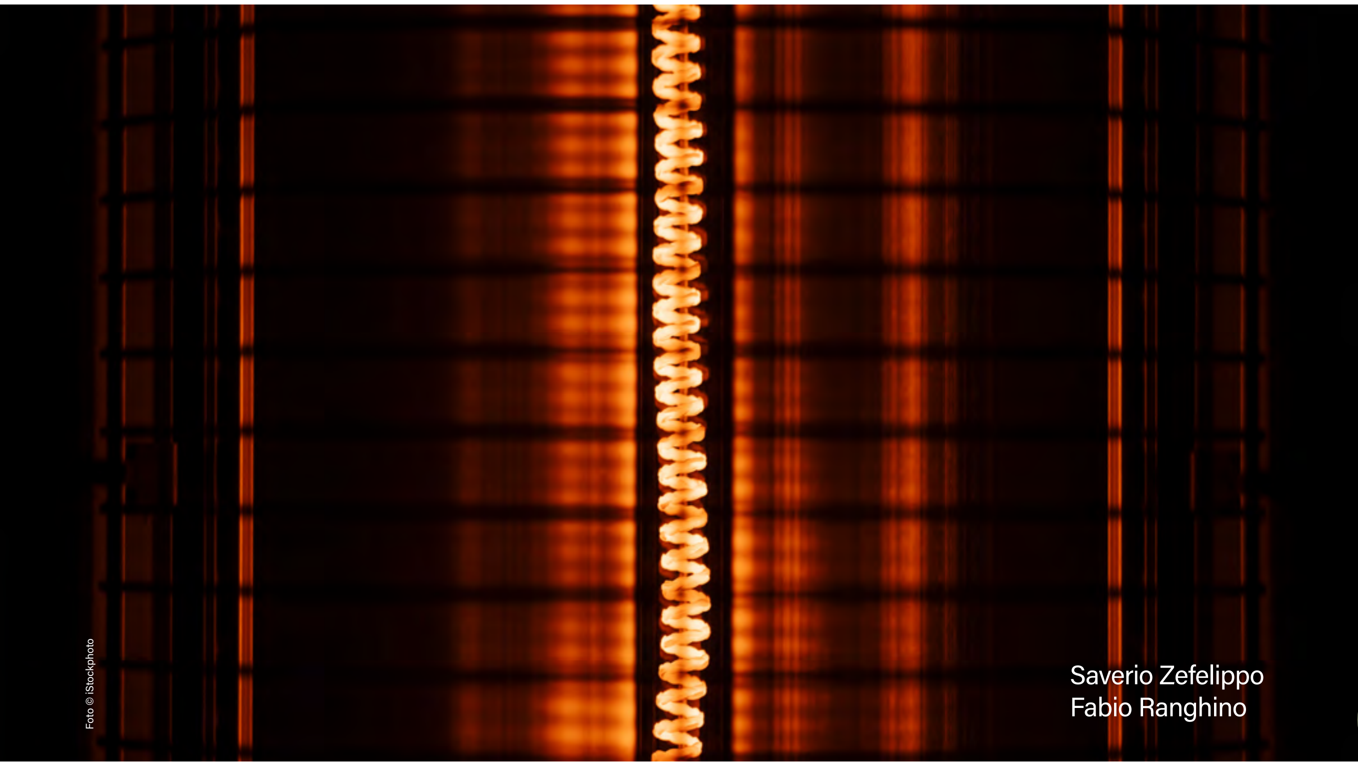


Saverio Zefelippo
Fabio Ranghino

Electrifying Industrial Heat: A Trillion Euro Opportunity Hiding in Plain Sight

Industrial heat is largely invisible to consumers but represents about 20% of global final energy demand and 10% of the world's CO_2 emissions. That is 2.5 times more than air and maritime transportation emissions combined and not far off those of road transportation.

Switching from fossil-based heating systems to those directly powered by renewable electricity in industry can eliminate 100% of CO_2 and air pollutants emissions and reduce primary energy demand by up to 70%. It can also deliver a € 1 Tn investment opportunity.

Despite the extent of its environmental benefits and of its economic opportunity, the electrification of industrial heat is largely overlooked, for at least three reasons. Firstly, it is technically complex: there are no silver bullets such as electric vehicles for transportation and heat pumps for residential heating. Decarbonizing industrial heat will require a variety of solutions, depending on the specific process. Secondly, direct electric heating technologies lack a coordinated support by industry associations, unlike alternatives such as hydrogen. Lastly, there is very little knowledge of electric heating technologies, and the misconception that "electric heating is better suited to lower temperatures" hinders an understanding of its potential elsewhere.

But things are starting to change. Barriers to adoption for industrial electric heating are becoming anachronistic. On one hand, geopolitics and carbon prices are making cheap, reliable fossil fuel supplies a thing of the past. As industry leaders and engineers inevitably embrace decarbonization, fossil fuels will tip into permanent decline. On the other, renewables are on a fast track to growth and affordability, which will lower the emission intensity of grids and simplify access to clean energy.

Electrifying industrial heating systems globally will require investments above € 1 Tn. While electric boilers and ovens have comparable costs to those of their gas-powered alternatives, heat pumps and electromagnetic heaters can be 10 times more expensive, driving the market value higher. But they also deliver the highest efficiency and process benefits, lowering operational costs to repay higher initial investments.

No industrial company can achieve net-zero without addressing its process heat. This Ambienta newsletter explores electric heating technologies and the reasons why we believe they represent the best path forward for a zero-emission industry.

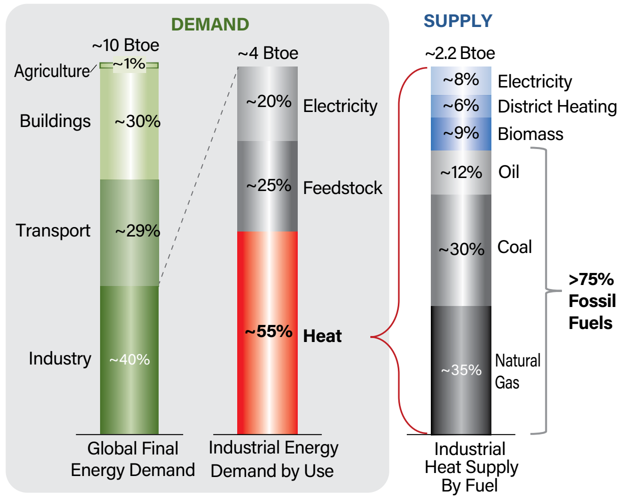
Industrial Heat and Electrification

Industrial Heat Is Ubiquitous

Since humans learned to use fire 40,000 years ago, heat has become one of our basic needs and a precondition to modernity. We need it to keep warm and manufacture just about everything we consume. While in homes heat is mostly used for space heating, in industry it has become ubiquitous. It is the backbone of any manufacturing process - cooking, sterilizing, melting metals - and provides for our daily needs: from the fertilizer to feed the world's growing population, to the steel and plastics for the cars we drive, and the cement for the buildings we live and work in.

Residential and industrial heat combined account for about half of global energy demand. In industry, today about 75% of heat is produced by burning fossil fuels, mostly natural gas, in a boiler, furnace or combined heat and power plant.

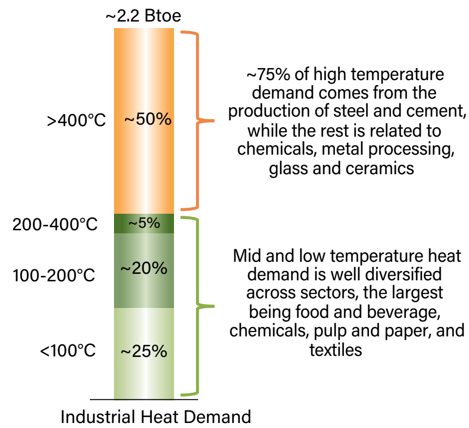
Graph 1: Industrial Heat In Global Energy Demand



Source: Ambienta analysis on IEA and McKinsey Data

Although industrial heat is typically associated with very high-temperature processes, like manufacturing steel and cement or melting glass and cooking bricks, half of it is actually used at well below 400 °C, across a vast range of sectors, namely food and beverage, chemicals, pulp and paper, and textiles. Burning natural gas can reach 2,000 °C, so using it to heat materials at 100-200 °C is like "cutting butter with a chainsaw", in Professor Kelbaugh's words, and is inherently inefficient.

Graph 2: Industrial Heat Demand by Temperature



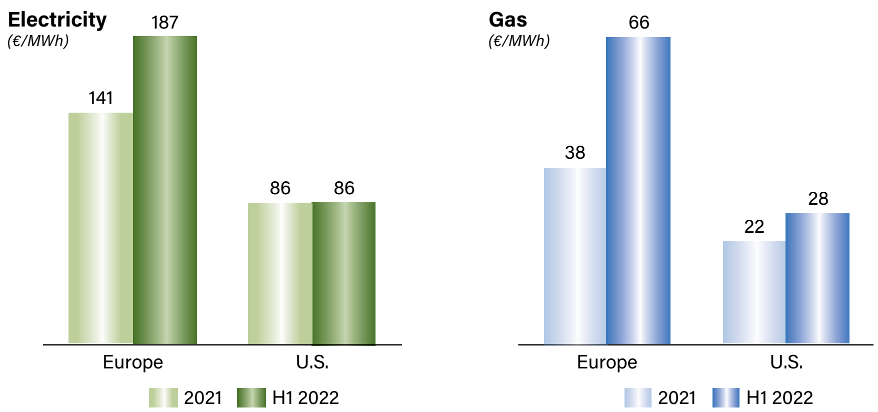
Source: Ambienta analysis on IEA data

Industrial Heat Costs

Industrial heat is also a huge cost globally. It accounts for 20% of the world's final energy demand and costs industry over € 300 Bn in fuel (more than € 1 Tn at 2022 spot prices) and € 30 Bn in equipment every year. Regional differences apply. Although the U.S. and Europe consume similar amounts of industrial heat annually (≈ 300 million ToE), higher European energy prices drive up the cost for European companies (≈ € 32 Bn) compared to their U.S. counterparts (≈ € 25 Bn).

Because industrial heat is ubiquitous and expensive, it must become a focal point for decarbonization, and electrification represents the way forward.

Graph 3: Energy Costs for Industrial Users – Europe Vs. U.S.



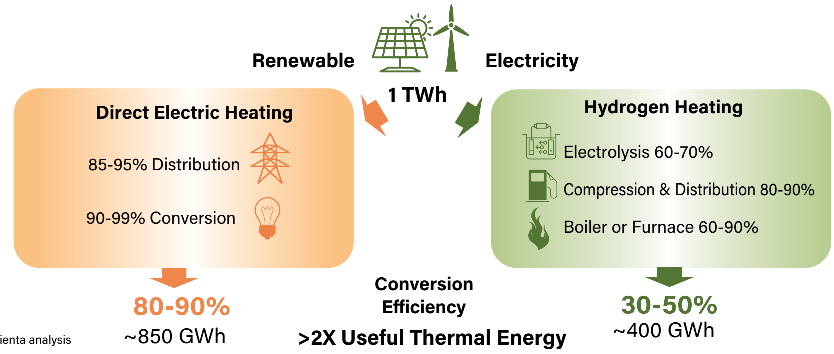
Sources: Eurostat, EIA

Electrification of Heat

Heat can be electrified directly, by converting electricity into heat, or indirectly, by using electricity to produce green fuels like hydrogen. The direct option is by far more efficient and, we believe, preferable. In fact, 1 TWh of electricity generates over twice as much heat when it is converted directly rather than indirectly, as shown in Graph 4.

Green hydrogen is not only inherently inefficient, but also not immune from air pollution issues, generating even more NOx than natural gas when burning.

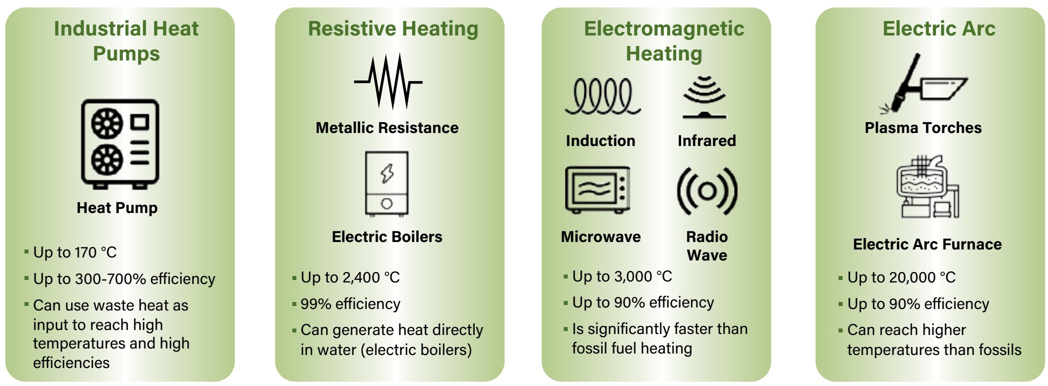
Graph 4: Direct vs. Indirect (Hydrogen) Electrification Efficiency



Source: Ambienta analysis

Direct electric heating can be achieved with four types of technologies: heat pumps, resistive heating, electromagnetic heating and arc-based technologies. They can convert electricity into heat very efficiently, at rates of 90% - 99% (and even 300%+ in the case of heat pumps), and can deliver temperatures ranging from 170° C (heat pumps) to 20,000 °C (plasma arcs), as shown in Graph 5. Below is a brief description of each technology and its industrial applications.

Graph 5: Electric Heating Technologies Overview



Source: Ambienta analysis

Industrial Heat Pumps, similarly to residential heat pumps, use electricity to transfer heat from a "source" to a "sink", rather than converting electricity into heat. By utilising residual heat from industrial processes, they can deliver temperatures up to 170 °C at 300% - 700% efficiency: 1 kWh of electricity can generate 3 to 7 kWh of heat. Heat pumps are especially suited to provide heat for cooking, drying, pickling, pressing, staining, and steaming in the paper, chemical, textile and food and beverage industries.

Resistive Heating releases heat when an electric current passes through the resistance of a conductor. It can reach 2,400 °C and 99% conversion efficiency. A wide range of industries already use it today, for example to protect pipelines from freezing and, in consumer products, to heat seats and windows in passenger cars. Its most interesting industrial use going forward will be in replacing the 500,000 gas and coal-fired boilers in operation today to make hot water and steam.

Electromagnetic Heating converts electricity into electromagnetic radiation at different wavelengths (induction, infrared, microwave, etc.) that can deliver heat at temperatures up to 3,000 °C. Although less efficient than other electric technologies, it reaches high temperatures faster, distributes heat homogeneously and delivers precise control of heat localization, unlocking process benefits that far outweigh higher costs. Induction heating is widely used for metals melting and heat treatment, and is also rapidly replacing gas stoves in residential applications. Infrared is used to heat and dry surfaces, bake food, fix coatings and dry paint in metallurgy and textiles. Microwave heating is used to cook, sterilize and pasteurize food, and to dry wood, chemicals and textiles, among others.

Electrical Arc Heating creates a stream of electrified atoms, a sort of continuous lightning bolt, that reaches by far the highest temperatures, even above 20,000 °C (much higher than fossil fuel flames, which go up to around 2,000 °C). Commonly applied in metals processing, it is used in electric arc furnaces (and in about one third of all crude steel globally) as well as in plasma torches, to cut and weld metals.

The Benefits of Electrification

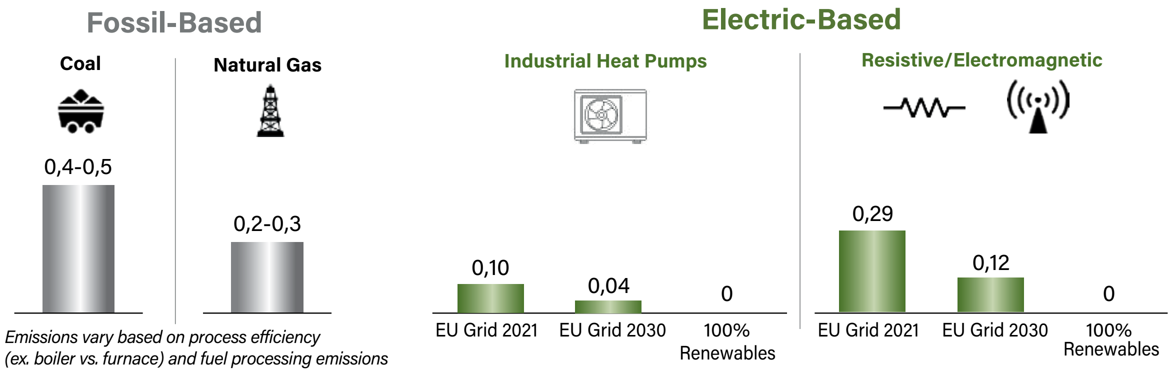
The electrification of industrial heat delivers a wide range of benefits, from a 100% reduction in CO_2 emissions to efficiency, process and system advantages.

1. **Environmental Benefits.** Industrial heat is responsible for 10% of global emissions and contributes to air, soil and water pollution: burning coal, oil and gas generates CO_2 and other air pollutants such as NOx, SOx, polycyclic aromatic hydrocarbons and particulate matter. Electric heating powered by renewable energy eliminates 100% of CO_2 and pollutant emissions. As average grid emission intensity declines, electric heating technologies provide increasing environmental benefits. With high natural gas and coal prices, renewables get more and more convenient, accelerating their penetration in the electricity mix. Heat pumps can lower emission intensity even when powered by the grid already today, thanks to their superior efficiency, as shown in Graph 6.

   Eliminating emissions not only delivers environmental benefits. It also significantly reduces permit burdens and times: Tesla's solar-powered, zero-combustion battery production facility in Nevada obtained its air permit in less than a day, compared to over six months for a typical gas-fired facility.

Graph 6: CO_2 Emission Benefits from Electrification

Kg CO_2/kWh of Useful Thermal Energy



Source: Ambienta analysis, Eurostat

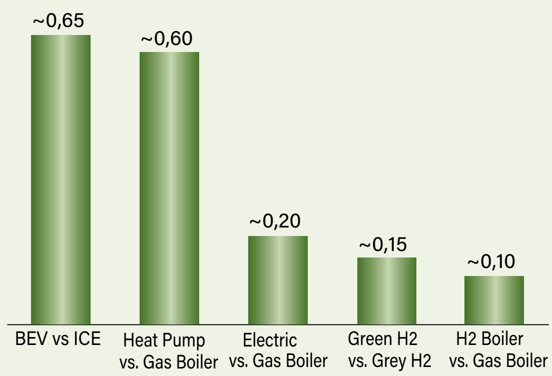
WHAT IS THE BEST USE OF 1 KWH OF RENEWABLE ENERGY?

In the race to keep global warming below 1.5 °C and abate emissions, policy makers and industry leaders must prioritize renewable energy use where it will yield maximum benefits. The need to give precedence to industrial heat is illustrated in the graph below. Ambienta compared the emission abatement potential of 1 kWh of renewable electricity vs. fossil fuels for different technologies. The analysis highlights two important outcomes:

- The cut in emissions when using renewable electricity in a heat pump instead of a gas-fired boiler is comparable to that of a Battery Electric Vehicle (BEV) in lieu of an Internal Combustion Engine (ICE) alternative. Hence, heat pumps and BEV's should be renewable energy's highest priority uses.
- More emissions are abated when using renewable electricity to fuel an electric boiler instead of a gas boiler than when using renewable electricity to produce green hydrogen (even if it is used to power a hydrogen boiler or to replace grey hydrogen). Thus, electrifying industrial heat should take priority over green hydrogen production.

What Is the Greenest Use of 1 kWh of Renewable Electricity?

(Kg CO_2e Abated By 1 kWh Of Renewable Electricity)



Sources: Ambienta analysis
Notes: BEV=Battery Electric Vehicle; ICE=Internal Combustion Engine; H2=Hydrogen

2. **Efficiency Benefits.** Fossil-fuelled heating systems lose 20% - 50% of their heat by discharging the toxic flue gases they generate. Electric heating technologies, on the contrary, do not generate toxic flue gas and, by not dispersing the associated heat, improve system efficiency by 30% - 100%. Different technologies deliver further benefits. Industrial heat pumps are 10 times more efficient because they exploit residual heat from other processes. Electromagnetic heating reduces heat loss in surroundings areas (through an oven's walls, for example) by generating heat directly within the target material.

3. **Process Benefits.** Electric heating systems are much easier to control, provide more precise and uniform heat distribution and, therefore, higher product quality. They also vastly improve processing speed (which

is particularly the case for electromagnetic heating). This translates into lower production times and defects, and cut overall production costs even if the direct cost of heat increases. For example, a Danish producer of wood- processing machinery has lowered the curing time for glue from eight hours (with a traditional gas-fired kiln) to less than 30 minutes (by using radio frequency). In another case, a U.S. metal manufacturer of painted cargo racks increased the speed of curing the paint by eight times and reduced blistering defects by switching from a gas-fired oven to infrared heating.

4. **System Benefits.** Flexibility of fuel supply and grid balancing are huge system benefits delivered by electrification. In the first case, industrial users using electricity from renewables are not locked into using one kind of fuel (gas or coal) to fire their ovens or boilers. Rather, they can choose from solar, wind, hydro, nuclear and geothermal. The Ukrainian War has shown how risky single-fuel dependency is.

Heat is easier and cheaper to store than electricity: electric heating systems coupled with heat storage systems can provide grid balancing services. Decoupling heat production from electricity supply enables the balancing of fluctuating electricity prices and variable production from solar and wind, unlocking two key advantages for industrial users.

First, they can be paid by the utility to provide grid balancing services and, secondly, they can benefit from lower electricity costs by exploiting intraday electricity price fluctuations, producing more heat when prices are low. A case in point: an Italian utility has installed a 10 MW electric boiler to test the use for grid regulation, using the heat generated in a district heating system.

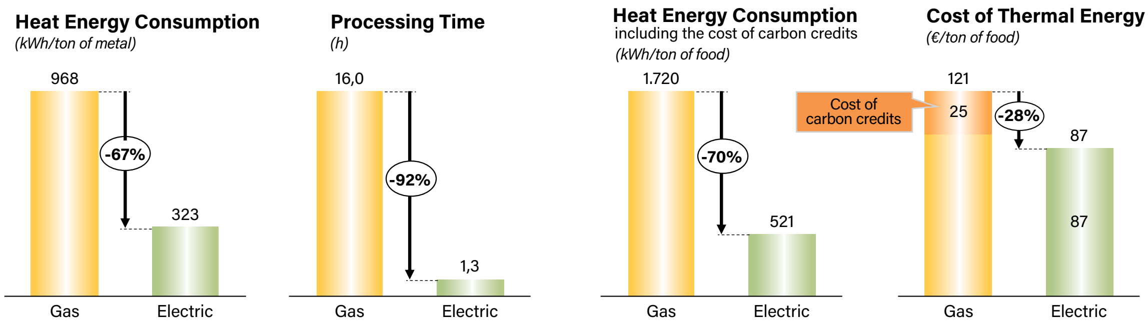
ELECTRIFICATION BENEFITS CASE STUDIES

Heat Treatment Of Aluminum Billets

- A U.S. manufacturer of components for transport and agricultural equipment **switched from gas-fired to infrared heating** for pre-heating and heat treatment of aluminum billets.
- The results were a **67% reduction in energy consumption and over 90% reduction in processing time**, which led to **40-50% lower costs**. An improvement in the consistency of product quality and in the structural and mechanical properties of the finished products were also achieved.

Ready-To-Eat Food Processing

- An Australian frozen pizza manufacturer **substituted gas boilers with industrial heat pumps** to provide hot steam, water and oil for the cooking processes, and replaced the gas oven with an infrared based oven.
- **The heat energy requirement per ton of food processed was reduced by 70%**, enough to offset the disparity in energy cost between gas and electricity. Using European energy prices, we estimate a 25-30% reduction in energy cost per ton of food when including the cost of carbon credits.



Source: Ambienta analysis on case studies presented in the report «Electrifying Industry»-Beyond Zero Emissions

Today's Barriers are Tomorrow's Catalysts

The barriers that have prevented the widespread adoption of electric technologies in industry to date – high cost of electricity compared to gas and coal, limited penetration of renewables, lack of knowledge and will to rethink heating processes – are rapidly becoming anachronistic and tipping the scales in favor of electrification. As the pressure to abate emissions and limit global warming to 1.5 °C grows, the prospects for electrification solutions are gaining new momentum.

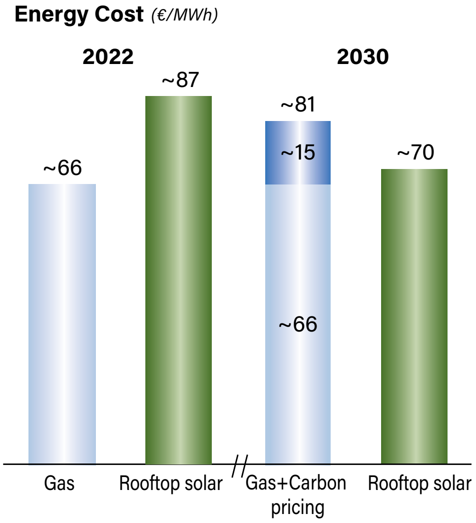
1. **Cost.** Today, electricity is two to four times more expensive per unit of energy than natural gas, which prevents many industrial users to even consider the electrification of heat as a possibility. However, the actual, overall benefits of electrification become evident in the total cost of ownership:

- efficiency benefits discussed earlier reduce the amount of electricity needed to obtain the same useful thermal energy compared to a fossil fired system;
- maintenance costs can be cut by up to 50%, according to different technologies;
- emissions monitoring is avoided altogether, delivering savings that run in the hundreds of thousands of euros per plant;
- carbon pricing will inevitably turn the scales in favor of renewables. Depending on the evolution of gas

prices, by 2030 even rooftop solar will probably be cheaper than natural gas, as Graph 7 shows.

Regulation will also play a significant role: today in Europe electricity is taxed 7 times more than gas, with incentives targeting the production but not the use of renewable electricity, as described in the box below. A review of the energy taxation framework that, at the very least, evens the playing field between fossil fuels and electricity, will reduce the cost gap. Furthermore, the animated discussion occurring in Europe on decoupling electricity prices from gas prices will increasingly favor electrification. Electricity costs are currently set by marginal cost producers, which are typically gas-fired power plants. Electricity, regardless of its source, is therefore priced based on the cost of gas, even though wind, solar, nuclear and hydro are significantly cheaper at current gas prices.

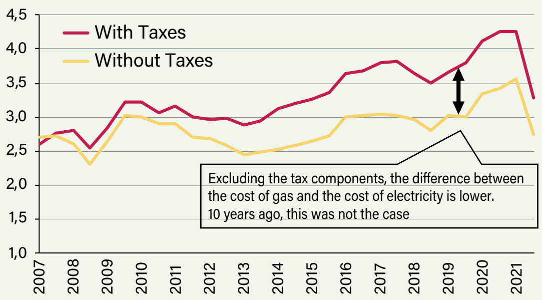
Graph 7: Energy Cost Outlook for European Industrial Users



Source: Ambienta Analysis on Eurostat and IRENA Data

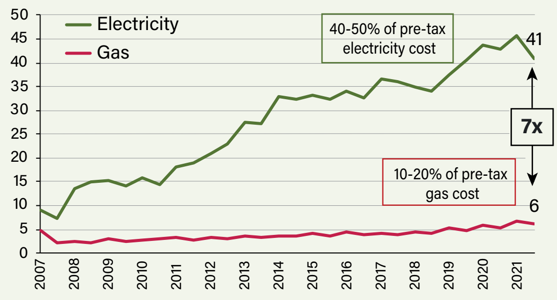
THE IMPACT OF TAXATION ON THE PRICE OF ELECTRICITY VS. GAS IN EUROPE

Electricity To Gas Price Ratio - Europe
(€ kWh electricity/€ kWh gas)



Note: Excluding VAT and recoverable taxes

Tax Component On Energy Cost - Europe
(€/MWh)



Source: Ambienta analysis on Eurostat data

Currently, European energy taxes favor the use of fossil fuels compared to electricity: an industrial user in 2021 paid ~40-45 €/MWh in taxes for electricity but only 6-6,5 €/MWh for natural gas. Compared to their pre-tax prices, it means that electricity is taxed 40-50% and gas only 10-20%. About 2/3 of revenues from taxes on electricity are then used by governments to subsidize renewable energy generation. The net effect is that Europe is subsidizing the decarbonization of electricity supply while at the same time disincentivizing the electrification of demand, favoring the use of gas. This is a clear obstacle to its overall decarbonization plan.
A review of the taxation framework in favor of the direct use of electricity would accelerate the switch away from fossil fuels and towards renewable energy, which is the cheapest way to generate electricity. Until then, industrial users will be better off by self-producing electricity via solar panels or by signing long term Power Purchase Agreements for renewable electricity.

2. **Limited Renewables Penetration.** Renewables penetration is growing quickly: solar and wind doubled from 5% of global electricity production to 10% between 2016 and 2021. In 2021, 80% of the new power capacity installed globally had zero emissions. This is driving down average grid emissions (the amount of CO_2 emitted per average kWh of electricity) in Europe, which declined by 20% in the past 10 years. As they drop, electric heating systems deliver increasingly higher environmental benefits even if they are not directly connected to a renewable energy plant, but simply by being linked to the grid. If electricity is produced by burning fossil fuels, electrifying heat production makes no sense, both from a system efficiency and environmental perspective. But, as shown in Graph 6, today an electric boiler connected to the European grid already has similar emissions to a gas boiler. As average grid emissions are expected to decline by 60% by 2030, the electric boiler will become by far the greener option, whether it is linked to the grid or powered by a dedicated renewable energy plant.
3. **Lack of Knowledge and Will.** Industrial heating systems are long-lived and have significant sunk costs (we estimate that about € 300 - 400 Bn are tied down in fossil fuel heating systems). Without a strong commitment to decarbonize from top management, the decision to replace existing assets is unlikely to come from plant and process engineers. Plus, the myth that

"electric heating is for low temperatures" keeps being perpetuated despite the fact that electric heating systems can reach 10x the temperature of a fossil fuel flame, preventing many non-experts from exploring electric heating opportunities. Finally, the fact that most thermal processes are managed by mechanical engineers familiar with combustion processes and with limited knowledge of electrical alternatives, poses further obstacles to direct electrification: burning hydrogen seems like the obvious path for someone who has always burned gas or coal for heating.

However, the pressure on industry to decarbonize is quickly mounting from all sides, creating the will needed to address emissions from industrial heat. The Science Based Target Initiative (SBTI) reports that today 1600 companies have pledged to achieve net zero emissions, up eight-fold from 200 in 2020. By 2040, equity investors that embrace the SBTI will need to prove that 100% of their portfolio companies have a decarbonization plan that can be met by 2050. This will increase pressure on public and private firms to decarbonize or risk limiting their access to capital.

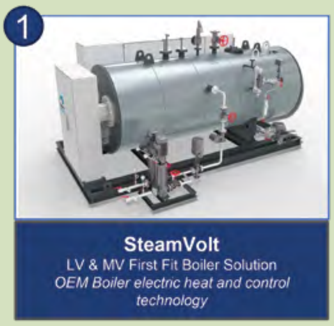
From the regulatory side, countries representing over 80% of global GDP have professed commitments to Net Zero. While not all have stringent measures to target industrial decarbonization like Europe, with its Emission Trading Scheme, they will have to turn their pledges into action if they are serious about achieving their targets.

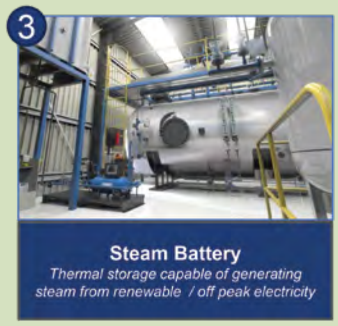
4. **Grids.** Power requirements from grids will increase as industry switches from fossil fuels to electric heating. Today, industrial electricity is mostly used for lighting and motion (with motors, pumps and compressors), but using it also for heating can double power needs. The higher efficiency of electric heating technologies can mitigate this increase, especially thanks to heat pumps. One manufacturer of high temperature industrial heat pumps indicated that only 10% of his projects need an upgrade to the grid connection. Furthermore, captive power generation through solar, coupled with heat storage, can reduce reliance on the grid.

   Regulators should support this transition by preventing bottlenecks caused by permits and grid connections, which can slow down the deployment speed of production and the use of renewable electricity.

AMBIENTA'S INVESTMENT IN SPIRAX-SARCO ENGINEERING

Spirax-Sarco Engineering is the world leader in industrial steam management solutions and one of the few listed companies focused on process heat. Steam circuits waste up to 25% of their energy through condensation, leakage and poor insulation. Spirax helps minimize these losses: it estimates that energy savings from products sold in 2021 exceeded 70 TWh, comparable to the yearly electricity consumption of a mid-sized country like Austria.
Spirax was a pioneer in electrification and has developed a deep expertise in electric heating technologies through four acquisitions since 2017. It now provides a full range of solutions, including a retrofit technology to electrify existing fossil-fuel boilers and a "steam battery" to integrate steam generation with variable renewable power.





Source: Spirax-Sarco Engineering investors presentation

Investment Opportunities

Ambienta estimates that replacing 100% of heat generation with electric technologies would amount to over € 1 Tn in investments in heating equipment alone, with further opportunities for servicing and renewable energy providers. We also expect Europe to be a frontrunner in the electrification of industrial heat, mostly thanks to its ambitious decarbonization targets and carbon pricing scheme, but also because of the renewed focus on energy independence.

Key investment opportunities along the value chain are:

- **Financing Heat Electrification Projects:** providing capital to companies looking to eliminate their heat emissions is likely the most impactful way to support industrial heat decarbonization. The initial investment for electric heating technologies is likely to be much higher than for fossil-based ones, therefore companies might need external financial support. The savings in operating costs, however, as we showed in multiple case studies, will provide sufficient returns to quickly repay the initial investments. This is an interesting proposition for asset managers, manufacturing companies and, most importantly, the environment. Ambienta is exploring various ways to support companies in their journey towards Net-Zero with dedicated financial products.

- **OEMs:** high temperature heat pump manufacturers are the most attractive opportunity in the short term. Industrial refrigeration equipment producers have an advantage given by existing customer relationships and technological similarities between refrigeration equipment and heat pumps. Trane Technologies and Carrier, for example, are the global leaders in commercial and industrial refrigeration systems, and they both offer MW-scale heat pumps suitable for industrial scale heat.
- **Components Suppliers:** moving up the value chain, critical components suppliers to OEMs represent another attractive way to gain exposure to the heat electrification opportunity. Resistive heating elements will be the base of a variety of electric heating solutions. Spirax Sarco Engineering has developed a technology to retrofit existing gas boilers with resistive heating elements and maintain the same boiler vessel. Components suppliers to industrial heat pump manufacturers certainly represent another attractive opportunity, as many of them also benefit from the increasing penetration of heat pumps in residential applications. For example, Carel is a global leader in control systems, and Alfa Laval is a leading producer of heat exchangers.
- **Electrical Equipment Suppliers:** as mentioned earlier, switching from fossil-based to electric heat will inevitably increase the power requirements of industrial plants, and electric heating technologies will require specific equipment: transformers, switchgears, power semiconductors, to name a few. Electrical equipment suppliers will therefore see incremental demand from industry on top of that from the electrification of transport and residential heat. Companies like ABB and Schneider Electric, global leaders in electrical equipment, or Infineon, a top player in power semiconductors, are set to benefit from the electrification of industrial heat.
- **Renewable Energy Players:** the faster the switch to electric heating, the faster will be the deployment of renewable energy generation capacity needed, creating an upside for players along the renewable energy value chain (equipment providers, developers, electricity producers).

Conclusion

Electrification of industrial heat, and the resulting investment to replace fossil heating technologies, represents a massive € 1 Tn economic opportunity.

Industrial decarbonization cannot happen without transforming heat generation, and direct electrification, as we have shown in this newsletter, is the best way forward. Cheap, ubiquitous, renewable electricity will enable and reward electrifying virtually all fossil-fuel uses, delivering deep economic and emissions savings.

This newsletter explores the investment opportunities in industrial heat electrification. OEM's and components suppliers of electrical heating technologies, electrical equipment producers and renewable energy players will be the main beneficiaries.

In the race to abate emissions and curb climate change, Ambienta believes that the opportunities provided by the electrification of industrial heat are hiding in plain sight and should receive top priority.