Thermal Energy Storage Now! Activating Heat and Cold Batteries for Grid Reliability and Lower Bills

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ABSTRACT

The United States is entering a period of rapid electric load growth following more than a decade of stability. In addition, the grid is subject to increasing shares of intermittent generation. This poses challenges for utilities and grid operators, who must find ways to accommodate this variability on aging grid infrastructure. Energy storage has received increasing attention as a means of shifting load to better match available generation. Since over half of U.S. residential and commercial buildings' energy use is thermal (heating, cooling, and refrigeration), thermal energy storage (TES) in buildings should be part of the solution.

Based on findings from two years of stakeholder engagement and utility and market research performed as part of the federally funded Stor4Build consortium, this paper lays out current TES technologies, applications, and their total deployments. We then discuss the barriers to broader deployment, which include upfront costs, misaligned incentives, and lack of experience with and trust in the capabilities of TES—compounded by challenges with modeling TES performance.

Finally, we discuss the current landscape of utility programs across the United States and profile programs that have overcome the headwinds. Rural cooperatives in Minnesota have achieved significant deployments of residential space and water heating TES, while several investor-owned utilities around the country have started deploying and have the potential to scale by building on their demand response, time-of-use rates, and battery storage offerings. Other potential strategies include aggregator participation in wholesale markets and utility capacity planning.

Introduction and Scope

After fifteen years with little growth, electricity consumption in the United States is rising. Much of that growth is being met with variable renewable generation, which does not always coincide with peak demand (EIA 2025; Global Power System Transformation Consortium 2024). The electric grid needs far more flexibility than it has today—not just on the supply side, but on the demand side as well.

Buildings use about 40% of U.S. energy, with much of that energy delivering thermal services (heating, cooling, and refrigeration): 74% for residential buildings and 51% for commercial (EIA 2023a, 2023b). Buildings use 75% of U.S. electricity (Shoemaker 2023) and thermal loads drive peak demand, through cooling on summer afternoons and heating and water heating on winter mornings. Furthermore, as space and water heating electrify, peak loads will increase and further strain the grid (Walton 2025).

Thermal energy storage (TES) enables thermal loads to be time shifted without compromising service quality, by pre-cooling or pre-heating the storage so that electricity is consumed when it is cheaper and cleaner, then delivered as thermal energy when needed. This time shifting can enhance grid reliability and reduce customer costs. Importantly, TES technologies are already commercialized across key building types and applications, and they offer some complementary features to electrochemical batteries, making them a potentially valuable part of demand flexibility solutions.

This paper summarizes research on market barriers to TES deployment and strategies for overcoming them, conducted between 2023 and 2025. The authors and other collaborators conducted reviews of materials published by TES manufacturers, trade associations, government agencies, and utilities; and conducted interviews and held three virtual and two in-person convenings, attended by dozens of participants from the above groups. The findings were reviewed by TES researchers and manufacturers and summarized in a series of unpublished briefs and reports.

We first define TES and the core building-sector technologies and contrast TES with electrochemical storage. We then examine market status and deployment patterns, followed by a discussion of value propositions for utilities, customers, and society. We step through utility program design and experience, synthesize barriers to widespread deployment, and conclude with near-term market opportunities and targeted actions to scale those opportunities.

What Is TES and Which Technologies Matter for Buildings

TES stores heat or cold for later use, decoupling the timing of energy consumption from thermal service delivery. Two fundamental mechanisms are used: sensible and latent storage. Sensible storage depends on the simple temperature change of a medium such as water or ceramic bricks. Latent storage involves a phase change, such as freezing (or melting) ice or another phase-change material (PCM) with a melting/freezing point appropriate for the application. Latent storage is much more energy dense and is good for maintaining a particular temperature; for example, it requires as much energy to melt ice at 0°C into water as it would then take to heat that water by around 80°C (Segar and Smoak 2025).

TES can be actively managed by equipment and controls or operate passively through material properties. The latter type of TES can be integrated into the walls or ceiling of a building or the shelving in refrigerated warehouses. This requires no wiring or integration with building systems, but nonetheless allows the cooling or heating system to be turned off during peak periods without affecting internal temperatures (S. Nabozny, director of energy solutions, Michaels Energy, pers. comm., September 26, 2025).

In commercial buildings, chilled-water tanks and ice systems have matured over decades, and deployed systems are frequently integrated with existing chiller plants to move cooling production off-peak. In homes, common examples include electric thermal storage (ETS) heaters that store heat in ceramic bricks for release during peaks and storage water heaters that can preheat water for later use. Ice storage products are also re-entering the residential space, bringing cooling flexibility into homes (E. Russell, operating partner, Ice Energy, pers. comm., September 30, 2025). These technologies are summarized in Table 1 and Table 2, below.

Table 1. Summary of key TES technologies for residential buildings

Technology	Storage type	Storage medium	Example products/manufacturers	Market maturity

Electric thermal storage heaters	Hot	High-density ceramic bricks	Steffes, Dimplex	Mature technology
Domestic hot water tanks	Hot	Water	Harvest Thermal, adaptations/controls for different electric storage water heaters	Pilot/early adopters/ mature technology
Novel system types	Hot/cold	Various	Sunamp – PCM based hot water IceCub – residential version of IceBear (in Table 2, below)	Pilot

PCM = phase-change material

Table 2. Summary of key TES technologies for commercial buildings

Technology	Storage type	Storage medium	Example products/manufacturers	Market maturity
Ice/water storage	Cold	Ice, ice slurry, water	Ice Energy Ice Bear, Shift Thermal, Trane/CALMAC Ice Bank, Evapco Ice-Pak, Nostromo IceBrick, Cryogel Ice Ball, Baltimore Aircoil Company TSU-M Ice Chiller, Caldwell TES, Rebound Technologies	Mature technology (some product configurations are emerging)
Passive PCMs for refrigeration/ cooling	Cold	Novel PCMs	Phase Change Solutions bioPCM, Viking Cold, Sunamp Plentigrade PCM, Michael's Energy IceRack	Pilot/early adopters
Ceramic brick storage	Hot	High density ceramic bricks	Steffes commercial forced air and hydronic furnace products (ThermElect, Commercial Comfort Plus)	Mature technology

Comparison to Batteries

Electrochemical batteries are a better-known storage technology and are often viewed as more reliable and flexible, spanning the full size range from utility scale to small household products (Maldonado 2025). They can also be completely controlled by the utility and provide quick response and dependable performance. Also, the costs of lithium-ion batteries have declined 90% between 2010 and 2023 (IEA 2024) and installations have increased, with U.S. residential battery installations growing almost 50% in the period between 2023 and 2024 (Martucci 2024).

TES systems share some of the functionality of batteries, with some types providing bi-directional storage (charge and discharge) and rapid response, which can be used to provide ancillary services to the grid such as frequency regulation (GridWorks Consulting 2025).

However, TES technologies and performance characteristics vary widely, which makes them more complicated to apply. As with other demand-side measures, the value of active, equipment-integrated TES from a utility perspective may also be reduced by the need to provide their primary function: thermal comfort and/or hot water to building occupants.

TES systems have some features distinct from electrochemical batteries. TES targets thermal loads directly, often at lower material intensity and cost and longer lifetime. Some types of systems (e.g., water heaters) are already in place in existing buildings, potentially reducing equipment costs. Most current TES deployments use inherently safe materials such as water and ice, which do not present any of the fire, environmental, or supply-chain concerns of lithium-ion batteries. However, novel PCMs could present challenges associated with the various material properties; for example, organic PCMs such as paraffin compounds are flammable, and inorganic PCMs such as salt hydrates can cause equipment corrosion.

TES can also be used to reduce operating costs by taking advantage of waste heat (Ragoowansi, Garimella, and Goyal 2023; Knudsen, Rohde, and Kauko 2021) or diurnal temperature swings by charging when the difference in temperature between the unconditioned space and the storage is lowest and the heat pump efficiencies highest (e.g., making ice at night in the summer; Odukomaiya et al. 2021).

Current U.S. Market and Installations

The TES market in the United States and globally is still nascent in many applications, making it difficult to estimate its size. One source puts the global installed capacity in 2019 at 234 GWh across buildings, district systems, industrial applications, utility scale systems, and seasonal storage. Of this, approximately 6% was for space cooling applications, and 20–30% was for heating in buildings or district systems The installed capacity was expected to triple by 2030 with new products entering the market and as a response to growing electric loads (IRENA 2020, 18).

Commercial Refrigeration

Commercial refrigeration is a large and growing energy user, with 330 million square feet of refrigerated warehouse space in the United States, consuming around 10 TWh of electricity annually. (EIA 2023a). TES is currently deployed in some commercial refrigeration spaces, reducing peak load, increasing the efficiency of the system, and maintaining low temperatures in the event of a power outage (Nabozny, pers. comm.; Coker 2020). Passive TES systems have no mechanical components (Viking Cold Solutions 2026), do not need to be integrated into the existing refrigeration system, and reduce time and cost versus battery storage or active TES.

Residential Buildings

In 2020, 44% of U.S. homes used electric storage water heaters (EIA 2024a), which are a form of TES, pre-heating water and holding it for later use. Only a small subset of these water heaters are currently enrolled in grid-responsive programs or operated on schedules that provide a load-shifting resource. With the addition of controls, such as simple timers or more advanced communications modules and an internal or external load-control switch, these common appliances could be used as grid assets, if a sufficient number are aggregated and operated in accordance with grid needs.

Similarly, many homes already have communicating, or "smart," thermostats, although most of these are not being actively controlled through programs. For example, the aggregator Renew Home can control 380 MW of load in PJM and 364 MW in ERCOT using Nest thermostats, by shifting 0.5 to 1 kW of HVAC load by 1 to 4 hours. There are more than 6 million homes enrolled in the Renew Home network, with several other companies providing similar services (Dreher 2023).

Electric thermal storage (ETS) heaters can also be used to shift residential thermal loads. These products, which use high-density ceramic bricks to store heat from overnight or off-peak electricity, are well established in the upper Midwest and Canada and are increasingly installed with heat pumps (K. Harrington, business development manager, Al Takle, director of electric thermal storage, Samuel Buck, commercial sales engineer, Steffes, pers. comm., September 5, 2025). They charge during inexpensive off-peak hours, typically overnight, and release heat throughout the day.

District Systems

District and campus thermal networks connect multiple buildings with a shared thermal loop. These systems can integrate waste heat, geothermal resources, and centralized TES to balance loads across the network. More than half of European district heating systems include some form of thermal storage, and while district systems are less common in the United States, interest is growing around university campuses and urban redevelopment projects. Low-temperature thermal energy networks, which typically do not use fossil fuel generated energy, have also attracted growing attention as communities look for ways to decarbonize heating (Kim 2023b; BDC 2023; Guelpa et al. 2023).

Total Installed Base and Future Outlook

Overall, our interviews and publicly available data suggest that roughly 10,000–50,000 commercial ice and chilled-water installations, 50,000–100,000 residential water heaters, and 100,000 ETS heaters are being leveraged for TES use nationwide, though precise counts remain uncertain and the distribution varies widely by region.

Emerging technologies are expanding the potential market and range of applications. Modular PCM units offer TES in a smaller physical footprint than conventional water tanks or ice systems. These products use engineered materials that change phase at tailored temperature ranges, allowing designers to match the storage medium to the specific application. While these technologies are still maturing and accumulating the field data needed for broad market confidence, they suggest that future TES technologies have the potential to be integrated into a wider range of buildings, including those with space limitations or other constraints (Sunamp 2025, 2024; Delforge 2025).

Value Propositions and Benefits

In suitable applications, TES can provide benefits to multiple parties, starting with peak load shifting for electric utilities.

Utilities

Shifting thermal loads to off-peak hours provides peak shaving and can support deferral of capacity investment. In Minnesota, rural cooperatives have used TES for years to absorb low-cost wind energy during overnight hours, thereby avoiding curtailment. Homeowners use that energy during the day, reducing reliance on peaker plants during high-demand hours (BEL 2025). The same principle applies in solar-rich regions, where TES can charge during the midday surplus and discharge during the evening ramp-down, therefore maximizing the value of solar generation (Denholm and Hand 2011).

TES can support grid reliability without the long lead times, interconnection queues, and supply chain risks that often characterize major infrastructure projects. As mentioned above, passive refrigerated TES for industrial and commercial settings, for example, requires no utility interconnection and minimal permitting. A range of TES systems, including tanks, modular ice units, and water heater controls, can be installed in weeks or months, providing benefits sooner than the years-long timelines associated with new generation or distribution upgrades (Nabozny, pers. comm.). For a utility facing near-term capacity constraints, the potential to deploy resources within this timeframe presents significant value.

Building Owners and Occupants

For building owners and occupants, the value proposition depends heavily on rate structure. Where time-of-use (TOU) rates create a significant price differential between peak and off-peak electricity, TES can meaningfully reduce bills. One implementer estimated a 12-cent-per-kWh difference as necessary for TES to be cost-effective for building owners (Nabozny, pers. comm.). Commercial customers who pay demand charges can also benefit from TES by spreading their load and reducing their peak demand. TES can also be used to enhance the performance of air conditioning and heat pumps by allowing the heat pump to operate in more optimal conditions, reducing the temperature lift required during the coldest or hottest hours, therefore improving the coefficient of performance, further reducing operating costs (Stor4Build Convening on Utility Programs in Residential Buildings 2024).[1]

Beyond bill savings, TES can allow HVAC designers to specify smaller heat pumps or chillers, since the storage can supplement or replace the heat pump during peak times.[2] This downsizing would reduce not just equipment costs but also the electrical infrastructure—wiring, panel upgrades, service connections—needed to support oversized HVAC systems.

Resilience is another important benefit as extreme weather events become more frequent. Stored thermal energy can help maintain healthy indoor temperatures longer after a loss of

[1] These kWh savings may allow TES to qualify for incentives from utility energy efficiency programs.
[2] Trane (2026) and Stein (2024) propose commercial heat pump capacity reductions of 56% and 78%, while Hirschey et al. (2023) demonstrate a residential capacity reduction of 20%.

power. This benefit is clearest with passive, building-integrated TES, which can continue absorbing or releasing heat even after the power fails and the HVAC system stops working.[3] Prolonged power outages have increased in frequency in recent years, and the ability of TES to keep buildings at safe temperatures and prevent loss of goods such as food and medicine has real value for occupants and business owners even if it is sometimes difficult to monetize (Kim 2023a; Srivastava, Garfunkel, and Wood 2024).

General Public

At a societal level, shifting load away from peak hours reduces reliance on peaker plants, which tend to be older, less efficient, and disproportionately located near disadvantaged communities (Usry 2020; Cushing et al. 2023). Less peaker plant operation means lower emissions of carbon dioxide, nitrogen oxides, and fine particulates, as well as lower generation costs. The resultant lower transmission and distribution costs are also broadly beneficial, as these costs have been a major driver of bill increases over the past two decades (EIA 2024b).

If TES is used to support building electrification, then it can eliminate a localized source of combustion pollutants such as nitrogen oxides (NOx). A study estimated that gas appliances in California homes released 15,900 lbs of NOx in 2018, resulting in $3.3 billion in annual health costs and claiming more than 350 lives (Zhu et al. 2020, 36, 38–39). These benefits are real but difficult to monetize through existing market mechanisms, which is part of why TES has historically been undervalued.

Table 3. List of primary recipients of benefits from TES

Primary Recipient	Benefit
Utility	Enhance grid reliability without infrastructure modifications or interconnection queues
	Reduce transmission and distribution capacity needs by deferring infrastructure upgrades
	Enhance use of lower-cost generation
Building owners and occupants	Reduce operating costs through reduction in utility demand and energy charges (if rates exist)
	Reduce HVAC system size*
	Reduce electric capacity needs*
	Enhance resilience to power disruptions
	Increase performance of air conditioning, refrigeration, and heat pumps*
General public	Reduce power plant emissions
	Improve air quality in/near buildings

* Benefits provided by TES and not electrochemical batteries.

[3] In contrast, equipment-integrated TES would require a backup battery or generator to continue powering fans or pumps to circulate the stored thermal energy, but the amount of backup would be less, as there would be no need to power the compressor.

Overcoming Barriers Through Incentives and Utility Rates

As noted above, TES benefits accrue to diverse stakeholders, but costs fall on building owners. This misalignment is a barrier to building owner adoption of TES. Financial incentives (i.e., rebates) and utility rates are a key mechanism to better align incentives and costs by transferring additional value to building owners to realize the potential of TES as a grid resource.

National and State Incentives

Nationally, there is only one incentive for TES: the Section 48E Clean Electricity Investment tax credit, available through 2035. This credit equals 30% of the base cost, with a 10% energy community bonus and additional 10% domestic content bonus[4] (P. Delforge, chief product and innovation officer, Harvest Thermal, pers. comm., August 28, 2025). In addition, some states also offer incentives. For example, Maryland offers grants of up to 30% of the value of a storage system up to $5,000 for residential systems and $150,000 for commercial systems (Maryland Energy Administration 2025, 2). New York offers varying incentives depending on the system's observed discharge capacity over 1–4 hours and 5–6 hours (NYSERDA 2026, 44).

Utility Programs

Multiple utilities throughout the country offer TES incentives through programs with specific requirements on equipment type, size, and performance to meet their grid needs. Here, we distinguish TES programs from conventional demand response (DR). Conventional DR programs curtail loads for short periods during a limited number (~12) of peak events, often by cycling air conditioners or adjusting thermostats. TES programs rely on dedicated storage to shift load for four or more hours, often on a daily schedule rather than just during emergency events. This longer-duration, more-predictable shifting makes TES a valuable planning resource. However, the most effective programs require dedicated meters, telemetry, and in some cases larger incentives.

TES incentive programs tend to be concentrated among rural cooperatives in the Northern Plains but are also available through investor-owned utilities around the country, as summarized in Table 4.

Table 4. Summary of utility incentive programs for TES.

Program Location	Customer Class	Technologies	Typical Duration	Utility Benefits	Source
Northern Plains (Minnesota, Dakotas, Colorado)	Residential	Water heaters, Electric heating (bricks, hot water)	8+ hours	Low-cost off-peak energy, Peak shaving	Harrington et al., pers. comm.; Xcel Energy 2025a, 2025b

[4] Also subject to Prohibited Foreign Entity requirements. The credit phases down in the years 2033 (75%), 2034 (50%), and 2035 (25%).

Minnesota	Commercial	Cooling, Refrigeration	4 hours		Xcel Energy 2024
Southeast (Florida, Carolinas)	Residential	Water heaters	4 hours	Peak shaving	M. Carlson, chief executive officer, Aquanta, pers. comm., September 16, 2025
Québec	Residential, Commercial	Electric heating (bricks, hot water)		Peak shaving	F. Laurencelle, M. Coillot, researchers, Hydro- Québec, pers. comm., September 9, 2025
Arizona	Commercial	Ice and cold water for cooling, Refrigeration		Peak shaving	T. Swanson, program manager, APS, A. Magers, outreach manager, DNV, pers. comm., September 15, 2025
Hawaii	Residential	Water heaters		Low-cost off-peak energy, Peak shaving, Frequency regulation	Carlson, pers. comm.
Florida	Commercial	Cooling			FPL 2025
Texas	Commercial	Cooling, Refrigeration	3 hours	Peak shaving	Austin Energy 2022

The majority of existing utility TES programs target residential customers, incentivizing water heaters and sensible thermal storage for space heating such as hot water tanks or ceramic bricks. Residential programs typically offer up-front rebates—ranging from $25 for enrolling an existing water heater to $2,000 for purchasing a high-capacity program-specified unit—while commercial programs favor per-kW incentives that align payment with peak reduction. Only about one-sixth of the TES programs analyzed also provide a recurring bill credit as an additional incentive, and these are more common for water heating.

The research highlighted how generous up-front incentives can drive residential participation. The Lake Region Electric Cooperative in Minnesota achieved roughly 45% member participation in a TES water heater pilot by covering a share of system cost (BEL 2025). In 2025, the co-op offered $400 rebates for 100 gallon grid-enabled electric storage water heaters and a 5.5-cent-per-kWh off-peak rate (Lake Region Electric Cooperative 2025).

Other Minnesota cooperatives offer similar incentives paired with inexpensive off-peak electricity. Meanwhile, Hydro-Québec has increased incentives for its ceramic-brick ETS heater program to C$15,000, along with a C$1,000 incentive to the contractor (Laurencelle and Coillot, pers. comm.), resulting in significant growth in ETS installations in Quebec (Harrington et al., pers. comm.). Even with these incentives, the utility benefits by avoiding costly peak generation and new infrastructure (Laurencelle and Coillot, pers. comm.); as of 2026, the 8,000 ETS installations have resulted in 80 MW of load shed during winter peak periods (A. Takle, Director of Electric Thermal Storage, Steffes, pers. comm., June 17, 2026).

Utility Rates

Time-of-use (TOU) rates create ongoing incentives for those who have adopted TES to continue using it to shift load. TOU rates offer reduced pricing for off-peak consumption on a set schedule. Critical peak pricing and variable peak pricing build on TOU by adding a significant rate increase during a limited number of high-peak events per year. Finally, highly dynamic rates vary by hour and day based on grid conditions and wholesale prices. All of these rate structures help align utility benefits with customer costs.

These variable rates are sometimes provided only to the TES equipment through a dedicated meter and device-specific rates. They can also be combined with incentives, but even in the absence of incentives the rates can drive adoption of TES system components, such as do-it-yourself water heater controllers (Carlson, pers. comm.).

Other Considerations

Even with sufficient incentives or rates, there are additional barriers to broad TES adoption.

Split incentives. In rental and multifamily housing, split incentives complicate the picture above: the landlord pays for the TES system, while the tenant benefits from lower bills. In some states, the landlord has the opportunity to benefit from additional revenue streams, for example, selling ancillary services (frequency regulation) or buying electricity at commercial rates and selling to the tenants at residential rates (G. Vaudreuil, chief executive officer, Mosaic Power, pers. comm., September 8, 2025).

Bankable business models. TES manufacturers and aggregators can face barriers to deploying their product as it can be challenging to get capital based on utility incentives. In contrast, contracts for capacity with the utility or markets run by the regional transmission organization/independent system operator (RTO/ISO) provide more stable revenue streams and help secure financing (Nabozny, pers. comm.).

Customer experience. Successful programs prioritize the customer experience, avoiding situations where participants run out of hot water, lose cooling, or feel they have ceded too much control. Programs should also coordinate rebates and training across installer territories, involve contractors early, emphasize reliability or sustainability benefits depending on the customer segment, and make the technology easy to understand and use (J. Stallman, member strategist, Great River Energy, pers. comm., August 21, 2025; Harrington et al., pers. comm.; Laurencelle and Coillot, pers. comm.; Swanson and Magers, pers. comm.; Carlson, pers. comm).

Measurement and Verification. Measurement and verification (M&V) underpins successful TES deployment. For a utility to count TES as a reliable resource, it needs confidence that load will be shifted in the right amounts at the right times. Programs measure performance using different approaches, such as separate metering, device-level telemetry, and aggregator reporting. (Carlson, pers. comm.) However, two-way communication with TES devices gives utilities real-time visibility and enables more precise dispatch (Vaudreuil, pers. comm.).

Controls and interoperability remain persistent challenges. For example, there are multiple ways to control electric storage water heaters for demand flexibility: through a custom application programming interface (API) that communicates with a manufacturer's online "cloud" application; through a module plugged into a communication port meeting Consumer Technology Association (CTA) standard 2045, present on some models; or through specialized switches that can be wired in line with any water heater. The built-in communication capabilities, such as the manufacturer cloud or CTA-2045 ports, are less expensive but provide less functionality than the specialized switches, which can offer whatever communication, control, and measurement that the utility needs (Stor4Build Convening on Residential Water Heaters 2025).

This diverse landscape makes large-scale aggregation difficult and measurement and verification costly.

Modeling and experience. Optimal TES performance depends on multiple connected design considerations. Heat pumps introduced an extra level of complexity compared to combustion appliances, as heat pumps' performance is dependent on temperature; with storage, the performance also depends on temperature and user behavior over time. The modeling and design tools that engineers rely on to size HVAC systems often do not adequately represent these TES dynamics. This modeling gap introduces additional risk for consulting engineers to specify TES because they cannot confidently predict its performance within their standard workflows (Stor4Build Convening on Heat Pumps 2024).

There are also few publicly available, long-term field studies of building TES with consistent performance metrics. Establishing this information base would be helpful to industry, utilities, and building owners (Stor4Build Convening on Heat Pumps 2024).

Priority Market Opportunities and Key Next Steps

Our research identified several priority market areas where aligned incentives can motivate TES deployments to solve important problems using mature technologies. Table 5 summarizes these six opportunities.

Table 5. Priority market opportunities for TES adoption.

Opportunity	Why priority
Large commercial buildings (>100,000 ft²)	Small number of buildings consume large share of energy; single projects yield large grid benefits.
Space cooling (commercial)	Growing cooling demand; mature ice/chilled solutions; clear peak value.
District heating/cooling	Centralized systems can integrate TES cost-effectively and use waste heat.

Aggregated residential water heaters	Almost half of U.S. homes have electric storage water heaters; aggregations can provide VPP-scale flexibility
Heat pump + TES integration	TES reduces heat-pump size and improves cold-climate performance; manufacturers are engaged.
Commercial refrigeration	Year-round loads and insulated spaces enable fast paybacks and reliable dispatch.

VPP = Virtual Power Plant, a collection of smaller, distributed energy resources that collectively provide utility services similar to a power plant (Downing et al. 2023, 6).

To further TES adoption in these markets and any others, our research suggests the following practical set of actions focused on information sharing and standardization rather than new technology developments.

Publicly available data is key to identifying and demonstrating successful TES deployments. Funding and publicizing field demonstrations would contribute to a body of evidence that is necessary for TES to be a successful part of buildings solutions. This is especially important across priority segments, such as large commercial buildings, district systems, refrigerated warehouses, multifamily water heater aggregations, and heat-pump-plus-TES systems. Critically, these demonstrations should follow standardized M&V protocols and publish their results openly, so that each project builds on and learns from the previous projects. The U.S. Department of Energy's (DOE) Connected Communities program has previously awarded grants to several TES implementation projects, and expanding this pipeline would accelerate learning (LBNL 2026). Deploying TES in public and institutional buildings, including universities, hospitals, and government facilities, offers another way to test and demonstrate benefits at scale.

Program, rate, and market design is another key factor. The research suggests that programs can be more effective by combining generous up-front incentives to overcome the initial financial barrier with TOU rates to align long-term operation with grid value. As many utilities already have battery programs, building on these to include TES could present an easier path forward (Russell, pers. comm.). It is worth noting that rates and programs are typically managed by different parts of a utility and approved through separate regulatory proceedings, so coordination between rate design and program design teams is essential to avoid conflicting or duplicative incentives. An alternative approach would be developing standardized contracts and broader markets to pay TES implementers for capacity through the independent system operators and regional transmission organizations (ISO/RTOs).

Interoperability standards and performance metrics are still lacking. Improving communication standards such as CTA-2045 or manufacturer cloud APIs to provide more capabilities and confidence in product response would make aggregation more reliable and M&V less burdensome. Equally important is the development of standard performance metrics, such as shiftable kW, usable kWh, round-trip thermal efficiency, and response time, that would allow utilities and building owners to compare TES options on a level playing field, much as they already compare batteries.

Federal and state policy can accelerate these efforts and support beneficial, effective adoption of TES. The Section 48E investment tax credit is a powerful tool for reducing capital costs, as are state storage targets (established in Oregon, Nevada, California, Maine, Massachusetts, Connecticut, New York, New Jersey, Virginia (Wallace et al. 2022, 7), Maryland (Fraser-Hidalgo et al. 2023), and Michigan (Hall 2025)). While most of these targets will be met with batteries, state policies can also motivate TES deployment as California has done with AB 2868 (water heater demand shift programs; Weintrout 2025) and Joint Appendix 13 to Title 24 of California's Code of Regulations (A. Cornelius, senior program manager, Consortium for Energy Efficiency, pers. comm., September 15, 2025).

Conclusions

Thermal energy storage is not a futuristic technology waiting for a breakthrough. The core applications include commercial ice and chilled-water systems, residential water heaters, and ceramic-brick heaters that are already mature and available on the market. In the future, emerging PCM products could expand the design space to serve additional applications and building types. In some use cases, and with effective system design, TES offers lower capital cost per unit of shifted energy, longer useful life, fewer safety concerns, and a lighter environmental footprint than lithium-ion batteries. TES is a practical complement to electrochemical storage for building-side flexibility.

AI-assisted Tools: Disclosures and Responsibility

AI-assisted tools used: Microsoft Copilot and Anthropic Claude.
Used for: Drafting and document generation.
Extent: Claude was used to synthesize content from six source documents into a cohesive narrative report, including structuring sections, writing prose, and generating the formatted .docx file
Human review: The authors reviewed and verified all content and citations and edited prose.

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