THERMAL BATTERIES

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Industrial Innovation Initiative

a partnership between Great Plains Institute and World Resources Institute

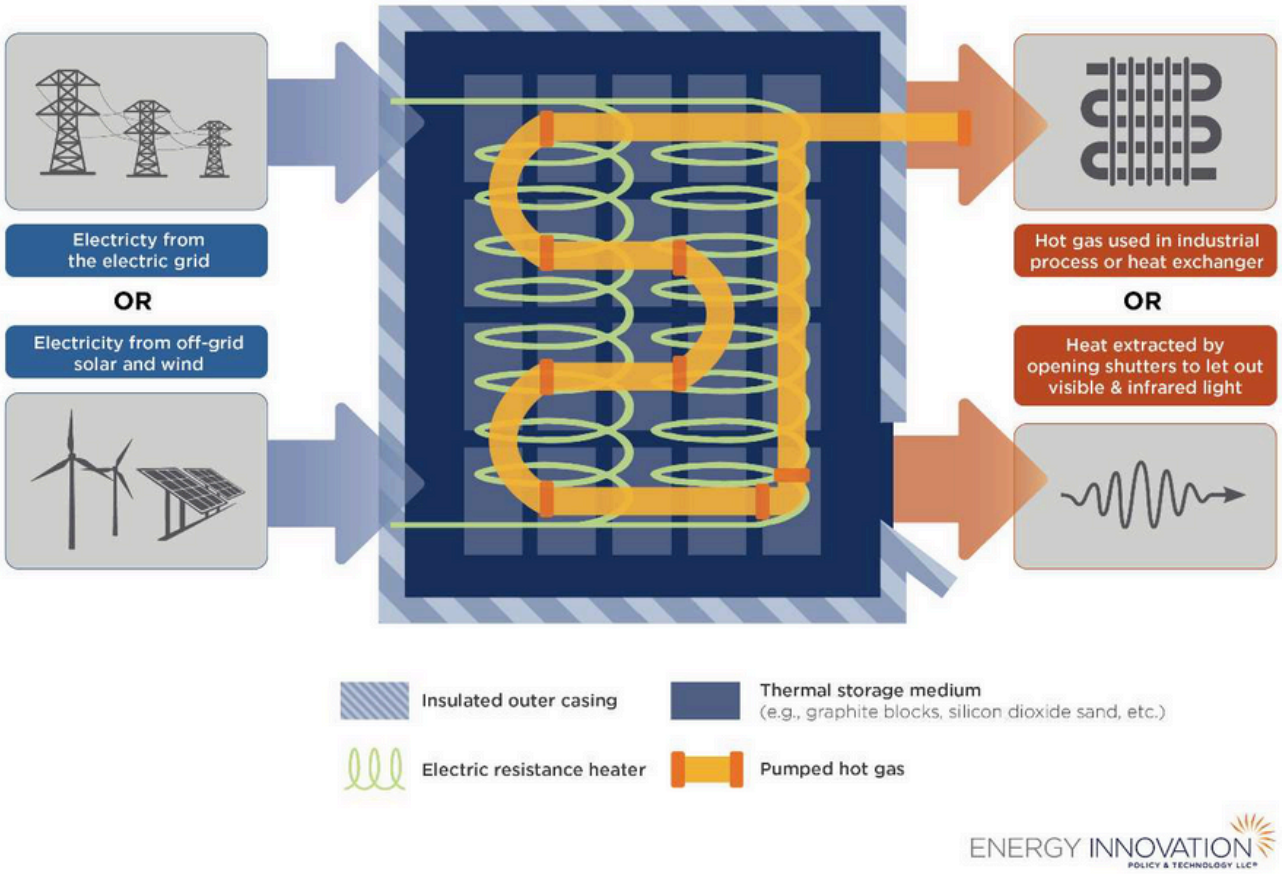
THE BIG PICTURE

Thermal batteries are a critical strategy for electrifying across industrial sectors because they can produce heat across a wide temperature range, typically 300°F to 4,000°F. This means that sectors that rely on low- and medium-temperature heat, like food and beverages, glass, pulp and paper, and chemical production, as well as those that rely on high temperatures heat, like steel and cement, can all benefit from thermal batteries. See our industrial electrification guide for a broader discussion of the potential benefits of electrifying manufacturing facilities.

WHAT ARE THERMAL BATTERIES?

Thermal batteries are a high-efficiency technology that convert electricity to heat; store the heat for hours or days in a medium such as bricks, blocks, or rock; and then discharge the heat for use in industrial processes.

DIAGRAM OF A THERMAL BATTERY



HOW DO THERMAL BATTERIES WORK?

Thermal batteries can be used in place of a fossil-fuel burning boiler, furnace, or kiln to provide heat. Thermal batteries charge using clean electricity when it is abundant and inexpensive, enabling them to deliver reliable heat on demand while reducing costs for all customers.

- **Charging:** Electricity (obtained either from the grid or from off-grid sources) powers the battery. Resistive heaters convert the electricity to heat (this is the same basic technology used in a toaster oven).
- **Storage:** The heat is stored in simple, low-cost materials, like brick or rocks, that can maintain heat at temperatures above what is required for industrial processes. According to the Department of Energy, thermal batteries are three times as energy dense as lithium-ion batteries. Because thermal batteries can produce heat across a wide temperature range they can be used across most industrial sectors, including food and beverage manufacturing, pulp and paper operations, and chemical production. Thermal batteries currently under development will be able to provide heat in sectors that rely on high temperatures, such as steel and cement.
- **Discharge:** A working fluid such as heating oil, water, steam, or air runs through the blocks to absorb the heat and deliver it to the industrial process. Some models can convert a portion or all the heat back to electricity using a turbine or thermophotovoltaic technology.

HOW DO THERMAL BATTERIES DIFFER FROM OTHER EMERGING TECHNOLOGIES?

The most important feature that distinguishes thermal batteries from other clean heating technologies is their ability to dramatically lower energy costs for industrial firms by enabling a firm to rely on off-grid variable renewables or by purchasing grid electricity only in the hours of the day when it is cheapest. No other electrified or hydrogen-based technology can achieve such discounts on electricity pricing.

Thermal batteries possess several beneficial traits that differentiate them from other technologies, including:

- **Material availability:** Thermal batteries contain only commonly used, abundant materials (as opposed to critical minerals) that can be domestically sourced.
- **Low maintenance:** They can operate for decades with minimal maintenance.
- **Versatile:** They operate over a broad temperature range, making them suitable for a wide range of industrial processes.
- **Reliable:** They rely on well-understood processes, some of which have been in use for thousands of years.
- **Scalable:** They are factory-built and can be scaled up as the need for heat or power increases.

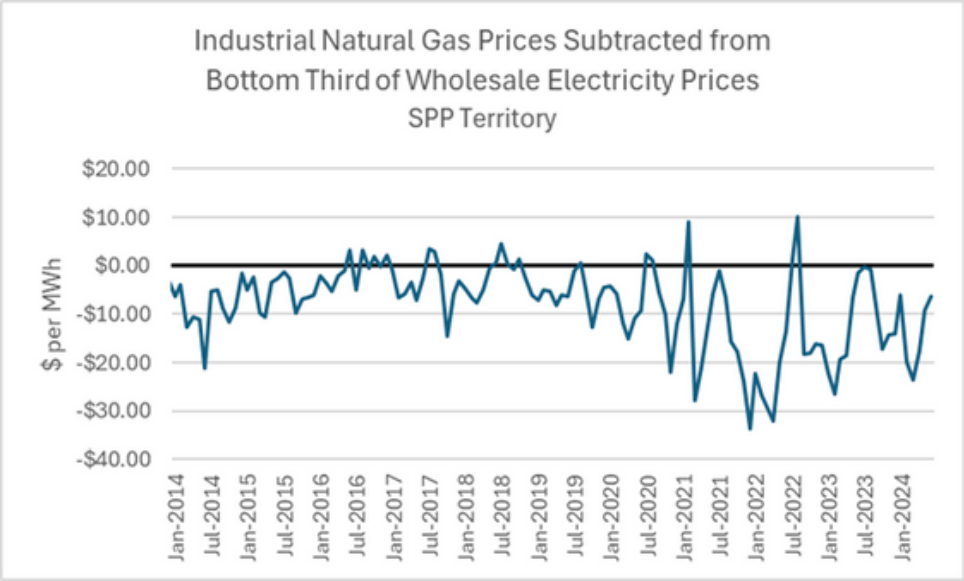
HOW CAN THERMAL BATTERIES BENEFIT MANUFACTURING AND INDUSTRIAL FACILITIES?

Thermal batteries can deliver a range of operational and social benefits to industrial facilities. Their potential advantages include:

- **Flexible charging:** The ability to charge intermittently from both grid-connected and off-grid sources, allowing facilities to charge whenever electricity is cheapest (and cleanest) and completely avoid periods of high electricity demand. This means thermal batteries efficiently use current electricity generation assets and infrastructure with minimal capacity, resource adequacy, or transmission expansion requirements.
- **Energy efficiency:** The ability to efficiently store energy with only minimal heat loss.
- **Versatility:** The ability to produce heat at a wide range of temperatures, dramatically increasing the types of industrial processes that can be electrified at reasonable cost.
- **Health and safety:** As an electrified heating technology, thermal batteries emit no on-site pollution. This means manufacturers do not have to purchase or operate exhaust treatment technologies and leads to better air quality for workers and the surrounding community. The lack of combustion may also reduce fire risk, which might result in lower casualty insurance premiums.
- **Price stability:** Facilities that can source electricity directly from renewable sources or from grids primarily powered by renewables will be insulated from volatile fossil fuel prices and sharp increases in the cost of natural gas.

Wholesale electricity prices: An opportunity

The image on the right depicts the difference in industrial natural gas rates and wholesale electricity prices accessed by thermal batteries. The natural gas prices are an average of Iowa, Kansas, Nebraska, and Oklahoma rates. The electricity prices are an average of the lowest one third of hours of wholesale prices calculated on rolling windows of approximately 50 hours. This reflects thermal storage charge/discharge ratios. As depicted by the graph, with access to wholesale electricity prices, thermal batteries would have been able to provide clean heat at rates cheaper than natural gas approximately 85% of hours over the past five years in the SPP Territory. Wholesale electricity prices are projected to beat natural gas prices even more consistently with additional deployment of variable renewables.



Source: U.S. Energy Information Administration. 2024. Natural Gas Prices: Industrial Price. https://www.eia.gov/dnav/ng/NG_PRI_SUM_A_EPG0_PIN_DMCF_M.htm; Orennia Inc. 2024. Energy Prices- LMP Explorer.

HOW CAN THERMAL BATTERIES IMPROVE GRID STABILITY?

In addition to the benefits thermal batteries can provide to industrial facilities, they can also stabilize electric grids. They can help grid operators reduce curtailments by utilizing low-priced or even otherwise curtailed renewable energy when it is most abundant. Thermal batteries store low market-value renewable energy and release it over time as heat locally, thereby reducing the need to build costly transmission to send the electricity elsewhere.

In addition to providing heat, some thermal batteries can return electricity to the grid or provide electrical power to industrial customers. This means they can serve other customers with power at times of high demand, and reduce emissions from industrial combined heat and power generation.

WHAT ARE THE BIGGEST BARRIERS TO ADOPTION OF THERMAL BATTERIES?

Legacy electric rate structures are one of the greatest barriers to widespread adoption of thermal batteries because they do not accurately reflect the time- and location-specific costs of providing electricity. While average costs may be appropriate for some consumers, legacy rate structures distort electricity markets. This harms both manufacturers (who must pay elevated rates for electricity in some hours) and utilities (which are forced to charge prices that are too low in difficult, high-demand hours and thus fail to incentivize demand to shift to off-peak hours, which would improve system utilization).

As a result, it often remains significantly cheaper to rely on natural gas as a heat source rather than electrifying with thermal batteries that could provide 24/7 heat using only the lowest market value electricity. A huge opportunity for electrification of industrial heat is being lost because many hours of low market value clean energy are being wasted or negatively priced. Significant renewable energy deployment is critical for thermal storage to offer full decarbonization value and access cost-competitive energy pricing. States should support grid decarbonization efforts with robust policies such as clean electricity standards.

Thermal batteries are typically engineered to charge very quickly with large amounts of renewable power. This allows them to provide valuable services to the grid and hunt for the lowest cost renewable power and charge for short periods of time. In fact, utilities can schedule the charging from hour-to-hour and avoid curtailment of renewable power. Unfortunately, many utilities do not offer commensurate tariff structures that only price the power and not the "always on" availability of power. In many cases, thermal battery operators must pay for the price of having power available in standby for when it is needed.

A more appropriate model would be: "When I flick the switch, I don't need the lights to come on. I wait until there is excess power, and only then the turn the lights on." This illustrates the potential that thermal batteries could have if appropriate electricity rate structures were available to industrial facilities nationwide.

THERMAL BATTERIES IN THE MARKETPLACE

Several companies are manufacturing, testing, and deploying thermal batteries. The materials used vary slightly between manufacturers, as do the temperature ranges each battery can sustain, but the batteries all operate according to the same basic principles. While thermal batteries are in the early commercialization stage, manufacturers have received significant funding from public and private sources, indicating confidence in the effectiveness of thermal batteries to reduce industrial emissions. The first large-scale commercial battery installations are expected to go online in the United States in 2025.

Thermal batteries qualify for tax credits under the Section 45X Advanced Manufacturing Production Tax Credit provisions in the Inflation Reduction Act. The tax credit values battery modules at $45 per kilowatt-hour through 2029, with a phase-down from 2030-2032. These tax credits will reduce the capital costs of thermal storage by enabling manufacturers to competitively price their units.

A short list of thermal battery manufacturers includes:

Antora Energy

Brenmiller Energy

Electrified Thermal Solutions

Rondo Energy

A more complete overview, encompassing 31 manufacturers, can be found in a March 2024 news article at solarthermalworld.org:

Worldwide overview of high-temperature energy storage system providers.

HOW CAN FACILITES OVERCOME COST CONCERNS RELATED TO HIGH ELECTRICITY RATES?

Negotiate project-specific power supply options:

While states develop new market participation rules for thermal storage that reflect its potential to lower grid and renewable deployment costs and decarbonize industry, individual industrial facilities can work with thermal storage providers to negotiate project-specific electricity purchase agreements that reflect time- and location-specific market values.

Get off the grid:

Facilities that generate electricity on site or purchase it from a renewable power supplier not connected to the grid can avoid paying inflated electricity costs. In some cases, this may be the most feasible short-term option for manufacturers in areas with unfavorable electricity rates.

Deploy thermal batteries selectively:

Manufacturers can cost effectively deploy thermal batteries in locations where modern rate structures (in which rates are closely tied to cost causation and time and location of use) are in place, ensuring that plants draw power from the grid only during low-cost periods. According to a report from Energy Innovation, manufacturers with thermal batteries can dramatically lower their power costs in such circumstances. “The resulting average cost of electricity is $10.50/MWh. In contrast, an industrial facility that purchased wholesale power from the grid evenly in every hour, without a thermal battery, would have paid an average electricity price of $30.80/MWh, roughly three times higher than the facility with the thermal battery.”

Emphasize the multiple benefits of modern rate structures:

In many parts of the country, electrical rate structures do not reflect the unique characteristics of renewable generation and thermal batteries. Industrial customers need to work with utilities and state policymakers to convey the potential benefits of more nuanced rate regimes.

A more favorable market or tariff rate structure can make thermal batteries and the energy savings they deliver a viable option for industrial customers. The most compelling argument that industrial customers can make in support of revised rate structures is a social one: facilitating large-scale deployment of thermal batteries will make the grid more reliable and reduce the need to add new generation, transmission, and other grid assets.

HOW CAN STATES FACILITATE DEPLOYMENT OF THERMAL BATTERIES?

Learn more about the potential benefits of thermal batteries:

States are diverse and often have vastly different industrial and electricity system profiles. Nonetheless, thermal batteries can help states meet their goals, whether they relate to emissions, reliability, or affordability. As renewables increase, so does the need for storage to capture excess production. Thermal batteries help ensure efficient utilization of electricity generated from renewable sources. State energy offices and public utility commissions can reach out to thermal battery manufacturers and consult detailed reports and studies on thermal batteries. Developing this knowledge base is a critical first step.

Update market structures or develop cost-reflective tariffs:

As previously noted, the electric rate structure in most states does not reflect the increased share of generation from renewables. This mismatch discourages efficient utilization of electricity, resulting in unnecessary curtailment during periods of high renewable generation.

- Enable thermal battery resources to directly access wholesale locational marginal pricing of electricity. This will encourage optimal scheduling of net renewable power injections and net withdrawals for thermal charging.
- Ensure reasonable transmission and distribution fees. In addition to covering the cost of generation, utilities often charge add-on fees to maintain the transmission and distribution system. Since thermal batteries utilize this grid infrastructure only when there is spare capacity available, fees that are fixed or based solely on peak demand from a particular facility may overcharge industrial facilities relative to the actual demands they place on the transmission and distribution system. Utilities should update transmission and distribution system fees to reflect the actual drivers of grid infrastructure investment. Basing transmission charges on consumption during annual, seasonal, monthly, or daily-coincident peak hours is one way to do this.
- Ensure that industrial customers that are newly electrifying via thermal battery systems are exempt from legacy system or restructuring transition charges, such as natural gas system “exit fees.” By establishing flexible and fair rate structures, states can nurture technologies that reduce emissions and contain costs.

CONTINUED: HOW CAN STATES FACILITATE DEPLOYMENT OF THERMAL BATTERIES?

Establish green public procurement programs:

States are major purchasers of industrial materials such as steel, cement, and plastics used in publicly funded buildings and infrastructure. A green public procurement program directs state dollars to industrial products manufactured with lower greenhouse gas emissions. This provides a guaranteed offtake market for these products, giving industrial facility managers the confidence to invest in new production lines and technologies, such as thermal batteries. Several states have established such "buy clean" policies.

Implement subsidy or tax incentive programs:

States can offer financial incentives to help foster competitive, clean manufacturing within their borders. For example, Pennsylvania's RISE PA program plans to distribute almost $400 million to industrial firms that wish to build or retrofit manufacturing facilities in the state, cutting pollution and creating industrial jobs. When selecting award recipients, these programs should consider benefits to the electric grid and to society, metrics on which thermal batteries score highly.