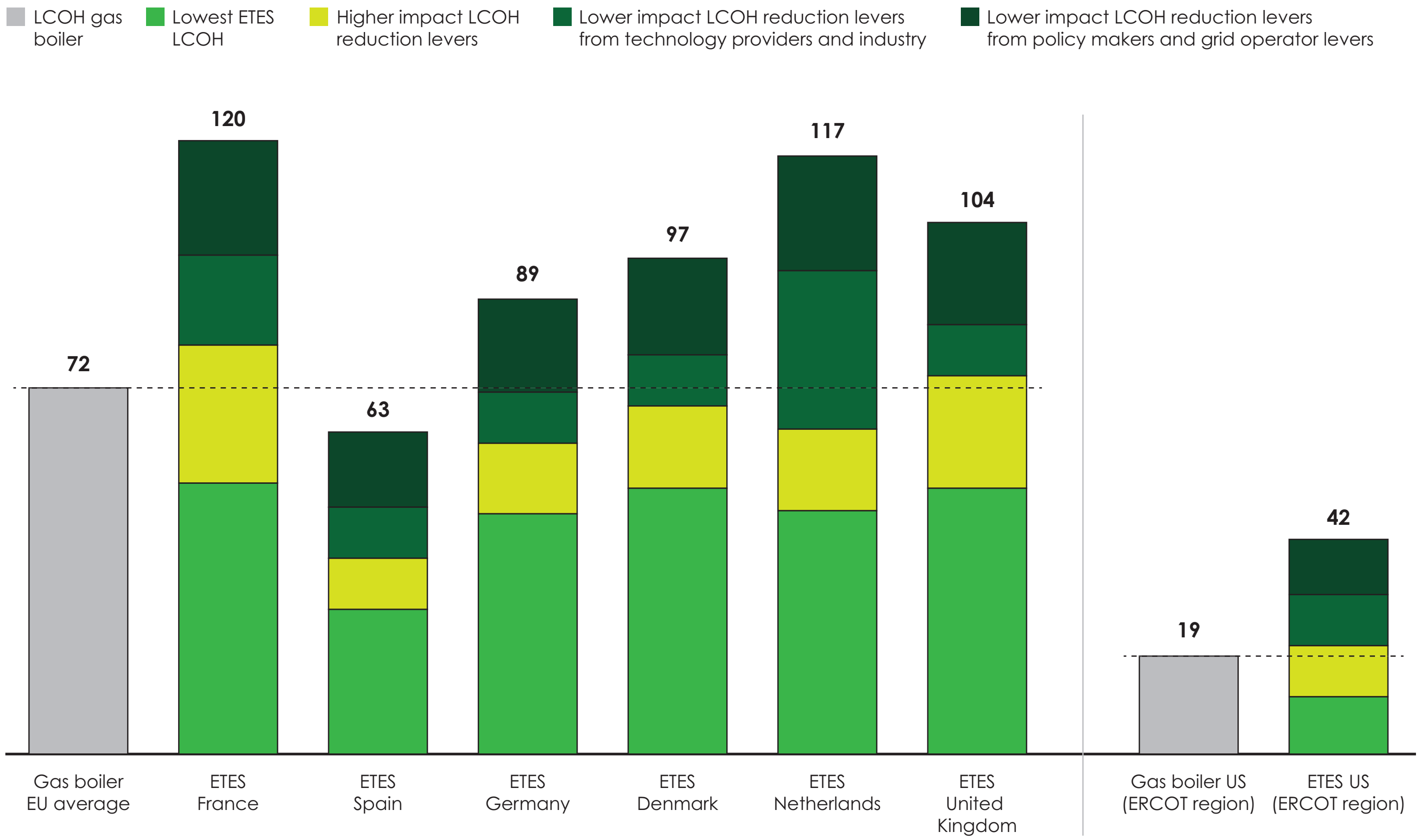
To give the best possible perspective on the ETES benefits and actions for policymakers and grid operators, detailed action plans for each country were created. These can be found in the country action plans for each of the seven countries assessed as part of this work, which can be found at **https://systemiq.info/etes.**

LEVERS TO BRIDGE THE AFFORDABILITY GAP BETWEEN ETES AND GAS BOILERS

The impact of levers on the affordability of ETES was estimated for all focus countries. Affordability gaps between ETES and gas boilers persist generally in all countries that were analysed. The only exception is Spain, where the wholesale power price is relatively low compared with wholesale gas prices. Policymakers, grid operators, industrials and technology providers can close the gap between ETES and gas boilers. An overview of all levers can be found in country action plans and technical appendix. An overview of the ETES LCOH after levers are actioned can be found in Figure 10. This shows the affordability gap can be closed in all regions analysed. No subsidies are required for 2030 if all levers materialise. These considerations are important for ETES investment decisions today, as these assets will be operational by 2030.

Figure 10 Illustration of levers available to close the LCOH gap between ETES and gas boiler

ETES levelised cost of heat including the impact of levers that close the affordability gap. Details can be found in the country action plans (EUR/MWh thermal, 2030)



NOTE: Starting point assumptions similar to those in Figure 7. Details can be found in the country action plans

Source: P2H Cost Calculator (2022) - Agora, IRENA Remap 2030, TNO Technology Fact sheet (2015), Thermal Energy Storage (2023) - RTC, Industrial Thermal Batteries (2023) - LDES, Prospects for LDES in Germany (2022) – Aurora, Expert interviews, TSO And DSO websites; Capturing the green-premium value from sustainable materials (McKinsey, 2022); Scaling textile recycling in Europe–turning waste into value (McKinsey, 2022); The Promising Eect of a Green Food Label in the New Online Market (Jiang Y, Wang HH, Jin S, Delgado MS, 2019); Historical gas TTF futures and day-ahead spot market power (investing.com); ERCOT; Thermal Batteries: Opportunities To Accelerate Decarbonization of Industrial Heat (Renewable Thermal Collective, 2023);

3.2 GENERALISING ACROSS COUNTRIES, ACTIONS FROM POLICYMAKERS AND GRID OPERATORS ARE KEY TO ENABLE THE RAPID DEPLOYMENT OF ETES

A number of key enablers are required for ETES to be rapidly deployed. The critical ones that came out of interviews and research into the seven focus countries are:

- **Reform grid fees, taxes and discounts to incentivise grid power usage during least-used periods.** The cheapest grid costs should be for usage that is least cost to the grid (i.e., flexible or off-peak usage), but this often not the case today. Grids are planned to serve peak load. Therefore, grid costs (fees, taxes and levies) and associated discounts could be aligned with how much usage profiles add to the peak load.

- **Introduce criteria to fast-track grid connection for flexible demand technologies.** Flexible demand could reduce grid congestion issues. However, there is currently a long wait time (of up to 10 years in some regions) to be connected to the grid. Some regions are proposing prioritising renewables and electricity storage connections. Even though ETES may reduce grid congestion (depending on charging schedule), it has not been considered for prioritisation.

- **Ensure that ETES is eligible for industrial decarbonisation, energy storage and flexible demand support schemes.** ETES being a relatively new technology means it is often not included in support schemes. The actions would not only enhance energy security and reduce emissions on-site, but also benefit the decarbonisation of the wider electricity system. Even today the affordability gap can be closed without subsidies in certain countries and setups. Subsidies put in place today will provide business case certainty for cost effective decarbonisation of heat to be implemented by 2030. Most business cases made today will include the LCOH around 2030 and beyond. Analysis shows that dedicated subsidies are not required in 2030 in the countries analysed if other levers are actioned.

3.3 ACTIONS FROM TECHNOLOGY PROVIDERS AND INDUSTRY ARE ALSO CRITICAL TO ENABLE THE RAPID DEPLOYMENT OF ETES

Consistent actions across all countries are also important from industrial end-use customers to understand the economic and decarbonisation potential of ETES for their sites:

- **Execute business case comparisons for a cost-effective electrification plan for sites.** Applicable industries of food and beverage, chemicals, pulp and paper, iron and steel and cement can invest the time now to work with technology companies to assess whether ETES would be a cost-effective solution for electrifying processes.

- **Assess demand and introduce a green premium if there is market/consumer appetite.** There is increasing demand from sectors across the board for Scope 2 and Scope 3 decarbonisation.

Technology providers today are already working closely with customers to identify attractive applications of their ETES systems. Action will continue to be required:

- **Work with policymakers, grid operators and industry to raise awareness of ETES applications and benefits, and to drive forward the implementation.** This is especially important because there will be a much wider variety of applications in the future.

- **Establish relationships with grid operators and utilities to provide a complete package for customers,** which removes the complexity of permitting, grid connection and charging pattern optimisation.

- **Identify and focus commercial activities and product design on locations and (sub-)sectors where ETES technologies are competitive today.** This will enable a ramp-up and maturation of the technology whilst market conditions further improve.

Many of the assessed countries are already heading in the right direction, with changes in grid fees and market participation being discussed to incentivise flexibility. Increasingly, technology providers and industrial companies are working together to find suitable and competitive applications for ETES technologies. With the actions as set out in this report, a tipping point in ETES that can unlock energy security, decarbonisation and both industry and power system benefits could become a reality.

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