Thermal Batteries and Industrial Decarbonization Load Growth

OPPORTUNITIES TO ACCELERATE DECARBONIZATION OF INDUSTRIAL HEATING

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Study Overview: Thermal Batteries

Goal: Describe the policy case and business case for thermal batteries as a means do achieve large-scale industrial heating decarbonization

Paper Scope Covers:

- What are thermal batteries?
- What role can thermal batteries play in the clean energy transition?
- What is the business case for using thermal batteries to decarbonize heating demand?
- What barriers to entry should be addressed to accelerate thermal battery deployment?
- Recommendations for industrial users, policymakers, and power markets

What are thermal batteries?

How do they advance the clean energy transition?

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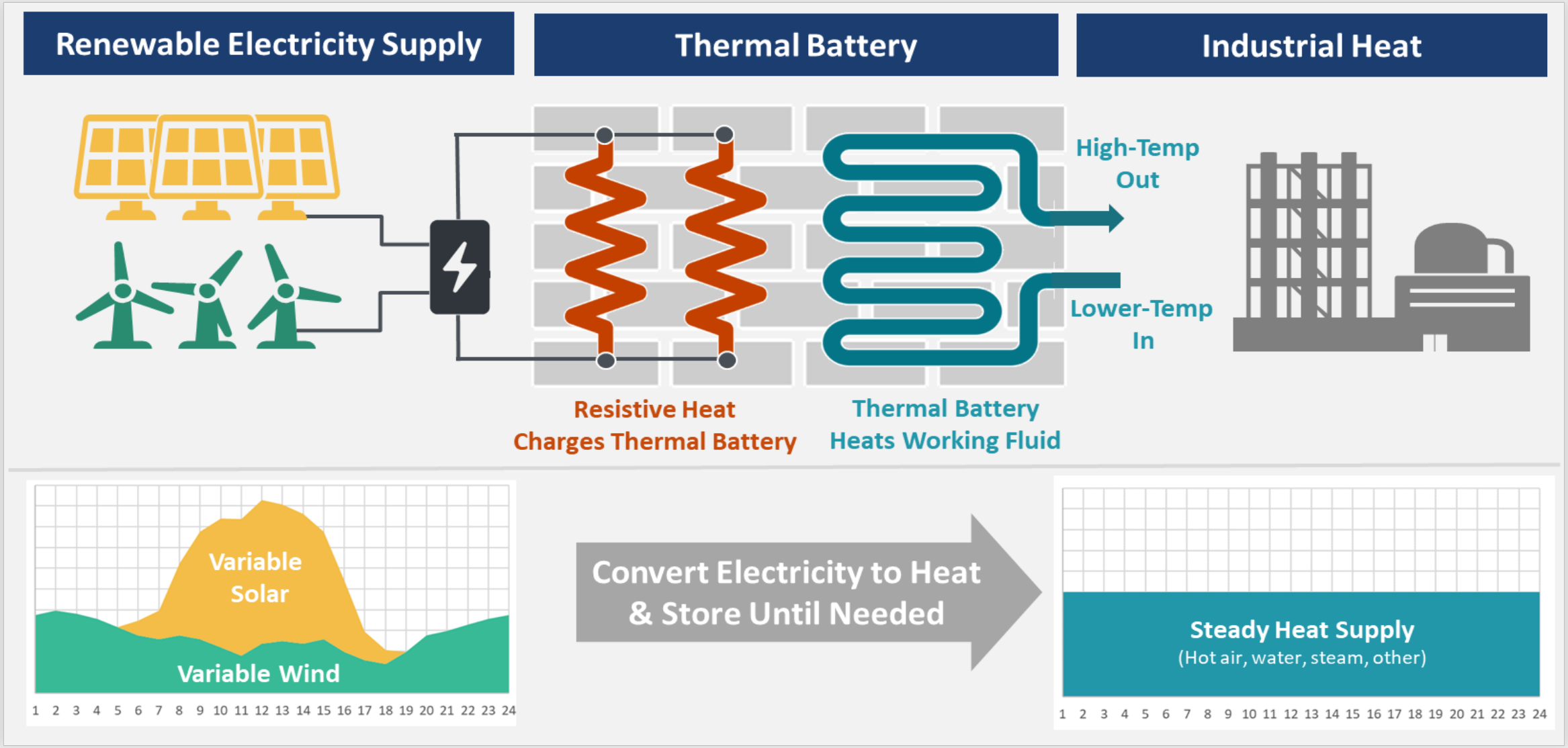
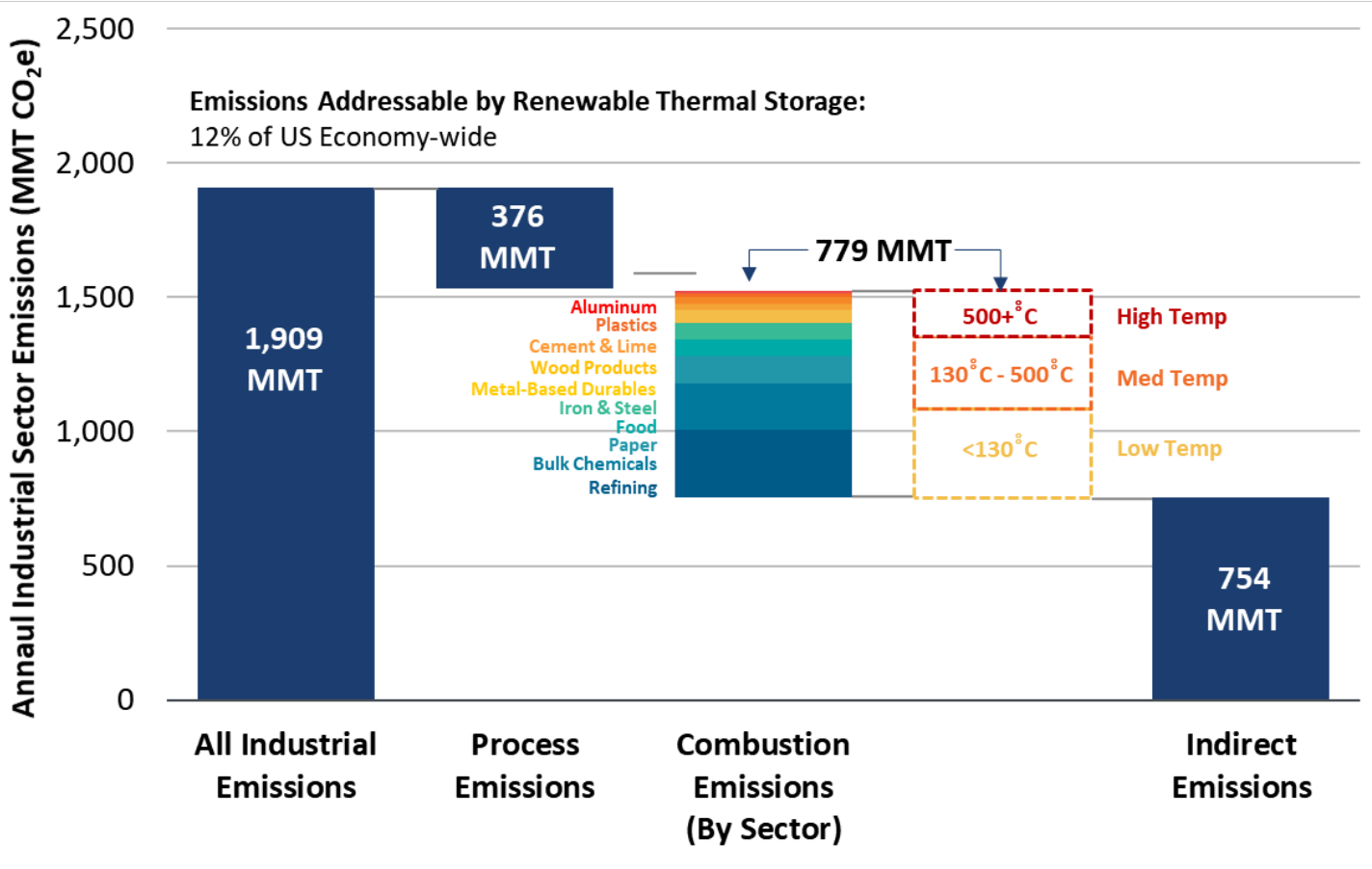


How do thermal batteries advance the clean energy transition?

Thermal batteries can play 2 critical roles:

- **Decarbonizing industrial heating demand** (up to 12% of US economy-wide GHG emissions)
- **Balancing the power grid** via flexible and controllable demand, enabling much more, cheaper, earlier renewable deployment in renewables-rich areas

US INDUSTRIAL HEATING EMISSIONS ADDRESSABLE BY THERMAL BATTERIES



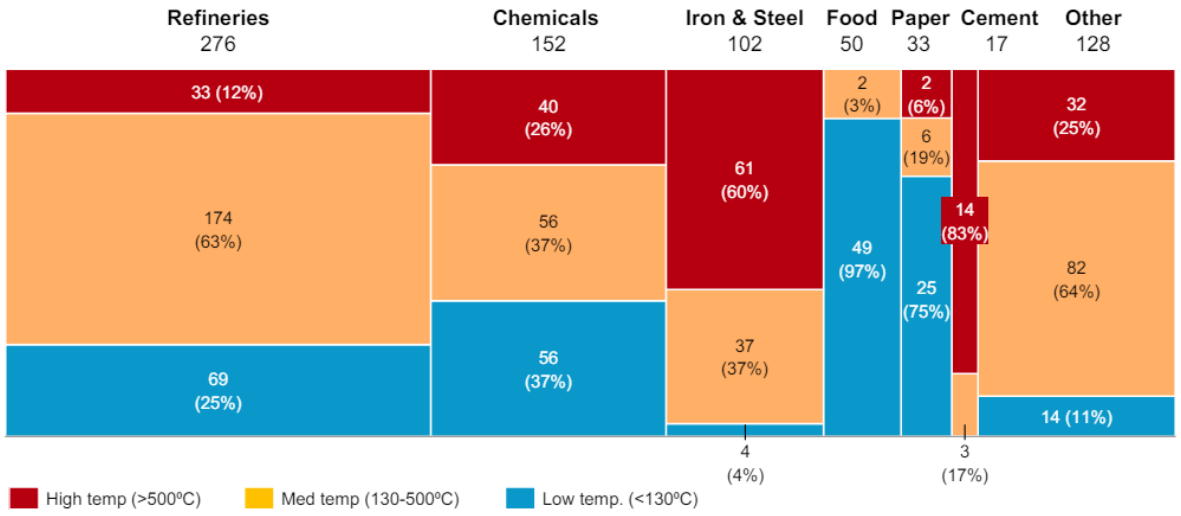
Sources & Notes: Maximum technical potential, consistent with US emissions in year 2021. Derived from EPA. *Inventory of US Greenhouse Gas Emissions and Sinks*. 2023; EIA. "Annual Energy Outlook 2023". 2023

Potential Scale of Industrial Electrification-Driven Demand

U.S. thermal demand is 10,000 TBtu per year, with about two-thirds from oil refineries, chemical plants, and iron & steel mills

- Fully electrifying thermal demand via thermal batteries would require 1,000 GW of batteries

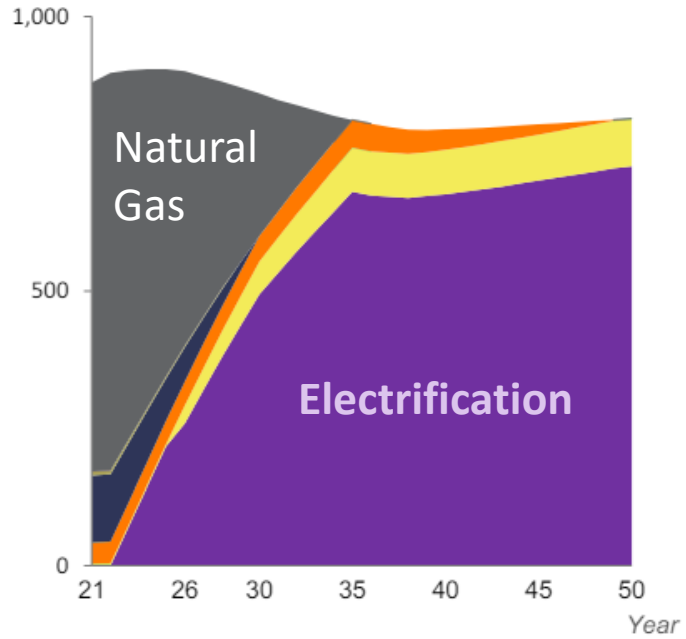
2018 Thermal Emissions by Temp and Sector (million tons of CO2e)



Decarbonizing food sector alone by 2035 would require 70 GW of thermal battery capacity

- 8 GW of heat pumps could also decarbonize food sector due to lower temp energy demand

Food Sector Thermal Energy Consumption (Tbtu)



Source: Renewable Thermal Collaborative, Industrial Thermal Decarbonization, Sept 2023.

Progress Deploying Thermal Battery Technologies

DOE announced $500 million in grants to support industrial decarbonization, including two thermal battery projects:

- **Electrified Thermal Solutions (ETS)** will receive $35 million to deploy a thermal battery at an ISP Chemicals plant to replace natural gas boilers
- **Rondo Energy** will receive $75 million to deploy its thermal batteries to replace gas-fired heat at production facilities for spirits, ready-to-drink cocktails, and whiskey; estimated annual demand is 95 GWh with a 30 – 40 MW charge rate

Commercially Available Thermal Batteries

Company	Thermal Battery Model (if relevant)	Temperature Range	Storage Medium	Commercialization Status
Antora Energy	-	Up to 1,500 °C (2,730 °F)	Carbon Blocks	Early Commercialization
Caldera	Storage Boiler	Primarily 90 °C – 300 °C (194°F – 572°F)	Recycled Aluminum and Crushed Rock	Pilot
Brenmiller Energy	bGen ZERO	130 °C – 750 °C (270 °F - 1,380 °F)	Crushed Rocks	Early Commercialization
Electric Thermal Solutions	Joule Hive Thermal Battery	Up to 1,800 °C (3,300 °F)	Firebrick	Pilot
Rondo Energy	RHB300	80 °C – 1,500 °C (180 °F – 2,730 °F)	Brick	Early Commercialization

What is the business case for using thermal batteries to decarbonize heating demand?

Business case for thermal batteries

Conducted a series of analyses comparing costs of industrial heat from:

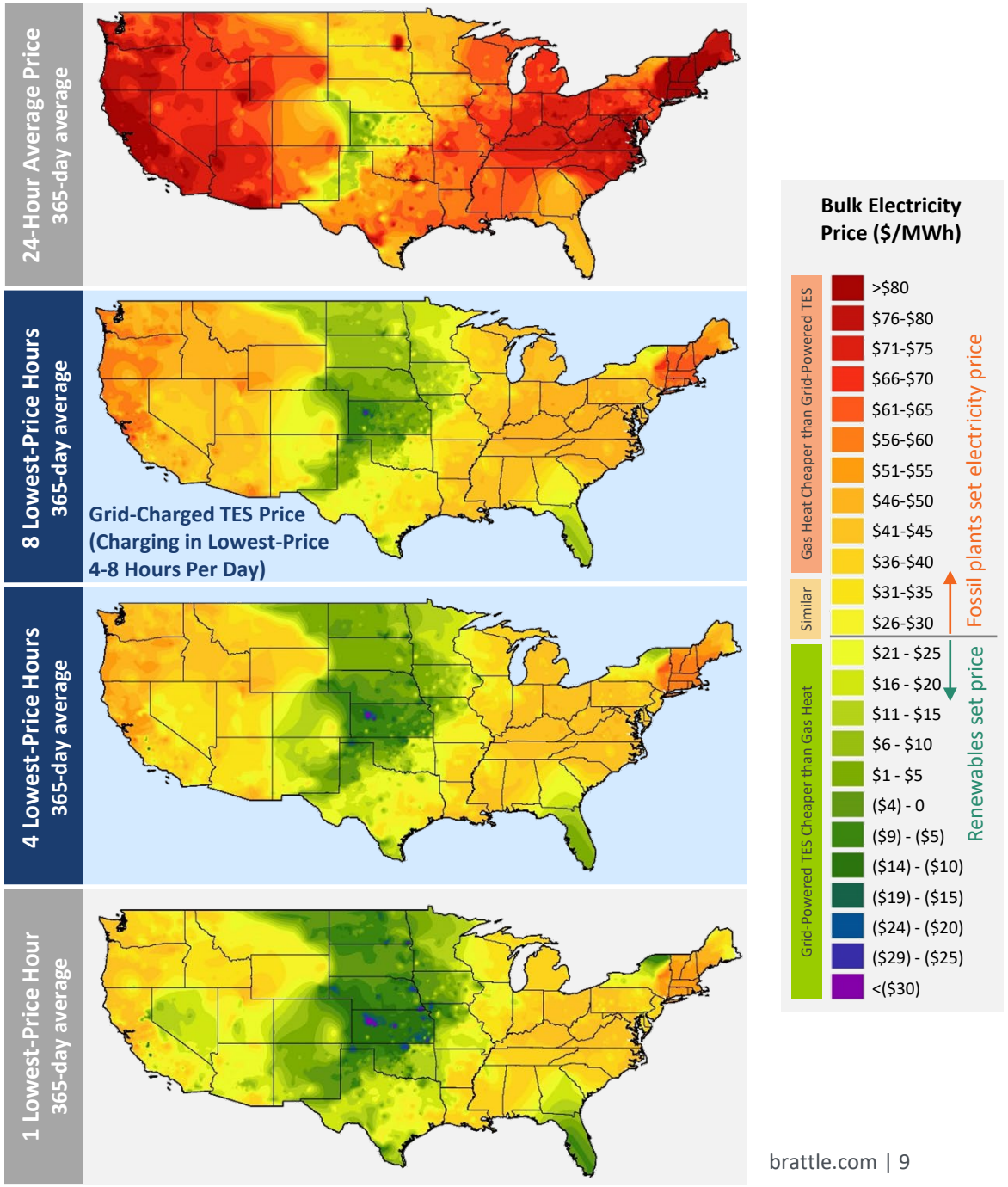
- **Natural Gas:** at $6/MMBtu, with or without $50/tonne GHG cost
- **Co-located Renewable + Thermal Battery:** under islanded, net-to-grid, and two/from-grid configurations
- **Stand-Alone Thermal Battery:** on-site with industrial heating customer
- **Grid-Delivered Renewables + On-site Thermal Battery:** under traditional utility rates, or under modern rate structures

Key Finding: Thermal batteries can be cost-competitive with natural gas, though strength of business case varies by configuration, location, GHG price and (critically) access to wholesale market prices

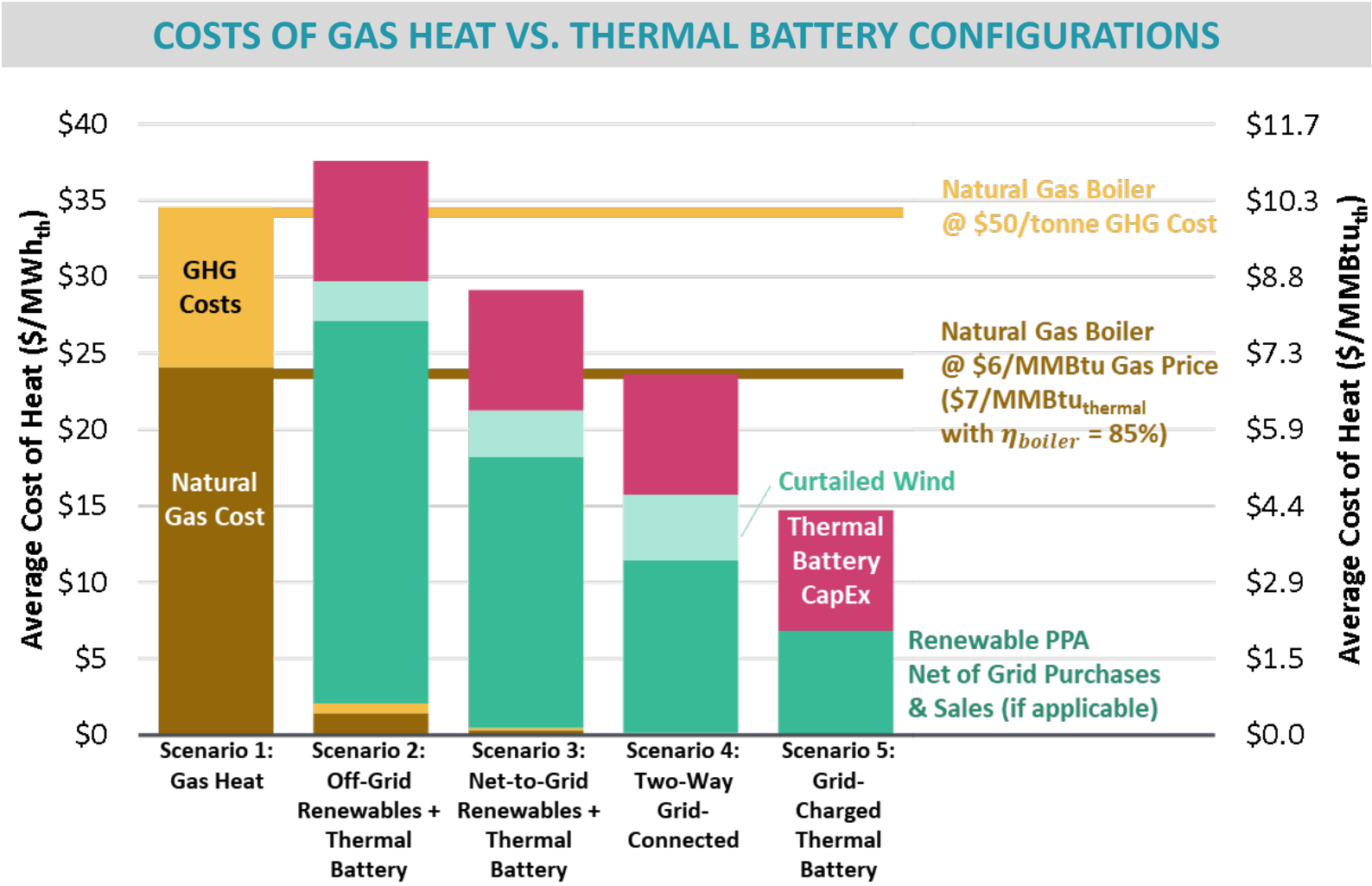
Where might grid-powered thermal batteries be cost-effective?

- Lowest-price 4-8 hours per day is when a thermal battery would charge
- Large parts of the country already offer near-zero bulk system prices for thermal batteries (West, Midwest, Texas), outcompeting gas as primary energy source
- In these locations, thermal batteries can absorb excess grid renewables that would be curtailed
- Regions with (very) low power prices will expand as renewables continue to dominate grid investments

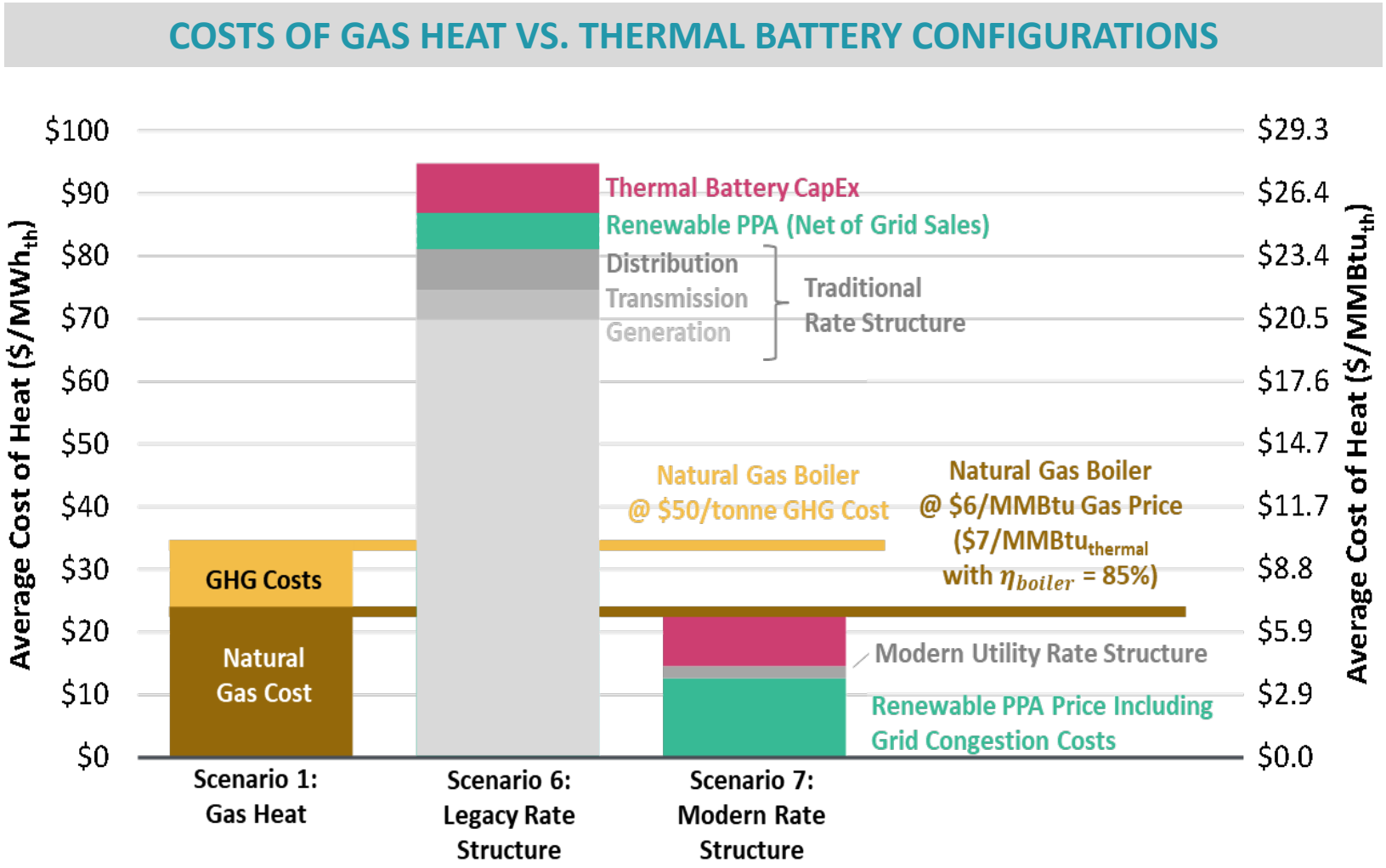
Thermal batteries with access to wholesale locational marginal prices (LMP) can out-compete gas heat in large regions



Economic Examples: Co-located renewable & thermal battery



Economic Examples: Grid-delivered renewable configurations



What barriers to entry should be addressed to accelerate renewable thermal storage deployment?

Key barriers to accelerated thermal battery deployment

Category	Barriers (Summary)	Assessment Outlook
Technical Barriers	Deployment experience needed	**Positive Outlook**
Customer Awareness & Readiness	Industrial heating customers not broadly aware of renewable thermal as GHG-free energy source	**Positive Outlook**
Policy Barriers	Policymakers not aware of thermal batteries, not considered in GHG policies, planning, or eligibility for all available incentives	**Enabling Reforms Needed**
Economic Barriers	Renewables still cost more than gas in many places (requires GHG value to be competitive in those regions). Many commodity product manufacturers face competitive pressures making it infeasible to pass on GHG abatement costs	**Positive Outlook**
Rate Structures and Retail Arrangements	Rate structures do not consider thermal battery capability to avoid charging at times that would drive costs, nor allow direct access to bulk power system prices	**Critical Barrier: Enabling Reforms Needed**
Wholesale Power Markets	No access to wholesale power prices (particularly for net withdrawals); lack of participation models for thermal batteries	**Critical Barrier: Enabling Reforms Needed**

Recommendations to accelerate thermal battery deployment

- **Industrial Heating Consumers:** Evaluate renewable + thermal battery options as a GHG-free source of primary energy supply that is cost-competitive with natural gas, and that may already be lower-cost in large regions of the country (caveat):
  - *Critical Challenge*: Early adopters will need to work creatively with local utilities, regulators, and thermal battery providers to ensure access modern rates and wholesale prices
- **Policymakers:** Consider thermal batteries as eligible technology under policy, planning, and incentive programs.
- **State Utility Commissions:** Adopt industrial electricity rates closely tied to cost causation. Ensure that rates clearly align with cost drivers (e.g., peak consumption) so that customers outfitted with thermal batteries can fully access bulk system power prices at all times
- **Wholesale Markets:** Adopt FERC Order (analogous to Order 841 for electricity-to-electricity batteries) that enables thermal battery systems to access wholesale market prices and provide grid services in all regions. RTO/ISOs can pursue such reforms in advance of FERC action

Industrial Thermal Battery Demand Key Takeaways

- Industrial electrification is at an earlier stage than other drivers of future load growth
- Industrials are actively seeking low-cost approaches to reduce their emissions with several technologies moving into larger-scale deployments
  - Industrials with corporate sustainability goals (or who sell to customers with supply chain targets) and relatively low energy costs are likely early movers
- Thermal battery demand will tend to be concentrated in industrial areas and areas with access to low-cost renewable energy sources and wholesale energy prices
- The “flexibility” of thermal batteries differ from other large new loads because they only charge during low-cost energy prices and will avoid peak demand periods
- Developers are considering different approaches to procuring low-cost renewable energy that will have significant impacts on its cost-effectiveness

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