RESONANCE
ASSET MANAGEMENT

Industrial Heat Management: Heat Pumps and Alternative Solutions

February 2023

Key Takeaways

- **Energy Efficiency and Sustainability** – 74% of the energy used in industry is converted into heat, 90% comes from non-renewable sources, and over 50% of this is lost as waste heat during process heating.[1] Due to the large proportion of carbon emissions, corporations are replacing fossil fuel heating systems to address external pressures and meet net-zero targets.
- **Reduced costs** – efficiency improvements and resilience to evolving regulations affecting industrial producers.
- **Diversified Returns** – investments are cash generative due to off-take contracts for heat as a service or via debt repayments. Industrial producers benefit from access to the latest operated technology, achieving cost savings and internal sustainability metrics.
- **The Investment Case** – low, medium, and high-grade temperature requirements can be met by different solutions. Examples included in this paper cover several technologies for each grade:
    - Low-grade – cost-effective and energy-efficient heat pumps effectively convert waste heat to desired temperatures below 120 °C.
    - Medium-grade - various low-carbon heat sources, including biomass, not only offer sustainability benefits but also reduce on-site waste management costs.
    - High-grade - green hydrogen presents a solution, but implementation at scale remains costly. On-site thermal storage for high-grade heating offers efficiency gains but may not achieve full decarbonisation.
    - Thermal Storage – co-locating thermal stores with heat-generating assets achieves cost savings from time-shifting opportunities and energy efficiency gains.

[1] Solar Playback Report, IRENA, 2020

What is Sustainable Industrial Heat Management

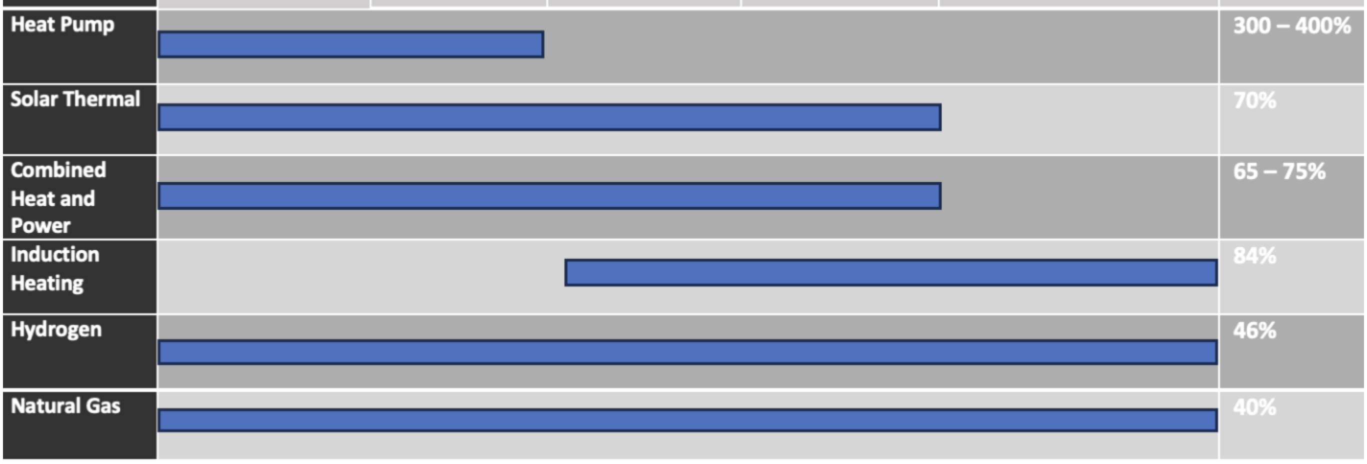
Effectively regulating thermal energy is crucial to most industrial processes, representing the largest form of energy use and source of carbon emissions.[2] Sustainable heating solutions provide a way for corporations to meet net-zero targets as they face pressure from customers, investors, and regulators.

Industrial heating can be categorised into three thermal grades: low <150 °C, medium ~150 – 270 °C, and high >370°C. Most thermal energy demand is met by fossil fuels; however, sustainable substitute assets exist at each grade with thermal storage solutions offering additional efficiency gains.

Low to medium-temperature industrial heat requirements are concentrated in the G-20 due to the industry base.[3] This makes up around 58% of industrial heat demand on average requiring temperatures below 400°C for which there are several decarbonised heat solutions.[4] Corporations looking to decarbonise would accelerate their progress by implementing these solutions.

The diagram below gives examples of applications of the three temperature grades and heat-generating assets able to achieve these:

	Low Grade		Medium Grade		High Grade	Efficiency
	0 – 100°C	0 – 150°C	150 – 170°C	270 – 370°C	370 - 1000°C	
Examples Industrial Applications	District heating Agricultural: Washing, pasteurising crop drying Food & beverage: brewing, biological processes	District heating Industrial: distillations, chemical and biological processes Seawater desalination	Steam generation Chemical and production processes Pulp and paper processing	Brick and ceramics production Chemical or other high temperature processes	Heavy manufacturing Metallurgy – steel making Petrochemical processes Glass and cement manufacture	



Data references in the footnote

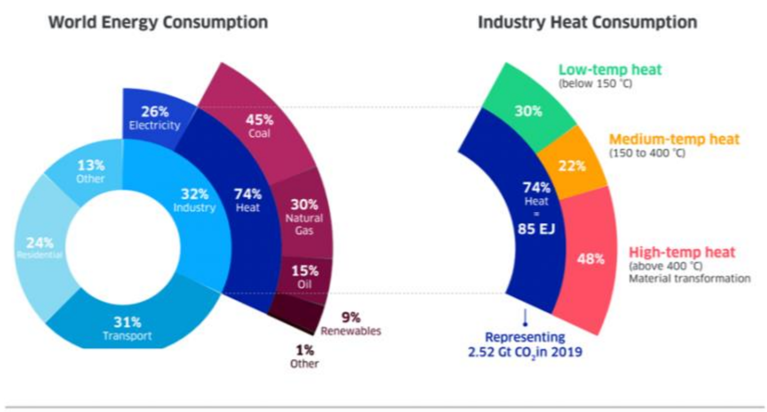
[2] The Royal Society, Briefing: Science and Soluitons, Low Carbon Heating
[3] IEA, IRENA, 2018
[4] IEA, IRENA, 2018

Table Data sources: Siemens Energy, Decarbonisation of District Heating 2023; Industrial Efficiency & Decarbonisation Office, Dept of Energy Solar Thermal Designs, The Open University, 2022; Heat Pumps, MIT Technology Review, February 2023; Efficiency of Induction Ultrafex Power Technologies, Science Coalition, April 2022

Drivers to Decarbonise Industrial Heat

Over-reliance on readily available and cost-competitive fossil fuel systems has created a barrier to the transition to low-carbon alternatives.

Industry Drives Global Energy Consumption



Source: Solar Playback 2020, IEA, IRENA data

1. **Emissions Reduction** to achieve net zero targets.
   - Environmental impact: Given 74% of industrial energy is converted into heat and only 9% of the demand is met by renewables, decarbonising heat would be a huge stride for decarbonising industry.[5]
2. **Costs Savings** are available and depend on the technology employed.
   - Efficiency gains: Renewable energy sector coupling for power-to-heat systems can save on procuring additional energy supplies. Most solutions are relatively energy efficient to fossil fuel heating, which sits at around 40% efficiency, heat pumps are the most efficient at 300 – 400%.
   - Policy and regulation: Decarbonising heat has gained policy.
     - The EU's 'Fit for 55' package, the EU is revising The Energy Tax Directive to introduce minimum tax rates on fuels to incentivise decarbonisation. The regime is expected to ensure that the most polluting energy products bear the greatest amount of tax.[6]
     - The UK the government committed to reduce building emissions by 50% by mid 2030. Schemes such as the Green Heat Network Fund providing £328m in capital, will advance deployment of large heat pumps, waste-heat recovery, solar thermal with storage, and biomass.

Low-Grade Heating: Case for Heat Pumps in Europe

For the industrial sector, large heat pumps are particularly effective in the paper, chemicals, food, and beverage industries. In Europe, there are 3,000 facilities in these sectors, requiring 15GW of heat pumps to meet their energy needs. European manufacturing capacity has grown as a response to this surge in demand, however, a four-fold global increase in supply is necessary to decarbonise heating across the continent.[7]

Heat pumps are considered a key technology for the heat transition and are appropriate for both residential and commercial installations. Heat pumps have the following specifications:

- 20 to 30-year asset life
- 3 – 5x more energy efficient than boilers: Coefficient of Performance (COP) of 3 – 5 times (heat pumps can transfer up to 500% of energy, whereas gas boilers are 95% efficient, creating a net loss of 5%)[8]
- Heat pumps can run off electricity from renewable energy sources.
- Currently providing temperatures of 140 – 160°C, extensive R&D continues to show promise as higher temperatures of 250C are expected to be possible by 2030.

[55] Data from Solar Playback Report, IRENA, in Renewables, Global Statistics, 2022
[6] KPMG 2021
[7] IEA, The Future of Heat Pumps, 2022
[8] Johnson Controls White Paper, Heat pump or boiler: what's the business case? 2023

A typical Coefficient of Performance is 3 to 5 times → for every 1kW of input electricity, heat pumps can produce 5kW of heat

Investment Attractiveness

Co-locating industrial heat pumps with heat-generating assets achieves waste heat recycling. The following factors make an investment in an industrial heat pump, powered by renewable energy, an attractive option:

Cost-saving opportunities improvements	○ Complies with incoming regulations, like the EU's Energy Taxation Directive, protecting producers from higher costs derived from changing, climate-related regulation. ○ Onsite renewable energy increases stability for long-term power costs ○ 300 – 500% efficiency conversions result in cost savings from efficiency improvements
Revenue Opportunities	○ Possible receipt of tradable carbon offset credits ○ Heat–as–a–service - district heating installations can provide lower carbon and cost-efficient heating to the locality.
Emissions Reduction	○ Achieved if powered by renewables ○ Efficient conversion results in lower electricity consumption
Proven and Available Technology	○ Easy to install and operate ○ Doesn't require rare earth metals and supply chains are currently not experiencing bottlenecks

Application Example: Hammerby District Heating and Cooling[9]

Europe's largest heat pump, 505MW district heating system was built in Stockholm, Hammarbyverket, in 1986. Seven industrial heat pumps upcycle waste heat from a wastewater treatment plant. The project highlights are listed below:

Image Source: IEA Technology Collaboration Programme on Heat Pump Technologies, Hammerby

- Heat is upgraded from around 7 – 22C to 70 – 80C
- Heat source: wastewater–heat pumps, supplemented by electric boilers and bio-oil-fired boilers
- Heats up to 95,000 apartments. Two large-scale hot water accumulator stores connected to the network smooth daily variations and provide stability to the system.
- Reduced carbon dioxide by 65%, 95% Sox and 80% nitrous oxide in Stockholm since 1980

[9] Facts and figures in this section taken from: Stockholm Exergi AB, Heat Pumps in District Heating and Cooling, December 2018

Medium-Grade Heating: Biomass Solutions

Biomass is a useful solution in sectors which require medium-grade heating solutions and waste management for materials produced onsite.

Biomass fuels can replace fossil fuel-based heating in industry using a variety of feedstocks and technologies ranging from direct combustion to gasification or liquefaction whereby it is possible to create biofuels with similar chemical compositions to incumbent fossil fuels.

Biomass systems provide viable economic solutions as they offer cost-saving opportunities for industrial sites that can repurpose biomass waste created onsite or procured locally for process heating.

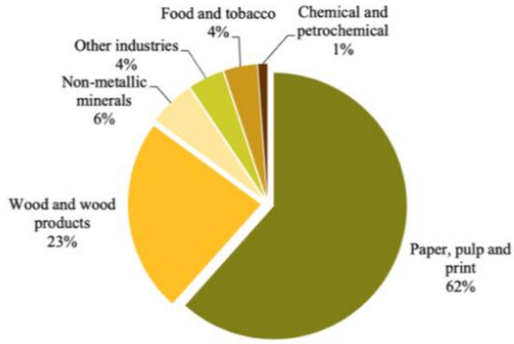


Image Source Status and future perspectives for energy production in European Industry, Renewable and Sustainable Energy Review, September 2019

Investment Attractiveness

Biomass systems provide viable economic solutions as they offer several economic and environmental benefits:

Cost Saving Opportunities	○ Feedstock is cheap and easily acquired - long-term off-take contracts provide local industries and municipal waste with a waste management solution ○ Lower disposal costs for sites that produce waste biomass as waste can be repurposed back into the operation ○ Reduced reliance on fossil fuels with a de-risking effect of avoiding price volatility
Revenue Opportunities	○ Biomass systems can qualify sites for government subsidy depending on local jurisdiction. Currently, in the UK this applies to smaller-scale/domestic boiler upgrades rather than industrial.
Environmental Benefits	○ Biomass is a carbon-neutral heating solution as CO2 released is later reabsorbed by growing the fuel ○ Reduced landfill from biomass deposits
Substitutability with Fossil Fuels	○ If treated further, biofuels can be created including biomethane which is chemically similar to natural gas and can be used as a carbon-neutral substitute.

Application Example: Swedish Paper Mill[10]

A paper mill in Sweden shifted its oil-based heating operation to using municipal solid waste for biomass heating. Paper mills require medium-grade temperature to generate process steam of around 200C, requiring a substantial amount of energy. The paper mill faced difficulties when oil prices fluctuated, especially between 2005 – 2009 when they ran unsustainably high energy costs. This inspired a shift towards an alternative, sustainable technology with added environmental benefits:

[10] Bristav, 2020, Case study

- Additional revenue received from waste management gate fees
- Using municipal waste makes efficient use of waste as an energy source
- Excess electricity and heat provided low-grade district heating to a nearby village
- The project offered de-risking due to a 20-year contract for feedstock

High-Grade Heating: Hydrogen Powered Heating

Biofuels can achieve high-grade heating; however, carbon-neutral solutions still generate significant quantities of CO2. A decarbonised heating system for high-grade applications can be achieved using green hydrogen produced from electrolysis powered by renewable energy.

This solution is gaining momentum and was named as a priority during COP27 where leaders discussed ways to mobilise capital to develop large-scale projects at lower costs.[11] With many companies setting ambitious science-based emissions targets, removing carbon from heating will achieve rapid progress towards these goals.[12]

Is there an Investment Case for Green Hydrogen Heating?

Most high-temperature applications (>500°C) are beyond the capacity of current electrification technology. Hydrogen, which burns up to 2100°C, can supply heat across the whole range of required temperature grades.

Currently, most available hydrogen is still produced from fossil fuels. In 2021, almost 47% of global hydrogen production came from natural gas, 27% from coal, 22% from oil, and only 4% from electrolysis.[13] Much more investment will be required to scale green hydrogen as a heating solution.

> Hydrogen burns up to 2100°C providing an effective solution for all heating grades required in heavy industry

Barriers to investment:

- **Infrastructure and cost barriers** persist in several parts of the hydrogen supply chain. Current estimates suggests using hydrogen for general heating in the UK would increase costs by 70%[14]
- **Storage and transportation -** storing requires temperatures of –253°C vs. –162°C for natural gas requiring a further build-out of technology[15]
- **Efficiency losses** result in an overall efficiency of around 35% for conversion to thermal energy. 30% of energy is lost during conversion from electricity to hydrogen. Round-trip efficiency losses vary between 18 – 42% depending on end-use application.[16]

In the UK, hydrogen heating is not expected to be an economically viable option until the 2030s - deployment would require scaled production and distribution networks and falling production costs.[17]

[11] UN Climate Champions. Race to Net Zero Article March 23, 2021. Accessed March, 2023
[12] Science Based Targets, Website SBTi target dashboard. Accessed January 2023
[13] International Renewable Energy Agency (IRENA), Accessed January 2023.
[14] Regulatory Assistance Project, RAP, April 2023
[15] Sepulveda, N.A. et al. (2021), Nautre Energy Journal
[16] Sepulveda, N.A. et al. (2021), Nautre Energy Journal
[17] National Infrastructure Commission, Technical Annex hydrogen heating, October 2023

Investment Attractiveness

Green hydrogen is considered a key component for decarbonising chemicals, cement, and metallurgy.

Revenue Opportunities	o Corporates can take advantage of tax incentives, such as the IRA in the US to accelerate decarbonisation on site.[18] o Hydrogen production and export can generate tradable carbon offset credits
Cost Saving	o 'Behind the meter' cost savings if co-located with renewable energy on site from educed network charges, connection costs and transmission losses. o Hydrogen can take advantage of arbitrage opportunities and generate H2 while prices are low and deployed for heating while prices are high, smoothing the effect of fluctuating electricity prices
Environmental Benefit	o Zero emissions solution to generating high grade heat

Given the efficiency losses involved across the hydrogen supply chain and in the conversion of electricity to hydrogen to thermal energy, hydrogen is not a cheap substitute for fossil fuels. However, hydrogen heating systems are being developed driven by decarbonisation goals and policy incentives.

Example: Green Hydrogen Steelmaking[19]

H2 Green Steel are a pioneering steel company building the largest industrial-scale green steel site in Boden, Sweden. The plant will be co-located with the largest hydrogen electrolyser plant in Europe, running on renewable electricity, with the only emission being water

H2 Green Steel, Website Rendering image

- On track to commission in 2026 and be fully ramped up by 2030, the facility uses hydrogen to heat furnaces for steelmaking.
- Excess heat will be recycled either through district heating, greenhouses, or electricity production. Plans are not yet final, but the general direction is to achieve a circular operation with little waste.
- Additional sustainability measure will be taken in water management – the plant will employ a closer water-cooling system, water will be sourced from the production process and Lule Rive, process water will be recycled or re-plenished.
- The facility will abate 95% CO2 emissions compared to traditional steel production. To achieve 'green steel' status, the metal will be produced from green virgin iron and scrap in a production process that uses electricity from renewable energy.

[18] Assessment of green hydrogen for industrial heat, Deloitte, US Advisorry, 2022

[19] H2 Green Steel, Website Accessed December 2023

Investment Case: Co-locating Thermal Energy Storage

Thermal storage can be co-located with any heating system to improve energy efficiency and reduce waste heat. Resonance's strategy seeks to invest in co-located, industrial-scale solutions to upgrade existing industrial sites or create green sites with enhanced efficiencies to reduce the environmental impact of operations. Storage achieves this among other benefits:

Revenue Opportunities	○ Time shifting – capturing low energy prices and deploying heat when prices are higher
Cost Saving	○ Reduced requirement to procure energy for the main heating system ○ Reduce losses associated with waste heat
Environmental Benefit	○ Energy efficiency improvements greatly reduce demand for generating heat and hence CO_2 emissions

Application Example: Energy Nest Thermal Battery[20]

The Energy Nest co-located a 4MWh thermal battery with a fertiliser producer, Yara. The company aims to accelerate industry transition by installing efficient low-carbon solutions. The project with Yara generated value by smoothing the price volatility of grid costs, locking in low-cost electricity storing it and discharging it when prices are high. Other highlights include:

Energy Nest, Web Page: Powering you into the future, a render of the Thermal Battery technology, 2023

- Solid-state thermal energy storage electrifies industrial heat for reliable low-cost thermal energy accessible 24/7, enabling high-grade temperature storage at low costs.
- Heat can be stored for long periods with efficiency losses at 1 – 2% per 24hrs
- Carbon payback time is around 2 months for this technology
- The Yara pilot project saved 6,000 tonnes of CO_2 since commissioning in 2015
- Decouples the heating system from volatile grid prices as the technology takes advantage of arbitrage
- The next steps will be to scale the thermal battery to suit industries at any size of facility

[20] Inspiratia, Q&A Thermal Storage, 2023

Investing in Co-Located Solutions

Renewable energy systems and low-carbon heating solutions can present a packaged solution for circular energy use in industrial production. Integrating power, heating and storage systems increases the efficiency of operations and the penetration of renewables in the energy mix.

Resonance is a specialist asset manager investing in debt and equity of sustainable infrastructure projects. We have the technical know-how to partner with heating solutions providers to guarantee the supply of low-carbon heat to clients over the lifetime of long-term contracts or to upgrade existing infrastructure on the industrial producer sites.

The following benefits can be derived from outsourcing investments without impacting the industrial clients' balance sheet

Benefits for Client Corporations

A low-carbon solution for both energy and heating would enable the industrial client to:

- Outsource expertise for constructing and operating the assets
- Achieve emissions targets with access to the latest low-carbon solutions and expertise
- Reduce costs from efficiency savings
- Comply with current and incoming regulation
- Gain approval from end-consumers, hence supporting brand reputation

Benefits for Investors

For Resonance's investors, sustainable solutions create:

- Tangible and measurable impact by reducing emissions and limiting waste
- A diversified portfolio of environmental investments
- Predictable cash flows due to long-term off-take contracts
- Additional upside from various subsidies and tradable carbon offset

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