February 26, 2025

Industrial Heat Reinvented: The Case For Electrification

Despite its vast potential, electrification of industrial heat processes remains an underutilized solution to both decarbonize industry and improve manufacturing efficiency. Historically, electrifying industrial heat was deemed unfeasible due to high costs and the technological challenges of producing adequate temperature ranges for industry. However, recent innovations have begun to unlock the scalability of electric alternatives to fossil-fuel-based heating. As it stands today, industrial heating remains vastly unsustainable (Box 1). With only 13% of industrial energy currently electrified and a mere 5% of industrial heating powered by electricity, the potential for growth is enormous.

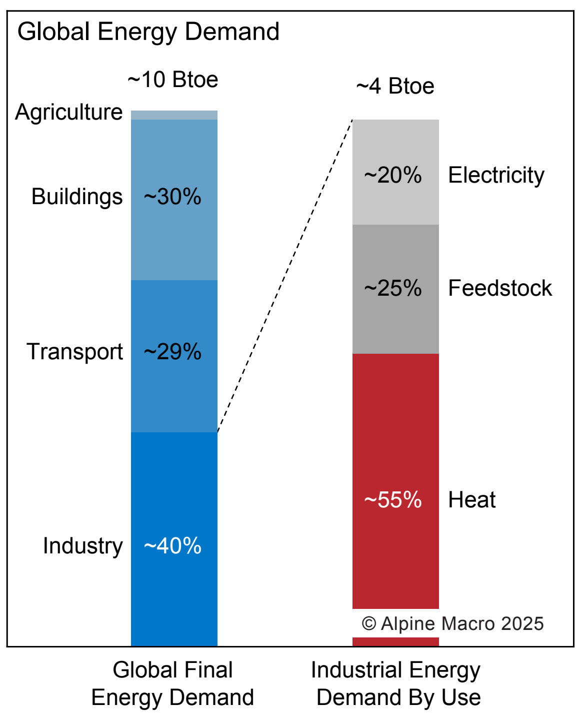
This report argues that electrifying industrial heat processes will not only drive decarbonization but also pave the way for more sustainable, high-quality industrial growth. Decarbonization is just the start – electric industrial heat boosts efficiency, ensures uniform heating, and significantly reduces pollutant emissions.

Box 1: Industrial Heating's Energy Thirst And Carbon Problem

Heat production is the world's largest energy consumer, accounting for roughly half of all energy use and over a third of all carbon emissions. The industrial sector alone accounts for roughly 40% of global energy consumption – primarily driven by heat generation in manufacturing industries (Chart 1). Industrial heating specifically draws 30% of global energy demand, with 90% of it still generated from fossil fuels, contributing around 10% of global CO_2 emissions. This exceeds air and sea transport emissions by 2.5x.

In This Report

Chart 1 Industrial Heating's Energy Appetite



Source: Ambienta analysis on IEA and McKinsey Data

Below, we break down the most promising electric heating technologies, their ideal use cases based on temperature requirements, and the essential role of clean energy and thermal/energy storage systems – offering key insights for investors looking to capitalize on this industrial shift.

Consensus Currently Underestimates Electric Industrial Heat's Potential

Low-carbon industrial heating is classified into three categories based on heat requirements (**Table 1**). While it is widely believed that all fossil fuels are essential for industrial heating and uniquely capable of providing high temperatures, electric heat is far more viable than commonly assumed. Consider that over 50% of industrial heating requirements are below 200°C (**Chart 2**). This positions roughly half of industrial heating applications to have high or medium potential for electrification with commercially available technology today.[1]

Three Emerging Electric Heating Pathways

The electrification of industrial heat processes is contingent on access to low-carbon energy/heat. **Table 2** presents the three best positioned heat/energy sources to facilitate this industrial overhaul.

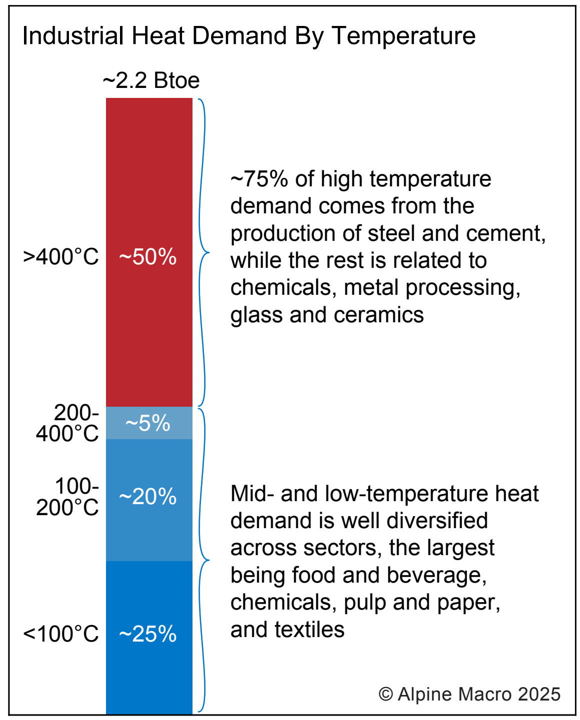
Leading Electrical Heat Technologies

The optimal electric heating technology for a specific industrial process is a direct function of the application's heating requirements. We note that the higher the heat requirement, broadly speaking, the more nascent the technology across maturity and adoption (**Chart 3**).

Table 1 Industrial Heat Temperature Ranges

Low Temperature	Medium Temperature	High Temperature
1-100°C	100-400°C	> 400°C

Chart 2 Roughly Half Of Industrial Heat Falls Under Low/Mid Classification



Source: Ambienta analysis on IEA

Low to Medium Heat:

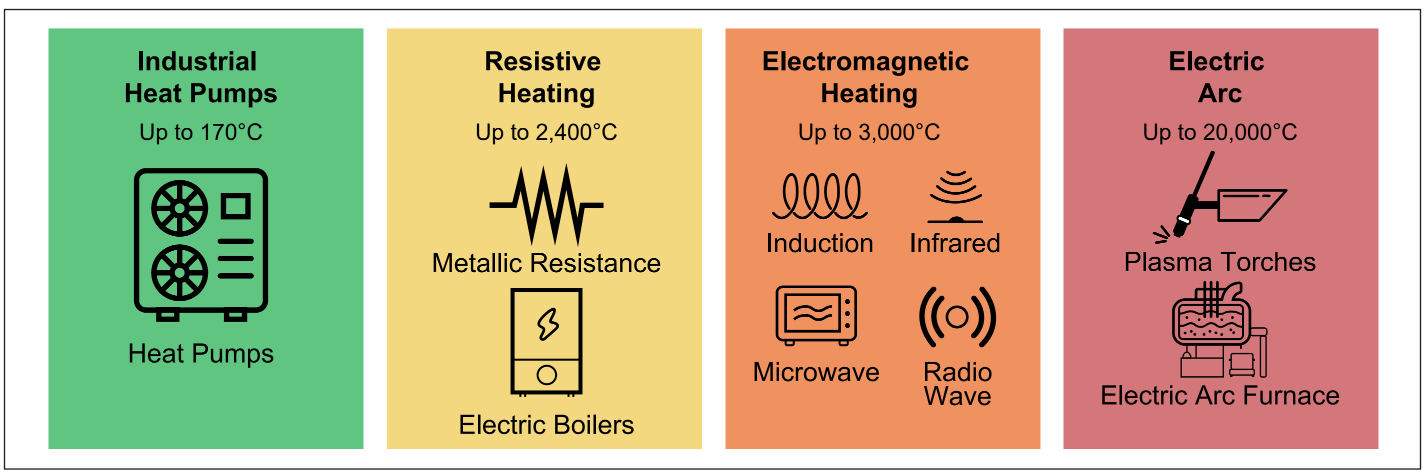
- **Industrial Heat Pumps:** Are the leading technology in this classification. Rather than converting electricity into heat, these systems transfer thermal energy from a heat source to a heat sink. Mature pumping technologies can achieve temperatures up to 170°C, with emerging advancements pushing these limits further. Additionally, by recycling waste heat, these pumps can boost efficiency by 300-700%, depending

1 Lawrence Berkeley National Laboratory

Table 2 Most Viable Energy Sources For Electrifying Industrial Heat

Heat Classification	Direct Heat	Direct Electrical Heat	Indirect Heat
Method	Generated by low-carbon sources such as geothermal or nuclear, pumped directly into processes as heat without need for conversion. Heat is transferred directly to industrial systems in its usable form.	Takes clean energy from renewables (e.g., solar, wind) to generate low-carbon heat through electric heating elements. The electricity directly powers heating equipment.	Leverages clean energy from renewables to produce green fuels like hydrogen. The heat is transferred *via* the combustion or use of green fuels in existing systems.
Benefits	• Highest efficiency • No electrical conversion needed • Baseload capability	• Precise temperature control • Grid adaptability • Retrofit integration	• Versatility in fuel sources • Highest energy density and temperature ranges • Baseload capability
Limitations	• High CAPEX • Geographic constraints • Early stages of integration	• Requires energy/heat storage infrastructure • Intermittency • Energy loss during conversion	• Reliance on underdeveloped green fuel production, higher operating costs • Storage and transportation challenges • Efficiency losses in energy conversion

Chart 3 Electrical Heat Innovation

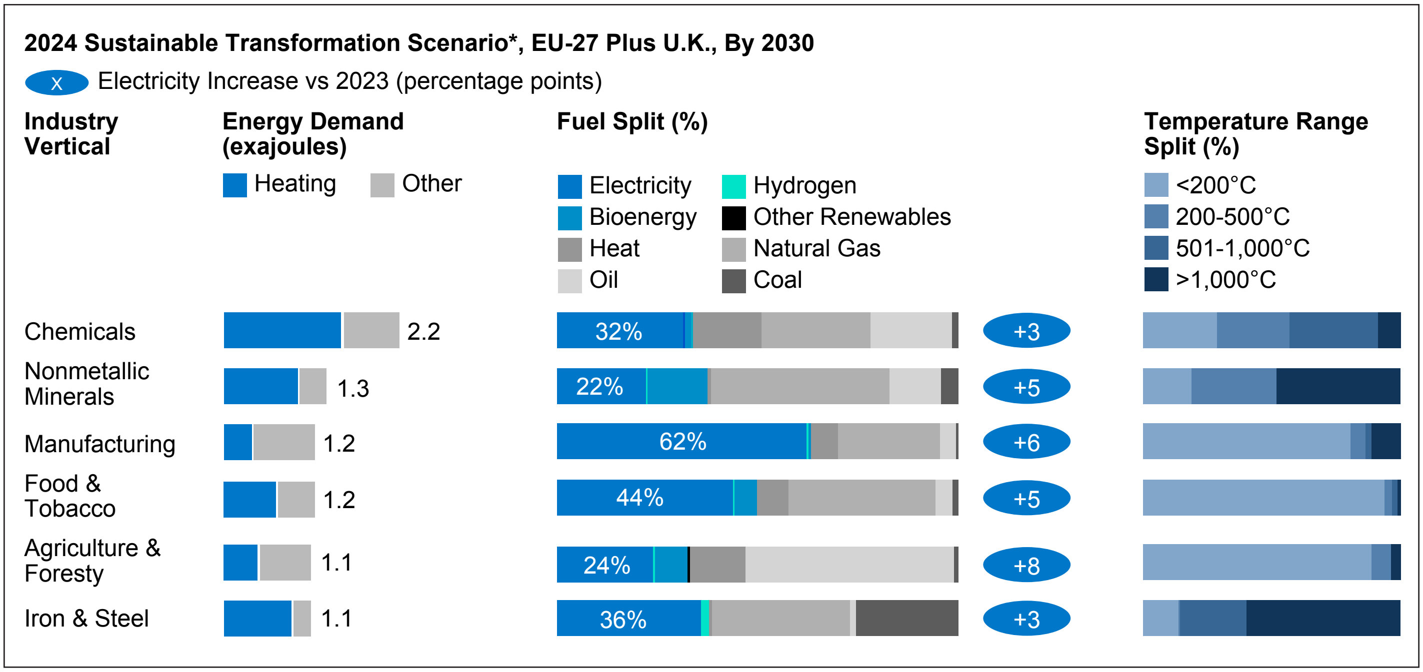


on the configuration. Heat pumps are ideal for applications such as beverages, drying, cooking, and textiles, as they can achieve a coefficient of performance (COP) of 2 or more – meaning that for every unit of electricity consumed, at least two units of heat are produced.

Medium to High Heat:

- **Resistive Heating:** Based on Joule heating, this method converts electrical energy into heat through the resistance of a metal conductor. Depending on the material used, resistive heating can reach temperatures between 2,000°C-

Chart 4 Electrified Heat Potential By 2030



*Scenario from Global Energy Perspective 2024, McKinsey, September 17, 2024
Source: McKinsey & Company

2,400°C, with products such as electric boilers, immersion heaters, and cartridge heaters.

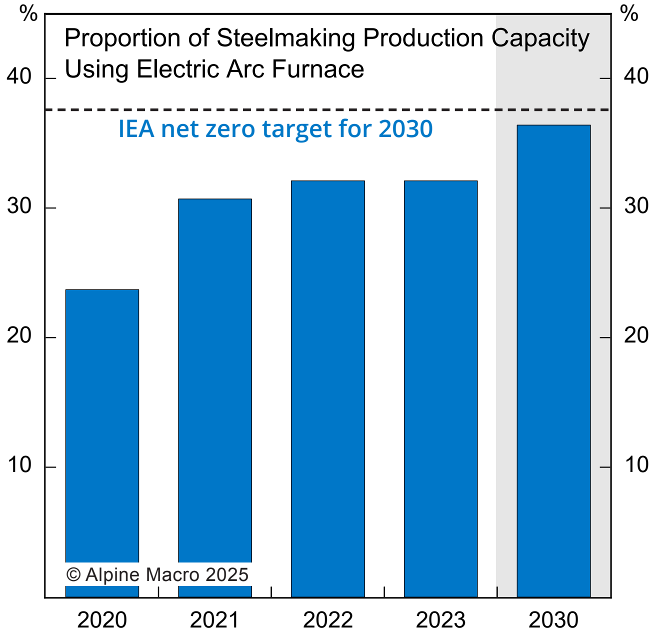
- **Electromagnetic Heating:** This technology converts electricity into electromagnetic radiation at various wavelengths, utilizing methods such as induction, microwave, infrared, and radio frequency heating. Although it is the least efficient of the methods, electromagnetic heating can rapidly elevate temperatures and offers precise control over localized heating zones, achieving temperatures in excess of 3,000°C. Examples include induction heaters and furnaces, microwave dryers, vulcanization systems, radio frequency dryers, and welders.

- **Electric Arc Heating:** By passing a high-voltage current between electrodes (typically carbon, tungsten, or graphite), an electric arc is generated as the surrounding gas ionizes. This process can achieve the highest temperatures – up to 20,000°C – far surpassing legacy fossil fuel heating solutions. Key applications include plasma cutters, electric arc furnaces, and plasma arc welding systems. By 2050, global investment of $130bn in electric-arc furnaces would allow low-emission steel production, to make up 28% to 50% of global output.[2]

The growing adoption of advanced heating technologies in high-emission sectors signals strong momentum (Chart 4). For example, BASF, SABIC, and Linde have launched the world's first pilot facility for large-scale, electrically heated steam cracker furnaces. With a processing capacity of nearly four metric tons of hydrocarbon feedstock

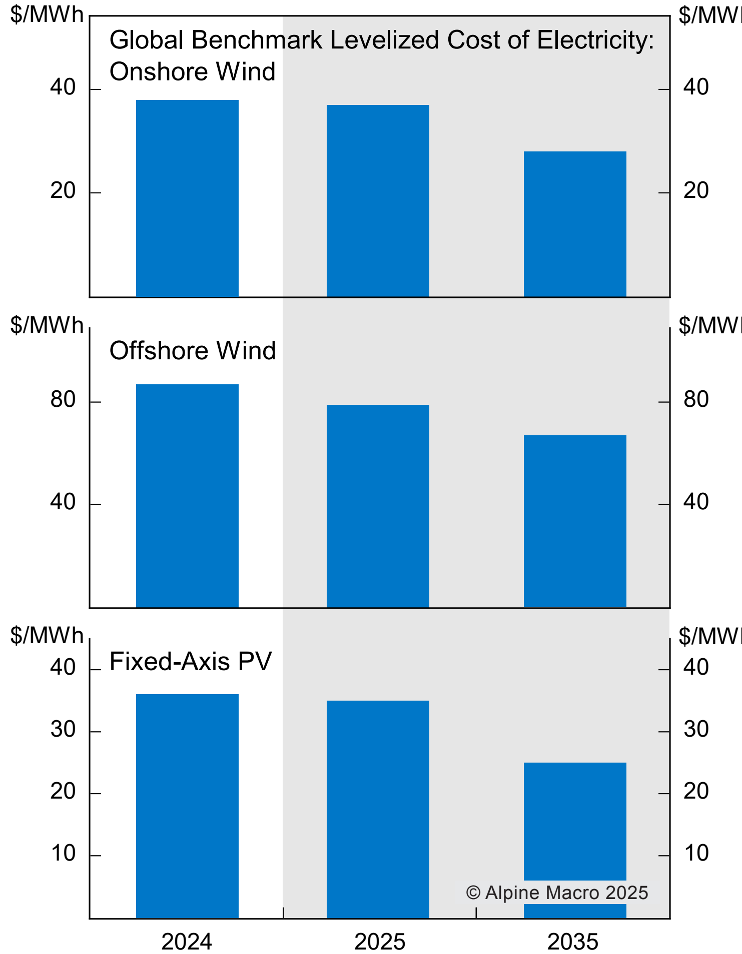
2 Wood Mackenzie

Chart 5 Electric Steel Making Potential



Note: Shading denotes projections; source: Global Steel Plant Tracker, Global Blast Furnace Tracker, Global Energy Monitor, IEA

Chart 6 Falling Renewable Costs



Note: Shading denotes projections; source: BloombergNEF

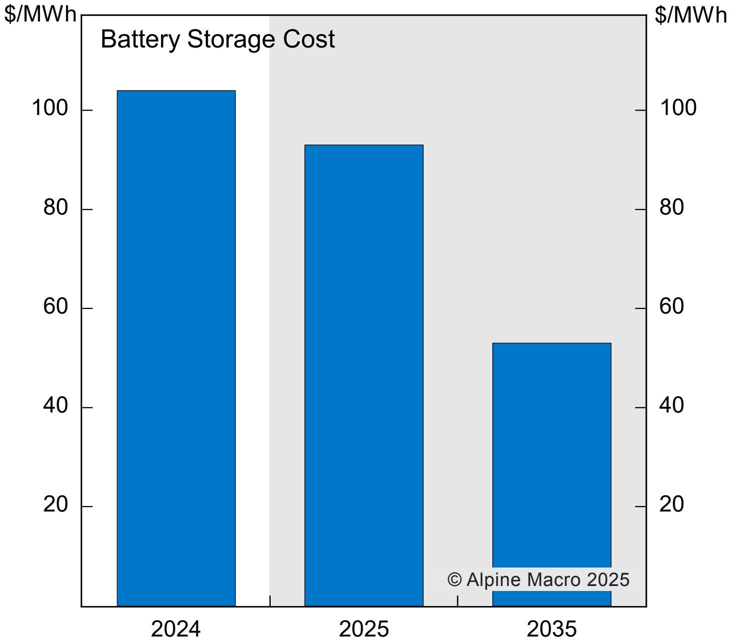
per hour and a combined consumption of six MW of renewable energy, this innovation has the potential to cut CO_2 emissions by up to 90%. Additionally, Spain's Roca Group has introduced the first-ever fully electric industrial tunnel kiln for ceramic production, demonstrating the viability of electrification in high-temperature manufacturing applications. Over 5,000 businesses globally have set emission-reduction targets, a key tailwind for the electrification of industrial heat. Steelmaking is emerging as an electrification leader, with 49% of new steel capacity using electric arc furnaces (**Chart 5**).

Boosting Clean Energy Production Critical To Supporting Electrified Heating

Despite political challenges and shifting incentives, renewable energy continues to grow more cost-competitive (**Chart 6**), expand its share of the global energy mix, and attract significant investment. In 2024, more than 90% of new electrical generating capacity in the U.S. came from renewable energy sources[3], while global investment in clean energy rose by 11%, reaching a record $2.1 trillion. In 2025, costs for clean power technologies are projected to drop another 2-11%, surpassing last year's records. In some regions, new solar farms are already cheaper than new coal and gas plants. This is critical to expanding the viability of electrical heating, particularly for high heat applications. Historically, electrification's largest headwind has been its

3 Federal Energy Regulatory Commission

Chart 7 Stationary Battery Costs In Decline

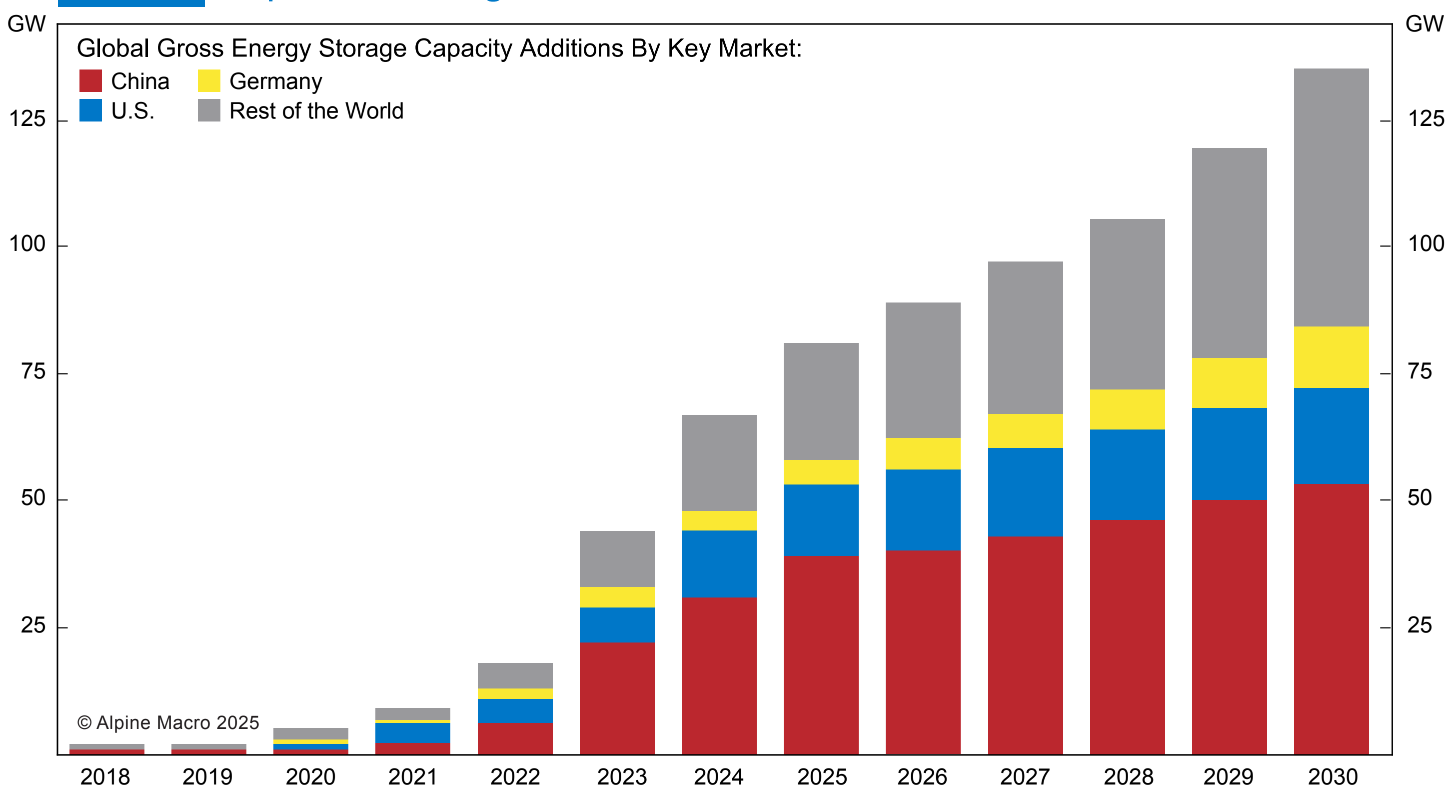


Note: Shading denotes projections; source: BloombergNEF

inability to compete from a cost's perspective with natural gas, which is roughly 3-5x cheaper than electrification.

Due to the intermittency of renewables, the co-location of long-duration energy/heat storage systems is a critical piece to the industrial electrification equation. These systems include grid scale batteries optimized for long cycle lives and thermal batteries, which are essentially heated materials such as graphite, crushed rock, and bricks encased in insulation. Thermal storage systems can capture and store heat – from renewably powered direct electric heat sources and store excess heat from industrial processes to be recycled. Costs across both storage systems are in decline. For example, global benchmark cost for battery storage projects fell by a third in 2024 to $104 per MWh (**Charts 7 & 8**).

Chart 8 Adoption Is Increasing



Source: BloombergNEF

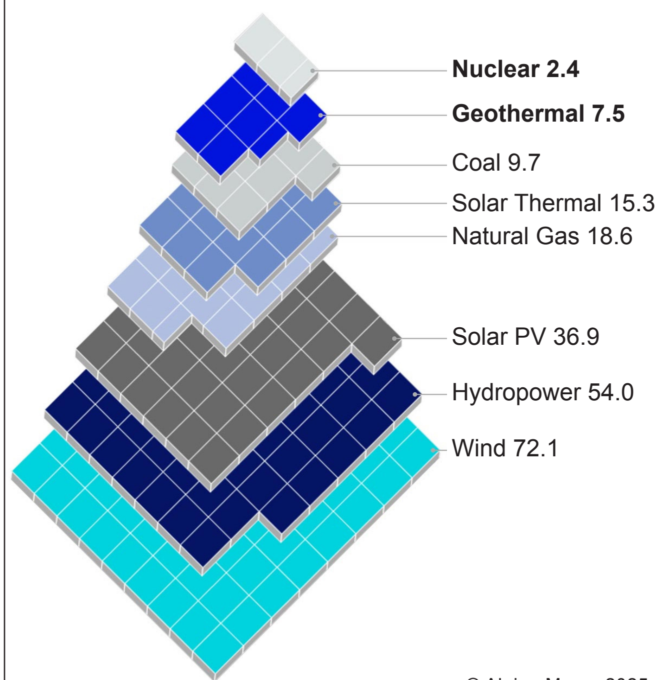
Geothermal And Nuclear To Emerge As Winners

From our perspective, geothermal and nuclear energy are set to benefit greatly from initiatives to decarbonize industrial heat due to their unique ability to provide "direct use heat". This critical advantage allows these energy sources to deliver heat directly to industrial processes without the need for a separate generation facility, ensuring a more efficient solution. As noted in a previous report[4], both geothermal and nuclear energy boast the smallest land footprint per TWh (**Chart 9**), enabling them to be located near the infrastructure they power. This capability is especially valuable, as transmission and distribution costs account for 44% of the total cost of delivered electricity in the U.S.

Innovative drilling techniques in geothermal energy – borrowed from the fossil fuel industry – are unlocking new possibilities for industrial heating. Traditionally limited to temperatures around 200°C, geothermal systems have now expanded with horizontal and deep drilling methods, enabling access to "superhot" rocks below the Earth's surface at temperatures over 300°C – making them viable for more heat-intensive applications. The most disruptive advancement is supercritical geothermal, which taps water at temperatures of 400-600°C, offering up to 10x more energy than legacy geothermal systems. Geothermal systems are also more efficient than fossil fuels, producing 3-5 units of heat for every unit of energy used. When combined with a heat pump, installing geothermal heat pumps in around 70% of U.S. buildings could save as much as 593 TWh annually – about 15% of the current annual electricity generation – and avoid seven gigatons of carbon-equivalent emissions by 2050.

4 Alpine Macro *Innovation Themes & Strategy* "Unlocking Geothermal Energy's Potential" (September 18, 2024).

Chart 9 **Minimal Land Footprint**



Note: Values are in square kilometers per terawatt hour per year; source: U.S. Global Change Research Program

On the nuclear side, reactors' high-capacity factor makes them ideal for energy-intensive industrial processes. High-temperature reactors (HTRs), operating at 750-1000°C, are particularly well suited as they can provide direct industrial heat without first converting it to electricity. Emerging HTR small modular reactors (SMRs) – such as molten salt and high-temperature gas-cooled reactors – offer the best solutions, as they can be located adjacent to industrial sites, enabling efficient heat transfer. SMRs also boast modular construction, lower upfront costs, and enhanced safety features – all traits that facilitate their buildout over their large reactor cousins.

Key Takeaways

The economic case for electrification is becoming increasingly compelling. Renewable energy costs continue to decline, while nuclear and advanced geothermal technologies progress along their development curves. At the same time, energy and heat storage systems are scaling up, further enhancing the feasibility of electrification. As a result, industrial adopters of electric heating solutions stand to gain a significant competitive advantage.

While regulatory uncertainty, particularly in the U.S., could pose short-term challenges – such as Trump's deregulation stance potentially slowing decarbonization efforts – the global momentum toward electrification remains strong. Geographies with established carbon pricing mechanisms, such as the EU, as well as manufacturing powerhouses in Asia, are already incentivizing industries to make the electric transition.

From an investment perspective, we see compelling opportunities across multiple segments of this transformation. OEMs of industrial heat pumps and key component suppliers of resistive heating elements are well-positioned to benefit from increased adoption. Grid infrastructure players facilitating the expansion of electrical capacity, specifically through grid enhancing technologies[5] and renewables integration, will be crucial enablers as full industrial electrification could more than double U.S. power demand. Additionally, next-generation nuclear and geothermal technologies, particularly those capable of providing direct-use industrial heat, represent a high-growth frontier within the broader decarbonization theme. Ultimately, as electrification moves from a niche solution to a mainstream industrial strategy, early adopters will not only achieve emissions reductions but will also redefine industrial competitiveness in the low-carbon economy.

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4 Alpine Macro *Innovation Themes & Strategy* "“The U.S. Grid: Revamp Time!" (July 31, 2024).

A Unique Mind On The Markets