SECTION 3

IDENTIFYING ASEAN'S TIPPING POINTS BY SECTOR

This section presents analyses on the six prioritized sectors in ASEAN discussed in Section 2. In each sector analysis, the report seeks to answer the following questions:

Global sector context

- What is the **global context** of how this sector will decarbonize?
- What are the **core low-carbon solutions** that will drive decarbonization?

Geographic sector context

- How is the **sectoral transition progressing** at **ASEAN level**?
- Are there **opportunities or challenges** specific to the region?

Solution status

- What is the **current status** of the core solution being adopted at ASEAN level?
- Is it only **in development**, or being adopted in **niche markets**, or starting to break into **mass market**?

Tipping point status

- How close are we to a **tipping point**, to help the solution break into mass market?
- What are the **key gaps** to be addressed to trigger one?

Tipping point calculation & levers

- What is the **comparison** of the **current** and **potential future costs** of the **low-carbon solution** versus **the incumbent**?

Target conditions progress to trigger tipping point

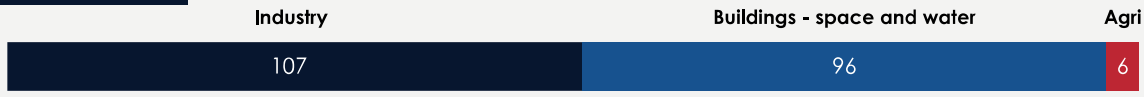
- What is **the current** and **potential future** status of the **tipping point conditions** (affordability, attractiveness, and accessibility)?

MANUFACTURING: INDUSTRIAL HEAT

4% OF TOTAL ASEAN GHG EMISSIONS 2020

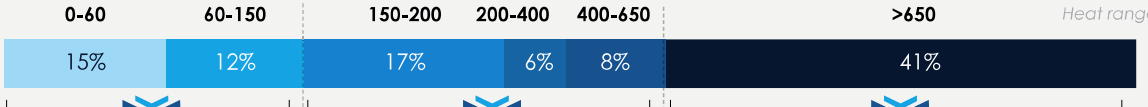
GLOBAL SECTOR CONTEXT

HEAT CONSUMED BY SECTOR[A] (EJ)



Heat accounted for half (209 EJ) of the world's total final energy consumption in 2019. Half of that came from industrial heating (107 EJ). [A]

INDUSTRIAL HEAT DEMAND BY RANGE[B] (EJ)

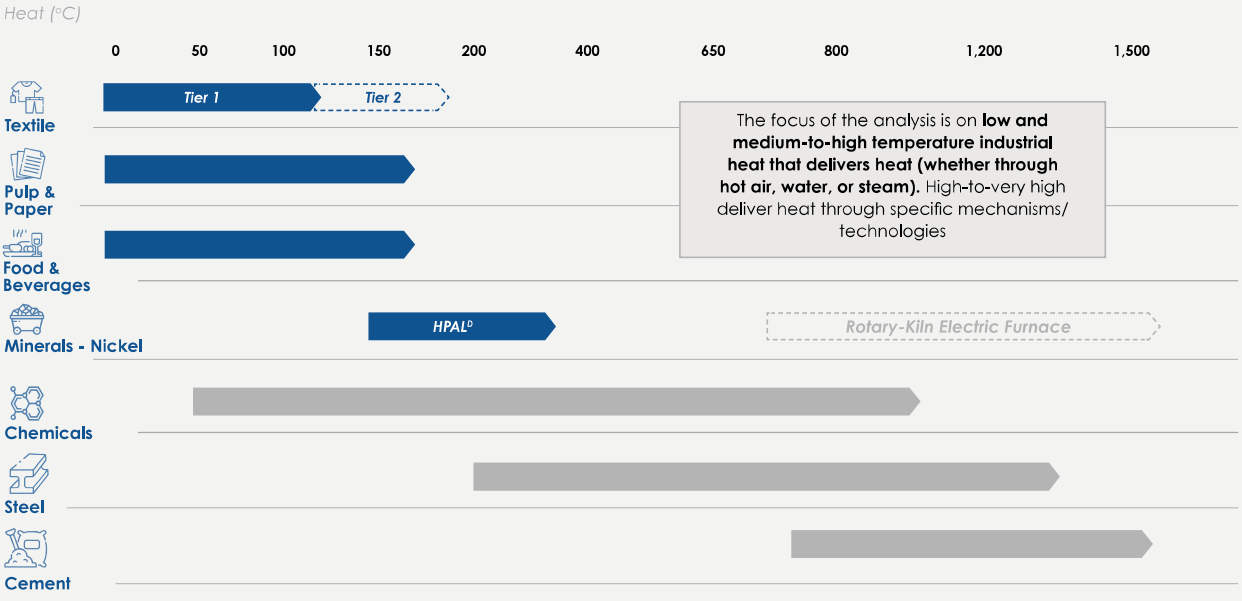


Low (<150 °C)
- Washing
- Rinsing
- Cooking
- Sterilisation

Medium-to-High (150-650 ° C)
- Drying
- Evaporation
- Distillation
- Activation

High-to-Very high (>650 ° C)
- Steam reforming & naphtha cracking
- Hydrogen heating for DRI steel
- Calcination of limestone for cement
- Melting in glass furnace

HEAT REQUIREMENT IN INDUSTRY[C]



The focus of the analysis is on **low and medium-to-high temperature industrial heat that delivers heat (whether through hot air, water, or steam).** High-to-very high deliver heat through specific mechanisms/ technologies

INDUSTRIAL HEAT DECARBONISATION PATHWAYS

Currently, there is a range of decarbonisation solutions: direct electrification (e.g., heat pumps, thermal storage), **low-carbon heat** (e.g., concentrated solar), and **low-carbon fuels for specific conditions** (e.g., biomass that is low-cost & sustainable supply):

Existing

Coal-based heat

Biomass/Gas boiler 1
Co-firing with byproduct biomass or gas, depending on industry process

Low-carbon solutions

Heat pumps 2
Deploy heat pumps (can also be for electrified resistance heating for higher temp and precise control requirements) in regions with relatively inexpensive electricity

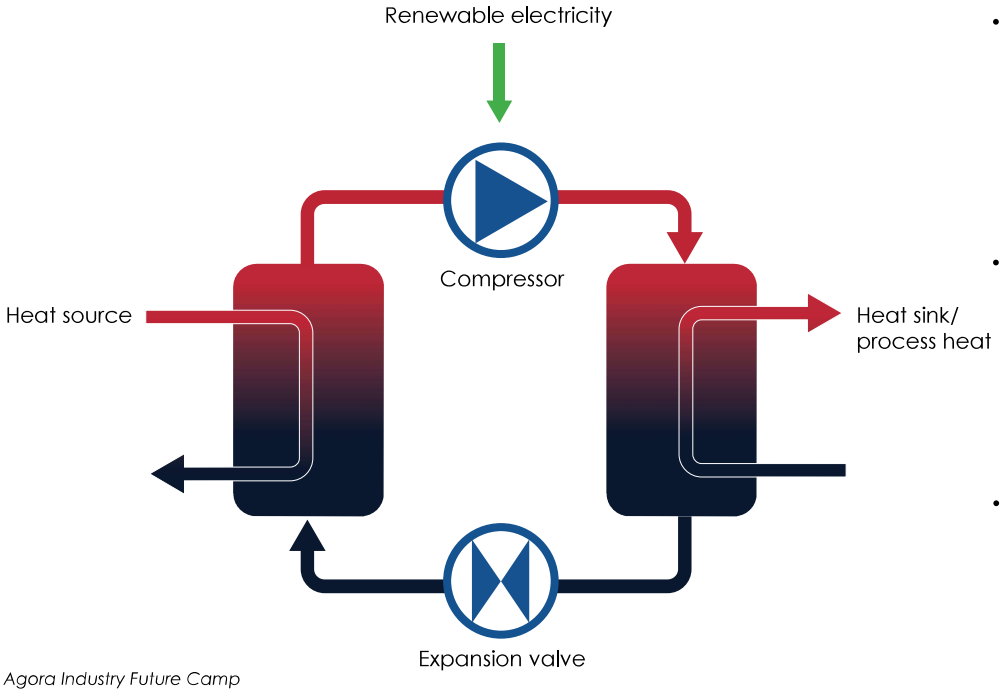
Electric-Thermal Energy Storage 3
Deploy in regions with inexpensive intermittent renewable electricity is available

Concentrated Solar Thermal 4
Evaluate solar thermal in advantageous areas for solar power

Focus of this analysis is on direct electrification of heat, the end-state solution. Since the use of alternative fuel are either site/industry specific or have supply constraints (e.g., biomass), it is therefore only considered as a niche solution.

Notes: [A] Sourced from IEA (2018); [B] Sourced from IEA, modified by internal calculation; [C] Sourced from Energy Innovation (2022), Decarbonizing Low-Temperature Industrial Heat in the U.S.; [D] HPAL stands for High-Pressure Acid Leaching

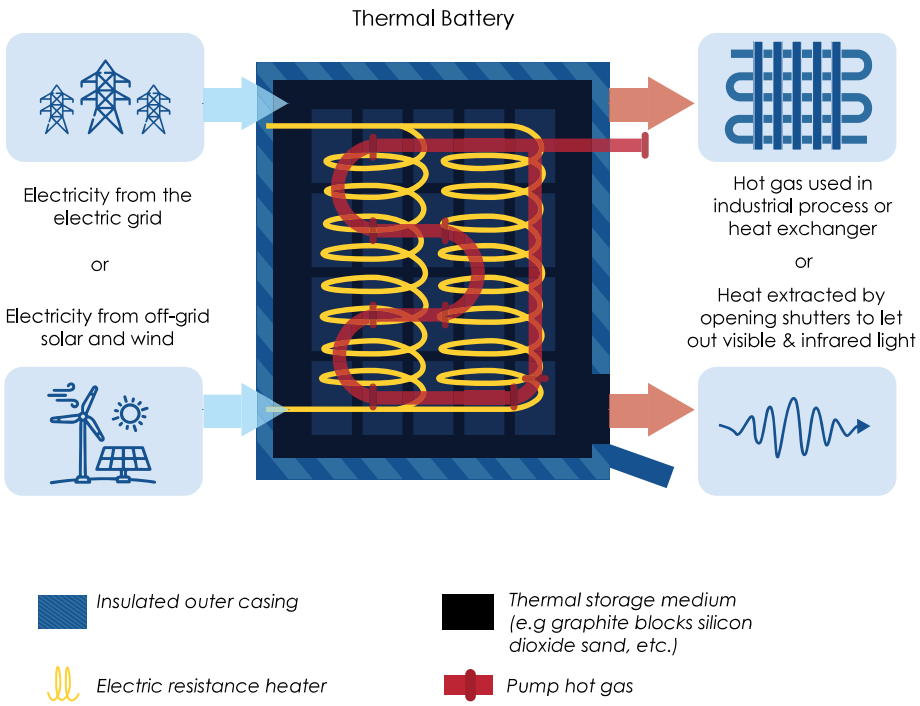
Heat pumps[E]



Agora Industry Future Camp

- **Simple technology. Air-sourced heat pumps** works like air conditioning, only in reverse. It extracts heat from a source (e.g., surrounding air or waste heat), lifts the temperature through compression, and transfers heat to where it is needed.
- **Heat pumps are far more efficient than conventional heating** (e.g., gas steam boilers) because heat is transferred rather than generated. It has the **efficiency of 200–500%** depending on the desired heat output range (up to ~200°C) and source.
- A heat pump typically consists of a compressor, which moves a refrigerant, and heat exchangers. Resulting heat from heat pumps can be delivered via **superheated air, hot water, or steam,** or to directly heat materials.

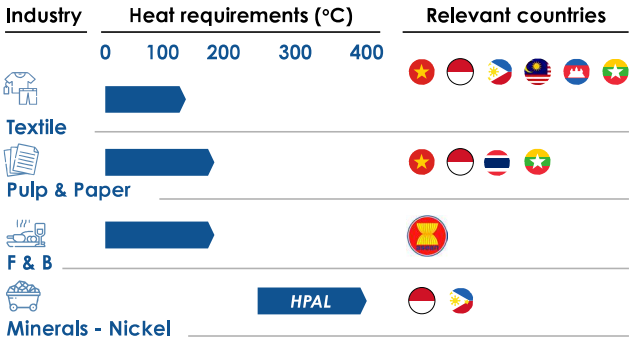
Electric Thermal Energy Storage (ETES)[F]



- **An Electric-Thermal Energy Storage (ETES)** is **a relatively new industrial heating technology** that can store heat at up to 1,800°C (using storage mediums such as volcanic rocks, molten salts, and clay bricks) and deliver heat at temperature up to 1,500-1,700°C.
- **ETES utilizes clean, low-cost, and intermittent power generation** such as wind and solar because its heating cycle does not have to be constant due to having the thermal storage capability.
- **Certain ETES solutions can also be setup to provide combined heat and power on a continuous basis.** Both heat and power can be at low-cost, where solar/wind are available at reasonably low-cost.

Notes: [E] Agora Industry, FutureCamp (2022): Power-2-Heat: Gas savings and emissions reduction in industry. [F] Energy Innovation: Policy and Technology LLC (2023); Industrial Thermal Batteries Decarbonizing U.S. Industry While Supporting a High-Renewables Grid (n.d.)

GEOGRAPHIC SECTOR CONTEXT



- **Industrial heat contributes to 30% of energy demand and ~280 $MtCO_2e$ emissions in ASEAN. Almost 40-50% of industrial heat comes from coal,** with some utilizing gas where available.[1]
- **Heating is crucial for >11% of ASEAN exports sectors.** Textile (5%), mineral refineries (5%), pulp & paper (1%).[2] Market restrictions (e.g., CBAM) are coming, these industries must decarbonize.[3]
- **Electrification must be coupled with grid decarbonisation.** Grid emission factors in ASEAN is 0.56~0.8 tCO_2/MWh.[4] Direct electrification solutions can also use near-site dedicated VRE.

SOLUTION STATUS IN ASEAN

Solution status stages: ● *Solution development* ❯ ● *Niche market* ❯ ● *Mass market*

NICHE MARKET

Heat pumps

For low-temperature heat using heat pumps, this solution is in the **niche market**.

- **Nascent uptake in ASEAN.** Even globally, industrial heat pumps adoption are not yet widespread (98% in buildings).[5]
- Despite its very high efficiency (3-5.5x), conditions like **cheap incumbent fuel**,[6] and **lack of awareness of the technology** provide barriers to adoption.

SOLUTION DEVELOPMENT TO NICHE

Electric-Thermal Energy Storage

ETES is on the edge of **development stage**. Some companies already completing early deployments.[7]

Competitive levelized cost of heat ($/MWh-th) is achievable with low-cost intermittent electricity (e.g., ~6 hrs/day) through[7]:

- **Direct connection to solar/wind farms,** or
- **Buying electricity from a wholesale market that has daily price dips during hours of high solar/wind generation**, i.e., where solar/wind are at high penetration in the grid mix, and there is a wholesale electricity market with hourly pricing.

TIPPING POINT AND ADOPTION RATE STATUS

Tipping point status

Legend: ✓ *Mostly reached* ○ *Reached in certain cases* – *Not yet reached*

✓ **LOW HEAT TIPPING POINT**

LCOH of Heat Pumps < LCOH Gas

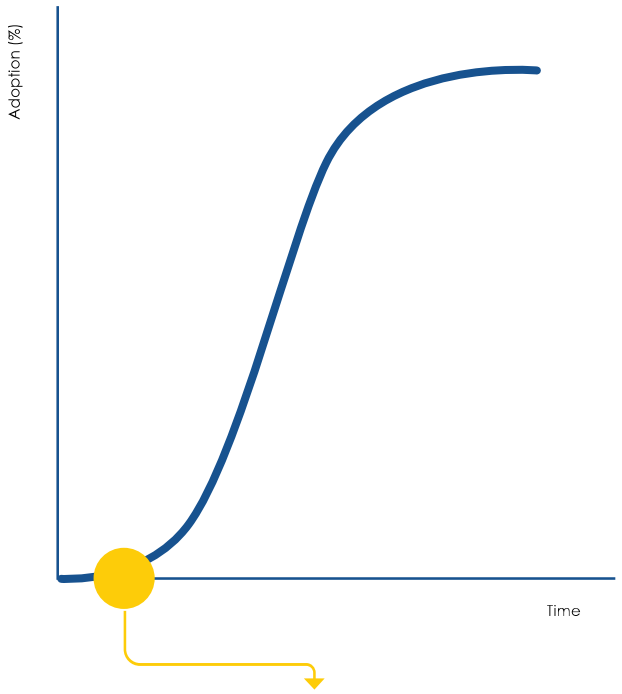
- **Has a closer path to the tipping point.** However, this is determined by market conditions, particularly energy costs (i.e., coal or gas prices vs. electricity prices).
- **Heat pumps can also provide protection against fossil fuel price fluctuations and security of supply for primary energy.**
- **Strong policy to disincentive fossil fuel usage** (e.g., carbon tax) can help accelerate heat pumps uptake.

○ **MED-HIGH HEAT TIPPING POINT**

LCOH of ETES < LCOH Gas

- **Heat provided through ETES has not yet reached a tipping point** due to solutions still being at early commercial deployments stage (e.g., early niche market), and conditions of low-electricity price for ~6 hr/day has not yet been reached.
- **However, ETES can reach an initial tipping point** where conditions are in place for superior economics, e.g.: dedicated (off-grid) VRE as electricity supply, and combined heat and power configuration.

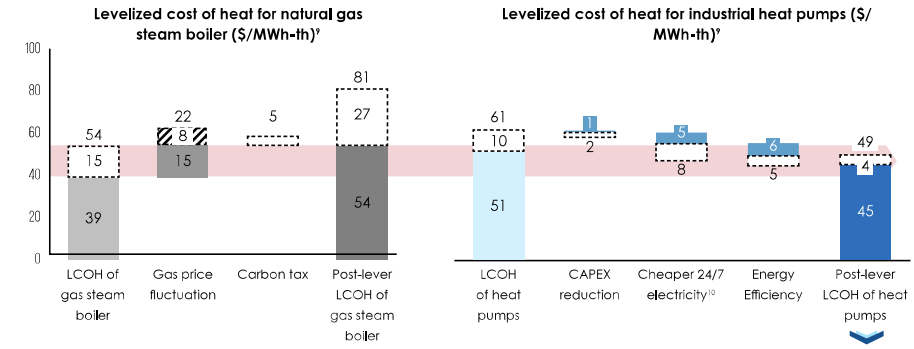
Current adoption status



Inflection point will be **driven by affordability** (LCOH: levelized cost of heat), **attractiveness** (push for lower- carbon products from market) and **accessibility** (availability of tech & engineering capability)

Notes: [1] ASEAN Centre for Energy (2022), 7th ASEAN Energy Outlook, Systemiq analysis. [2] Trade Map, Systemiq analysis. [3] European Commission (n.d.), Carbon Border Adjustment Mechanism. [4] ADB (2017), Guidelines for Estimating GHG Emissions of Asian Development Bank Projects. [5] Energy Innovation (2022), Decarbonizing Low-Temperature Industrial Heat in the U.S. [6] Electricity-to-gas price ratio is usually used to reflect the economics for fuel switching. Because heat pumps are very efficient technology, a ratio between 3–5 is enough for heat pumps to compete economically. In ASEAN, owing to relatively cheap electricity price, this is already within the range of switching (2.5–5.5) depending on whether there is domestic gas price cap and gas infrastructure available at the site. However, grid emissions factor will be another determining factor to switch. Source: Systemiq analysis, BloombergNEF & WBCSD (2021), Hot Spots for Renewable Heat. [7] Expert and industry interviews.

TIPPING POINTS FOR LOW-TEMPERATURE INDUSTRIAL HEATING



Heat pumps can be cost-competitive due to its ability to deliver efficient (2 to 5.5x) power to heat.

- **Industrial heat pumps are already close to a tipping point**, in part due to its electricity-to-heat conversion efficiency.
- **The issue on low adoption is more on accessibility** as air-/ground-source heat-pumps, as opposed to waste heat-based, are not well-known in ASEAN.
- **Mainstreaming technology through** collaboration with OEM and **greening the power grid** will be key to further accelerating the uptake of heat pumps.

Fossil fuel LCOH *Heat pumps LCOH* *Range of cost* *Additional but uncertain change* *Range of tipping point*

ENABLING CONDITIONS FOR LOW HEAT TIPPING POINT

PROGRESS

AFFORDABILITY

- **Comparable levelized cost of heat for heat pump vs gas boiler.**
- **Disincentivized coal and gas utilization through regulation.**
- **Supportive regulations and collaboration between OEM countries** on new technology adoption.
- **Low-interest financing for energy efficiency projects,** especially related to direct electrification.

✓ **Levelized cost of heat from heat pumps still varies** by geography and electricity price.

✗ **Regulation has not incentivized the usage of heat pumps** in place of fossil-fuel based heat.

✓ Some customers of major industries in ASEAN are **providing financing mechanisms to facilitate energy efficiency projects.**[7]

Key actions to accelerate progress:

- ❑ **Policy adjustment:** Specific electricity price for heating to support electrified heat source or carbon tax on coal/gas.
- ❑ **Financial support:** Grants, tax incentives, lending mechanism and access to low-cost financing.

ATTRACTIVENESS

- **Heat pumps reaching commercial scale Technology Readiness Level** for all temperature requirements (up to 160°C).
- **Opportunity to increase pricing on products with lower emissions intensity** (e.g., EVs with low production emissions in supply chain including battery metals such as nickel).
- **Increased pressure to lower carbon footprint from market requirement on emissions** (e.g., EU's CBAM.[4]
- **Availability of third party "Heat-as-a-Service" business model** (via a long-term Heat Purchase Agreement) **can be considered.**
- **Demand for increased safety and worker's health** in industrial areas due to cleaner and electrified heat generation.

✓ **Industries are pushing for lower-emissions products** in food, textile and critical minerals.

✓ **EU's CBAM came into effect on 1 October 2023 for initial sectors** and will only increase its industry coverage.[4]

✓ **Mass adoption of industrial heat pumps are limited to low heat, but** reaching commercial stage in >130°C heat requirements.[8]

✓ **Concerns for air quality has been increasing** in major cities.

Key actions to accelerate progress:

- ❑ **Policy adjustment:** Enabling power wheeling access to lower-cost PPAs from renewables developers.
- ❑ **Energy efficiency or emissions standard:** Mandate to raise industry energy efficiency standards.
- ❑ **Market advocation:** Key end- markets that are buyers of products from ASEAN (e.g., fashion brands buying textiles) should signal the need for low-carbon products.

ACCESSIBILITY

- **The existence of reliable power grid** to consistently power heat pumps.
- **The existence of heat grid** in some industrial parks **to enable "Heat-as-a-Service" model delivery.**
- **Availability of technology (OEM) and services (EPC) to install customized heat pump systems** that can be integrated/retrofitted with existing heating system.
- **Industrial park entities play a supportive role** in heat electrification.

✓ **Electricity reliability is acceptable.** Apart from questionable reliability (e.g., Cambodia, Laos), electricity is reliable.

✗ **Technology introduction from OEMs is not at the same pace** as European or USA industry.

Key actions to accelerate progress:

- ❑ **Increase reliability of grid:** To increase accessibility of heat pumps even in remote industrial locations.
- ❑ **Accelerate technology introduction:** Soliciting OEMs should be courted to introduce tech in ASEAN.
- ❑ **Industrial park electrification mandate:** Increasing uptake in electrification through industrial park managing entities.

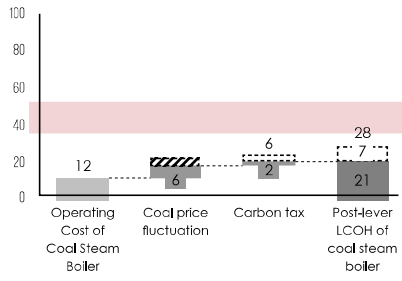
Legend: ✓ Progress is moving well ✓ Progress is mixed ✗ Progress is not happening (or happening far too slowly)

Notes: Tipping point enabling condition's rating guide: Affordability: Green – Parity achieved, Amber: Parity could be achieved with the help of levers before 2030, Red: Parity might only be achieved after 2030. Attractiveness & Accessibility: Green – No barrier to tipping point, Amber – Currently impeding tipping point but strong progress underway, Red – Currently impeding tipping point with limited progress to date.

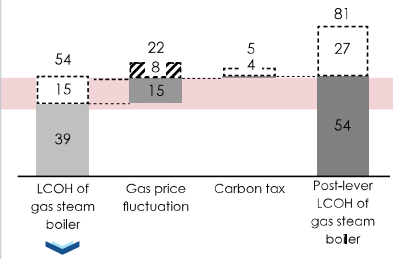
[8] Levelized cost of heat (LCOH) of gas steam boiler and heat pumps are calculated using Power-2-Heat transformation cost calculator developed by Agora Industry, FutureCamp, and Wuppertal Institute, accessible here: https://www.agora-energiewende.de/en/publications/transformationskostenrechner-power-2-heat/. Agora Industry, FutureCamp (2022): Power-2-Heat: Gas savings and emissions reduction in industry; and Energy Innovation (2022), Decarbonizing Low-Temperature Industrial Heat in the U.S. are used as primary reference for key cost and performance assumptions; [9] Heat pumps need 24/7 electricity, and on-site renewables are not able to provide that any reasonable cost.

TIPPING POINTS FOR MEDIUM-TO-HIGH TEMPERATURE INDUSTRIAL HEATING

Operating cost of heat from coal steam boiler ($/MWh-th)[11]

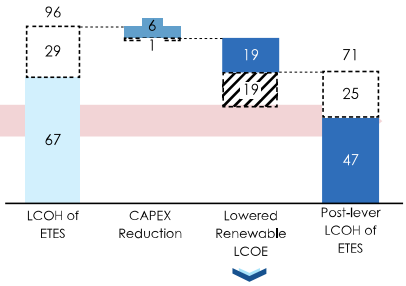


Levelized cost of heat for natural gas steam boiler ($/MWh-th)[11]



Gas is cheaper in some countries

Levelized cost of heat for electro-thermal energy storage (ETES) ($/MWh-th)[11]



Cheaper electricity price will be key in reaching cost parity for ETES deployment.

- **ETES technology is still in the early stages of commercialization.**
- **Moving forward, further cost reduction** for ETES will come predominantly through even lower cost of electricity for the ~6 hours per day, e.g., from dedicated solar/wind either on-site or delivered through the grid with PPA and power wheeling.

Fossil fuel LCOH *ETES LCOH* *Range of cost* *Additional but uncertain change* *Range of tipping point*

ENABLING CONDITIONS FOR MED-HIGH HEAT TIPPING POINT

PROGRESS

AFFORDABILITY

- **Comparable levelized cost of heat for** Electric Thermal Energy Storage (ETES) vs Gas Boiler.
- **Local / regional cost of solar reduced** (e.g., through enabling policies, economies of scale), to provide lower-cost electricity supply either off-grid with private or via PPA with power wheeling through the network. Combined with **streamlined permitting for building dedicated on-site or near-site power plant.**
- **Supportive regulations and incentives on new technology adoption,** e.g., CapEx subsidy, contract for difference on price of heat. Combined with **disincentives on use of coal and gas for heat.**

✓ **LCOH of electrified heat generation varies measurably across ASEAN,** due to different electricity prices from dedicated renewables (e.g., solar PV).

✓ **Historical learning curve has made Solar PV LCOE decline significantly in the last decade** and should further decline both driven by global tech cost declines and any supportive policies enacted locally/ regionally (e.g., lowered import tariffs).

✗ **Specific regulations and subsidies are not yet present as ETES is a new technology.**

✓ **Captive power development is less bureaucratic** than on-grid power project development across ASEAN countries.

Key actions to accelerate progress:

❑ **Policy adjustment:** capex subsidy, grants, tax and fiscal incentives, and policies to enable off-grid or power wheeling to support low-cost PPAs.

❑ **Commercial pilot project in ASEAN countries.**

ATTRACTIVENESS

- **Supportive regulations and incentives** on new technology adoption, particularly on its combined (clean) heat and power (CHP) capability.
- **Demand and green premium for products with lower emissions intensity.**
- **Increased pressure to lower carbon footprint from market requirement on emissions** (e.g., EU's CBAM).[4]
- **Demand for air quality and worker's health** in industrial areas due to cleaner heat generation.

✗ **Specific regulations and subsidies are not present** due to ETES technology still being developed.

✓ **Industries are pushing for lower-emissions products** in food, textile and critical minerals.[8]

✓ **Concerns for air quality has been increasing** in major cities.

✓ **EU's CBAM came into effect on 1 October 2023 for initial sectors** and will only increase its industry coverage to other sectors.[3]

Key actions to accelerate progress:

❑ **Policy adjustment:** Regulations on reduced air pollution which will drive industrials to clean alternatives to coal and natural gas.

ACCESSIBILITY

- **Availability of technology (OEM) and services (EPC)** to install ETES solutions.
- **Streamlined permitting for building dedicated captive VRE power** in nearby industrial parks.

✓ **ETES solutions are still at the stage of early deployment** and will take a few years before broad industry application.

✓ **Captive power development is already less bureaucratic.**

Key actions to accelerate progress:

❑ **Policy adjustment:** Streamlined permitting process for captive power that is designated for electrified industrial heat, including allowing private wires to connect near-site generation to industrial sites in proximity (e.g., <20 kms).

Legend: ✓ Progress is moving well ✓ Progress is mixed ✗ Progress is not happening (or happening far too slowly)

Notes: Tipping point enabling condition's rating guide: Affordability: Green – Parity achieved, Amber: Parity could be achieved with the help of levers before 2030, Red: Parity might only be achieved after 2030. Attractiveness & Accessibility: Green – No barrier to tipping point, Amber – Currently impeding tipping point but strong progress underway, Red – Currently impeding tipping point with limited progress to date.

[3] Same as previous page. [10] LCOH of gas steam boiler and electric-thermal energy storage (ETES) are calculated using Power-2-Heat transformation cost calculator developed by Agora Industry, FutureCamp, and Wuppertal Institute, accessible here: https://www.agora-energiewende.de/en/publications/transformationskostenrechner-power-2-heat/. For ETES, electric boiler function is used and adjusted. Agora Industry, FutureCamp (2022): Power-2-Heat: Gas savings and emissions reduction in industry; and Energy Innovation (2023), Industrial Thermal Batteries are used as primary references for key cost and performance assumptions. See Technical Appendix for more details.