U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Thermal and Electrical Storage Priorities for Residential and Commercial Buildings

BTO Peer Review, ET Strategy Overviews

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October 21

Introduction to special section

Today's Session

Hear our latest thinking now (and later)

Ask questions

Share your feedback

Listen for more from BTO, on strategies

The mission

The Building Technologies Office (BTO) conducts research, development, and demonstration activities to accelerate the adoption of technologies and techniques that enable high-performing, affordable buildings that meet Americans' need for resiliency and health while also supporting a reliable energy system.

90%

The amount of time people spend in buildings.

74%

Amount of electricity consumed by buildings.

$374 billion

Amount spent on energy costs annually.

BTO RD&D Activities Support America

- Energy Efficiency
- Energy Affordability
- Innovation
- Industrial Competitiveness
- Infrastructure
- Energy Reliability and National Security
- Resilience
- Indoor Environment and Health

A practical, inclusive definition of innovation

The Heilmeier Questions:

01 Problem

Stated without jargon

02 Impact

If you succeed, what changes and who cares?

03 Status

How is it done today?

04 Proposal

What is the new approach, why will it succeed, and what will the output be?

05 Midterm checks

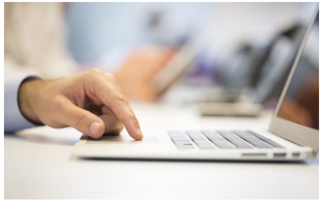
How will we know we're on the right track?

06 How much does it cost?

How long will it take? What are the risks?

Innovation for building technology is broad

It includes R&D for product development, testing, and validation. But also!



Market transformation

Partnership models

Service delivery modes

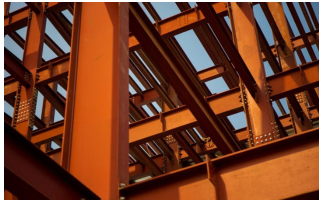
Value chain

Contractors

Trades

Specifiers

Reps



Supply chain

Materials

Components

System integration

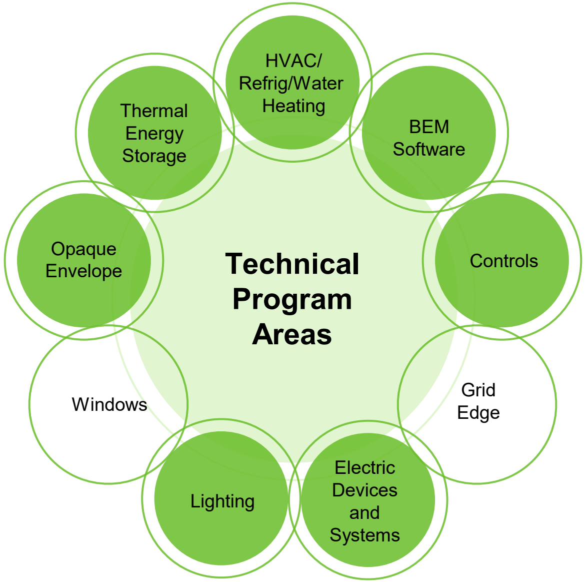
Logistics

Serendipity

Partnerships

Alignment

What does this strategy mean for DOE's applied R&D for buildings?



Reduce first costs

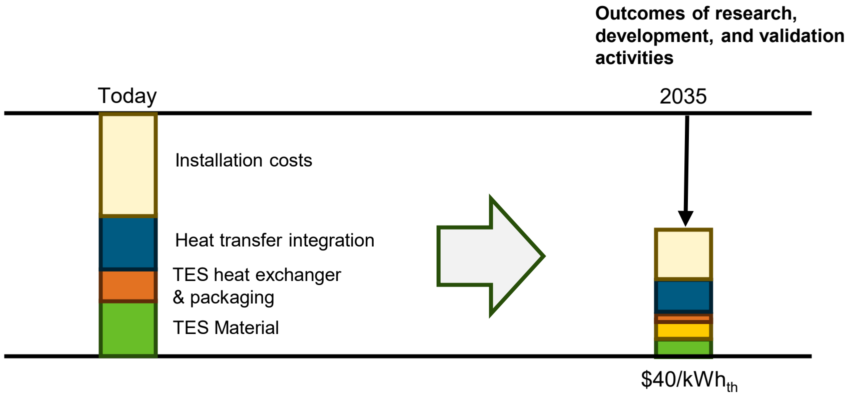
Make it easy

Deliver performance that matters

Ask, who's missing that we need?

TES system cost compression goal

The thermal energy storage subprogram goal is to achieve, within a decade, an installed cost below \$40/kWh_{th} and a system lifetime over 20 years, achieving an electric equivalent levelized cost of storage of less than 5 cents per kWh.



BTO Mission Alignment

Prioritize survivability and resilience – Behind-the-meter storage is central to building resilience. Storage technologies will be increasingly critical to the safety and health of occupants during blackouts and extreme weather events (heat waves, cold snaps), which in the worst case lead to avoidable fatalities. Storage will also be increasingly critical to preventing blackouts in the first place.

Prioritize affordability – There are applications where thermal storage is a less expensive, more sensible approach than battery integration. Strategic storage integration can also avoid costly upgrades and downsize HVAC systems and major appliances. Storage can lower retrofit costs for electrical distribution system components by right-sizing equipment, avoiding costly investments in electrical panels, service upgrades, and transformers by reducing system peaks and equipment rating, amperage, and footprint.

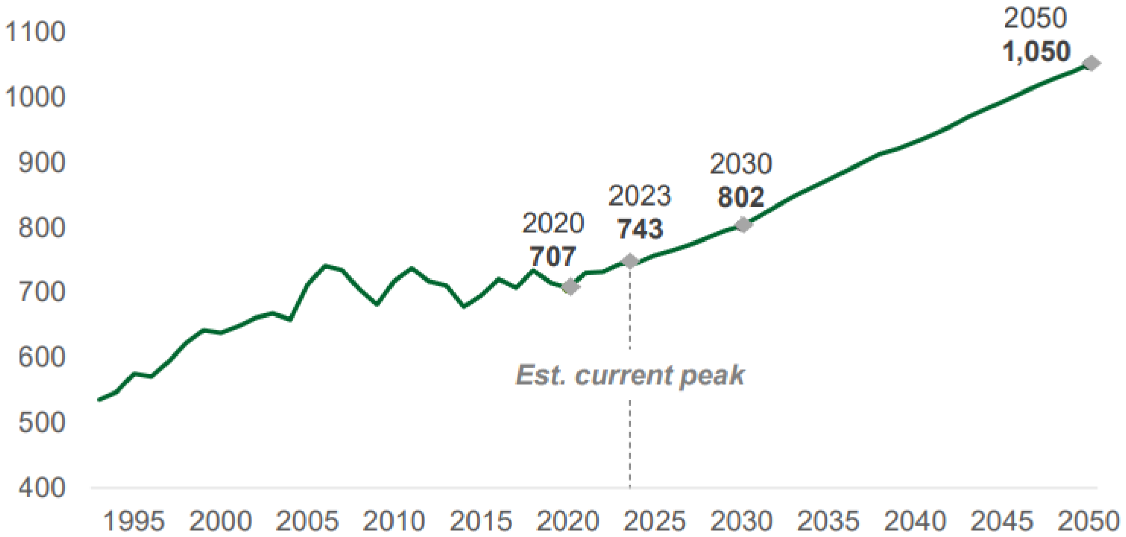
Increase building energy efficiency – TES can improve HP efficiencies or harness free heating and cooling by taking advantage of daily variations in ambient temperature. DC-coupled EES, PV, and certain end uses can improve system efficiencies by eliminating inverter losses.

Peak Demand in Buildings is on the Rise

- Widespread electrification goals of building end-uses can lead to 2.5x increase in annual heating electricity, along with higher coincident electrical peak demand, particularly for regions in colder climates. [Source: NREL Electrification Futures Study, 2018
- All-electric heating (high-COP HP) scenario can increase peak demand by 70% throughout US, along with 23 states more than doubling their peak. [Source: Waite 2020]
- New York independent system operator (ISO) forecasts winter peak will be twice current peak while summer peak will remain constant in next 30 years. [Source: NYISO]
- Extreme weather events further exacerbate building thermal load requirement which may not be considered in forecasts and studies

U.S. peak demand is expected to grow by ~60 GW between 2023 and 2030

US system peak demand, historical and projected, 1995-2050 (GW)



Source: Historical energy demand sourced from AEO; forecasted energy sourced from OP-NEMS mid-case scenario

Energy Storage in Buildings

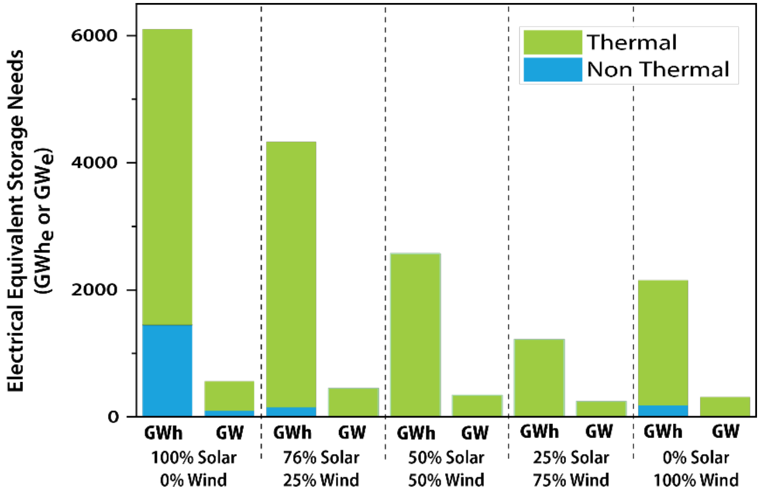
Energy storage makes buildings more resilient and significantly contributes to managing and shifting their peak electrical demand.

Thermal and electrical energy storage are main types of storage used in buildings

Thermal energy storage	Electrical energy storage
• TES systems provide storage capability for heating or cooling loads. • TES can lower heating and cooling equipment costs while increasing thermal system effective capacity.	• EES can handle a wide range of end loads to provide backup electrical power. • Useful for buildings that frequently experience power disruptions and need backup for critical loads.

Strategic investments to reduce TES and EES costs can be traded off with investments in electrical distribution system and service upgrades.

Energy storage required to support commercial and residential buildings in the United States for a 2050 grid with 100% renewable energy, disaggregated into thermal and nonthermal storage, assuming electrified heating with ASHPs.



Source: Odukomaiya 2021

Thermal energy storage can be more cost-effective for buildings than Li-ion batteries

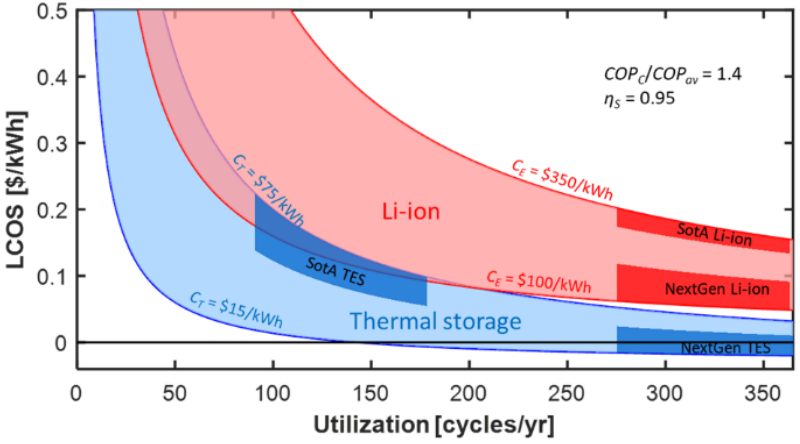
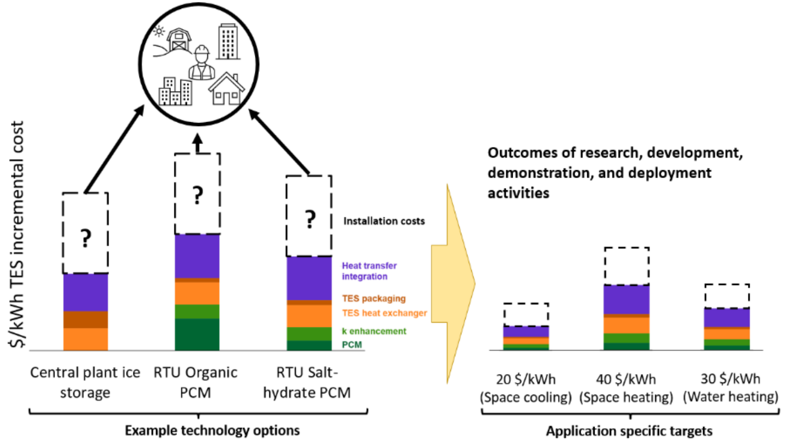
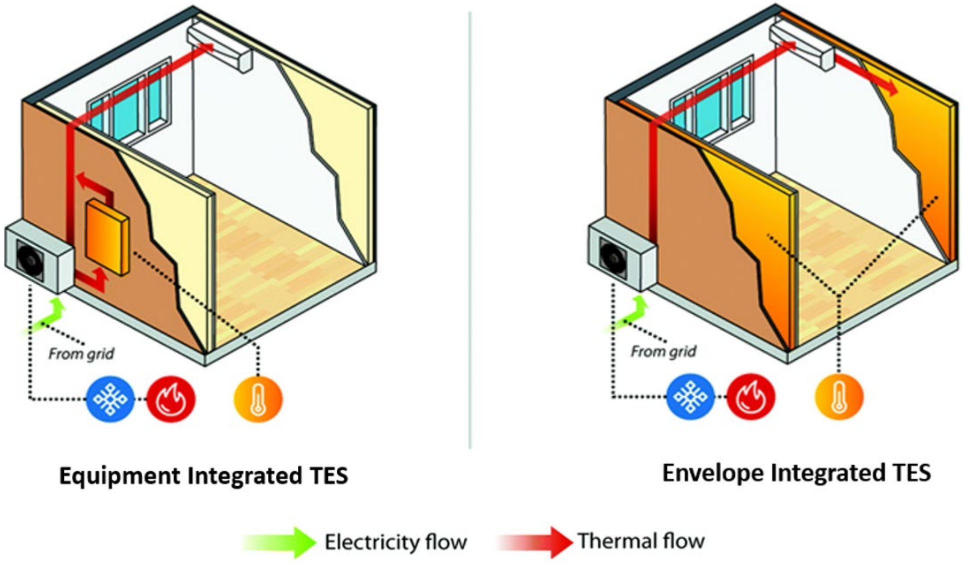


Figure: LCOS projections for TES + heat pump and EES + heat pump with varying capital costs, and utilization assumptions

Thermal energy storage system cost compression and simplification



TES System Integration



Equipment- and envelope-based TES systems

Stakeholder Engagement

2019
Workshop on Fundamental Needs for Dynamic and Interactive Thermal Storage Solutions for Buildings

WORKSHOPS & WEBINARS
2020
Thermal Energy Storage Webinar Series

2021
Thermal Energy Storage Systems for Buildings Workshop: Priorities and Pathways to Widespread Deployment of Thermal Energy Storage in Buildings

GUIDEHOUSE STAKEHOLDER DISCUSSION MEETINGS

2/10/2022
Electrical Storage Stakeholder Discussion Meeting (over 50 stakeholders)

2/14/2022
Thermal Energy Storage Stakeholder Discussion Meeting (over 70 stakeholders)

STOR4BUILD KICKOFF
11/30/2022
Kickoff meeting of the Stor4Build Building Energy Storage Consortium with over 48 stakeholders from industry, academia, state governments, and non-profits. Gained valuable feedback on key barriers, opportunities, and priorities to advance the adoption and deployment of thermal storage.

BTO PEER REVIEW
4/24/23-4/28/23
Review of building energy storage portfolio (AOP, FOA, TCF, and SBIR). Reviewer feedback on need for enhanced focus on systems integration and applications, overcoming market barriers, and focusing materials development and optimization concurrently with systems development.

WORKSHOPS & WEBINARS
2024
Grid friendly electrification with building on-site thermal energy storage (NRCAN)

Key Opportunities and Targets for TES

Key Actions Needed for Thermal Energy Storage

Short Term Impact

Design Tools: Assist with the selection, specification, and commissioning of envelope-integrated TES systems; analogous tools needed for component and system design, material selection and sizing for equipment-integrated TES.

Sensor Strategies: Develop low-cost and reliable sensing methods to indicate the status of TES which can inform the need for demand control or load shifting.

Modular Storage: Develop low-cost, highly scalable modular storage that can be easily integrated to retrofit HVAC, refrigeration, and water heating systems and companion plug-and-play controls that combine equipment and storage system operation.

Heat Exchangers: Develop TES-specific heat exchangers using low-cost materials and designs suitable for multiple equipment types and a range of power capabilities (C/8 to 1C) to maximize energy density while minimizing volume and weight for heat exchanger tubes.

Medium Term Impact

Deployment: Develop minimally disruptive, non-destructive, and non-invasive methods for deploying, testing, and repairing envelope-integrated TES.

Codes and Standards: Develop test protocols for TES components and integrated TES for certification, performance standards, building codes, and installation best practices.

Controls: Develop device and supervisory controls for TES and non-TES devices to provide low-cost monitoring and control for multi-objective operations to satisfy occupant and grid needs.

Materials: Develop low-cost TES materials for weight- and volume-constrained applications.

Utilization: Develop materials and system designs to increase total annual utilization of TES via flexibility in operating temperature regimes, such as tunable transition temperatures.

Long Term Impact

Life Cycle Analysis: Measure at-scale lifetime and cycling performance, including end-of-life impacts, through long-term demonstration in the field and accelerated cycling tests.

Materials: Develop and apply computational methods to discover new storage materials with desirable properties for buildings, and create an open, public web database for sharing findings about these materials.

Demonstration: Demonstrate materials and reactor systems for thermochemical storage as a high energy density and long-duration storage option for buildings.

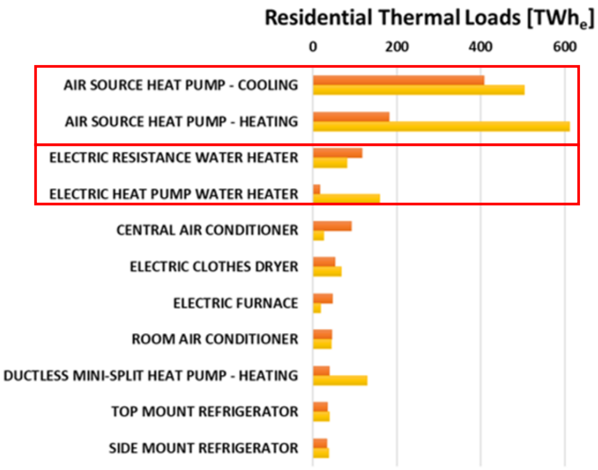
Formulation: Develop volume-stable phase change materials (PCM) that avoid phase change into a liquid or gel state (e.g., solid-solid phase change) to circumvent high costs long-term reliability of encapsulation for solid-liquid or solid-gel PCMs.

Summary Targets for Thermal Energy Storage by Application Area

Operating Mode(s)	Cooling		Heating		Cooling + Heating		Refrigeration	
	T (ºC)	Cost ($/kWh)	T (ºC)	Cost ($/kWh)	T (ºC)	Cost ($/kWh)	T (ºC)	Cost ($/kWh)
Equipment	0–10	5–20	35–50	15–40	0–25	30–40	-30–20	30–80
Envelope	24	5–20	20	15–40	20–24	30–40		

Priorities for Equipment-Based TES

Residential central air source heat pumps (heating and cooling), commercial rooftop units, and residential water heaters are the priority equipment types for TES integration. Commercial freezers are an early market opportunity, while commercial chillers continue to present a great opportunity particularly for ice storage.



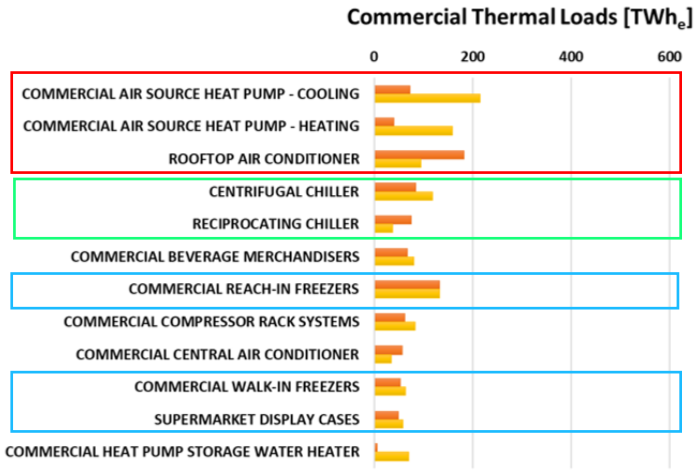


Figure: Predicted annual electricity consumption in 2030 and 2050 by equipment type

Opportunities for TES

Federal Support for TES

- Federal programs like Inflation Reduction Act can provide up to 40% investment tax credit# for installation of most TES systems. [Source: IRS Form 3468]

#Disclaimer: Consult your tax advisor for specific details on your project.

Stor4Build

Learn more on Energy.gov

- Stor4Build is a multi-lab consortium designed to accelerate the development and deployment of affordable thermal energy storage technologies for buildings.
- Includes active participants from industry, utilities, nonprofit organizations, communities, building owners, academia, government, and other research institutions.
- Two steering councils (R&D and Market Adoption) support scalable development of building energy storage technologies and market transformation to increase market viability.

Funded By
U.S. Department of Energy

Supported By
ACEEE and PNNL

Co-Directors
NREL, ORNL, and LBNL

Thank you!

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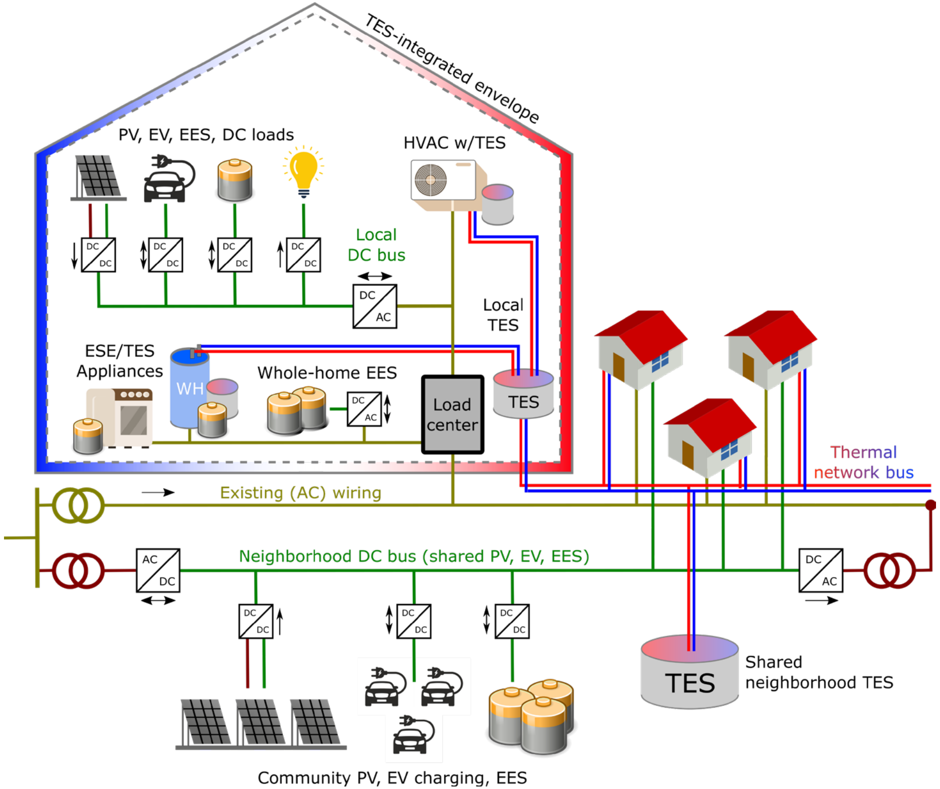
Incorporating electrical & hybrid storage

- **Storage functions on multiple scales**
  - Building-level
  - Device/appliance-level
  - Neighborhood/community-level
- **Storage can provide multiple benefits**
  - Building and grid resilience
  - Load shifting/flexibility
  - Utility bill reductions (based on TOU rates)
  - Avoided costly electrical upgrades (i.e. panels, transformers, wiring)

ET Goal: spur storage innovation solutions for buildings that are optimized for the scale and benefits most sought by the market at a cost that is competitive with other emerging storage applications (EVs, grid-scale)



Market barriers for EES

Service stacking: Control strategies for single use cases may not provide sufficient ROI for battery system integration. Instead, use cases may need to be stacked to reach a reasonable ROI. For example, having benefits for both resiliency and real-time arbitrage can enable a better value proposition for users, but it is important that sufficient energy capacity be maintained for resiliency events.
Changing utility model: Utility rate structures change over time, which can disrupt or alter the initial estimations for ROI, leading to a poor investment. This introduces risk into a project. More consistent rate structures or guaranteed pricing at the time a new system is installed will help reduce risks.
Utility pricing models: Utility price signals in many regions of the United States do not actively portray generation costs in real time (i.e., demand and supply are generally decoupled). Bidding strategies need to be developed for existing and future rate structures to include building battery storage and EV charging systems.

Opportunities for EES

Key EES barriers and technology development opportunities

- EES vendors offer many unique products and a high degree of customization, affecting integration complexity, system cost, and overall effectiveness for energy management. It can be difficult for building owners to assess benefits without direct comparisons and evaluations.
- Most existing EES installations do not use sophisticated control strategies. To be integrated into supervisory system-level, building-level, or even neighborhood or campus-level control, battery vendors must support standard sensing, status, and command interfaces and communication protocols.
- Building owners, builders, contractors, architects, designers, specifiers, etc. need tools for evaluating the suitability of EES for their projects and for choosing EES configurations and capacities.
- Flexible system design templates for common commercial, residential, and mixed-use configurations should reduce costs.
- Improved modeling and control capabilities can serve to better inform the deployment of EES in buildings.

EES Integration Technology Development Opportunities		Costs	Performance	Simplicity
#	Short-Term Impact			
S1	Battery system deployment case studies		■	■
S2	Intelligent decentralized device-level battery ESS	■	■	■
S3	Best practice guidelines from field deployment.	■		■
S4	Mobile energy storage			■
S5	Standardized testing		■	■
S6	Quantitative metrics and project evaluation tools	■	■	■
S7	National-scale analysis	■	■	■
S8	Battery sizing		■	
S9	Controls		■	■
#	Medium-Term Impact			
M1	Second-life battery	■	■	
M2	Advanced control		■	
M3	Bidirectional EV charging case studies			■
M4	Energy router	■	■	■
M5	Pricing models		■	■
M6	Flow battery modeling		■	

Why are EV batteries so much cheaper than home batteries?

$850/kWh (just a battery)

$500/kWh (+ 1 free car)

Beneficial embedded batteries

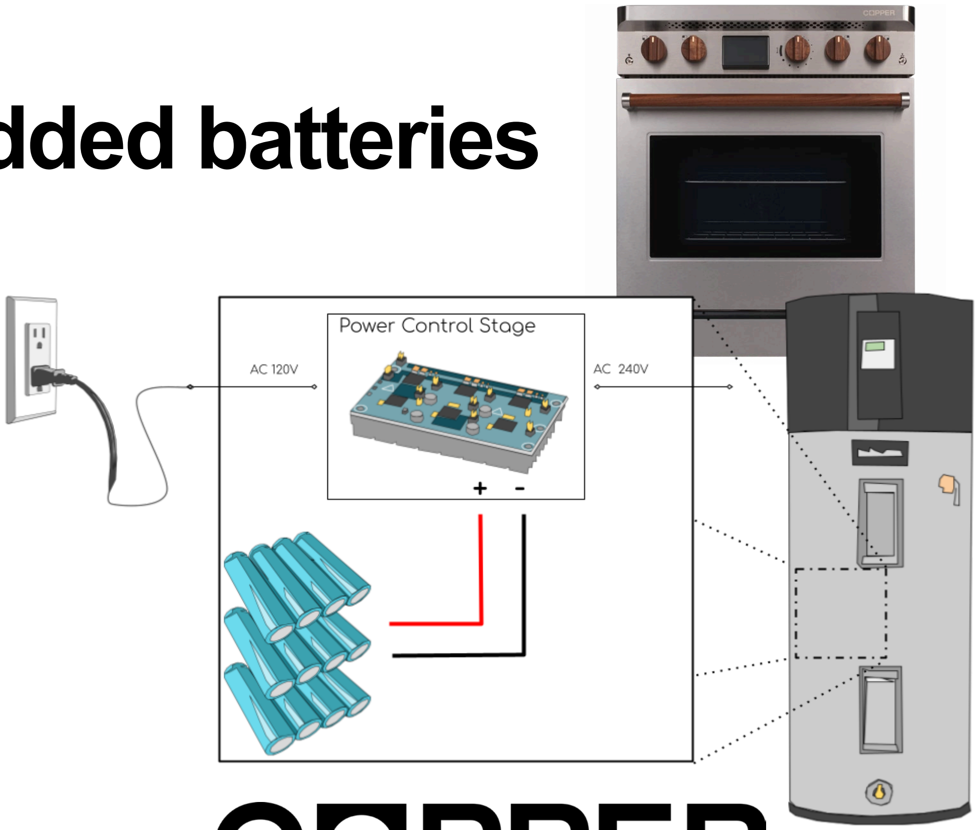
Reduced electrical work
No need to run new circuits, 120-V outlets already in most kitchens to power oven clock

Cheaper storage
Storage can be an order of magnitude less expense when factory-integrated with appliances

Resilience
Cook during blackouts, including auxiliary outlet for other appliances or devices

Load shifting
Battery can charge during off-peak hours, bidirectional models in development, aggregation possible

Backup resistive heat for 120-V HPWHs



COPPER

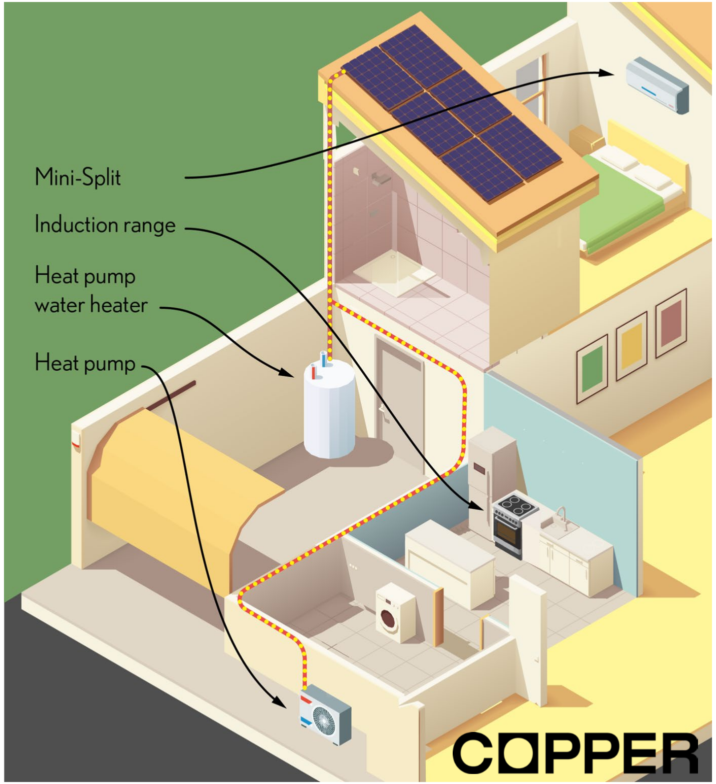
Emerging paradigms in home battery integration and control

New FOA project objectives/goals for energy-storage equipped appliances:

- Demonstrate functionality with both ESE hot water heater and heat pump mini-split.
- In home pilots - build and demonstrate an embedded and cloud software network for inter-appliance communication with the home energy network with 3+ appliances working together to load shift and simplify residential electrification.

Big questions/remaining opportunities for energy-storage equipped appliances:

- How would bidirectional ESEs work?
- ESE battery pack standardization/swappable batteries
- VPP participation
- When will major manufacturers get in the game?



Thank you!

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