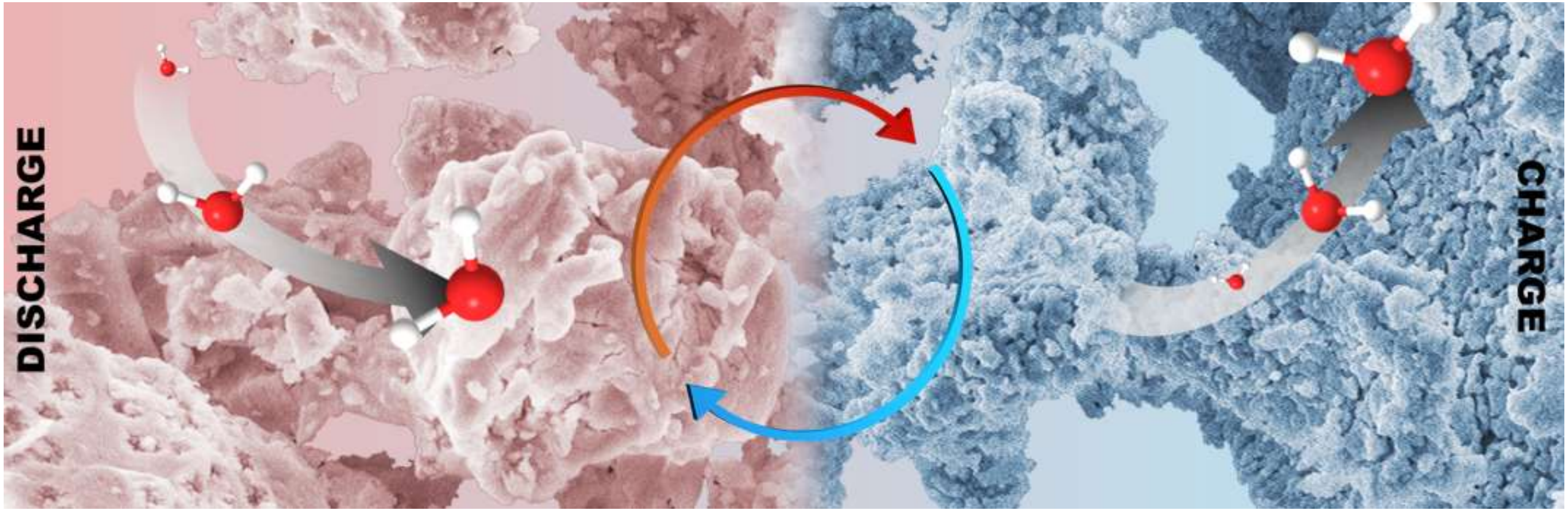
Stable Thermochemical Salt Hydrates for Energy Storage in Buildings



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WBS# 3.2.6.106 BENEFIT FOA # 2090-1762

Project Summary

Objective and outcome

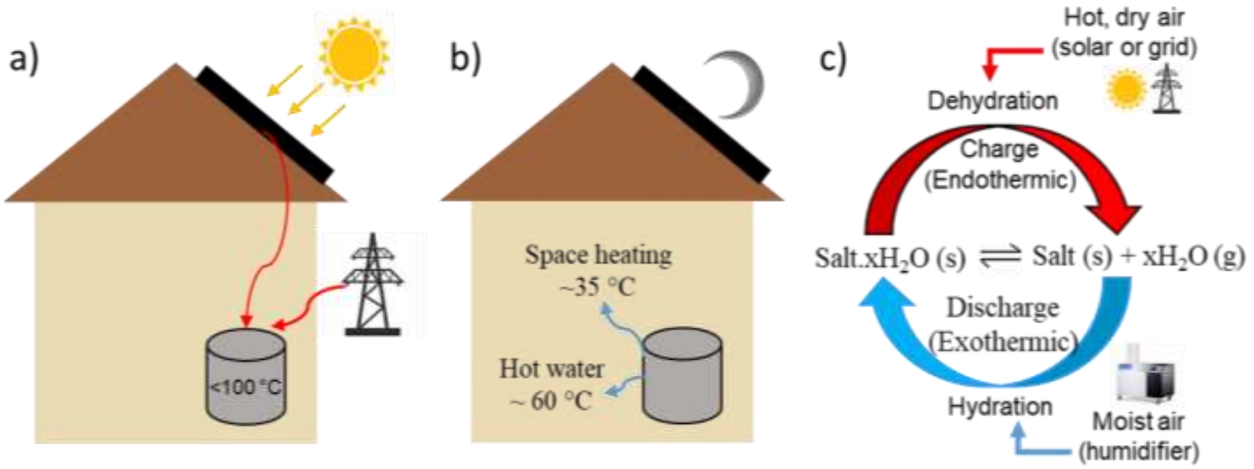
Thermochemical materials (TCM) based TES with high storage capacities (600 kWh/m^3) and negligible self-discharge are uniquely suited as compact, stand-alone units for daily-seasonal storage for heating. So far they are only explored for seasonal storage (10-20 cycles) in Europe.

The objective is to demonstrate that TCM based TES can be optimized for daily storage.

Outcome:

Stable TCM: Energy Density> 500kWh/m^3 ,Cyclability > 1000 cycles, cost<$2/kg

A reactor prototype with TCM with the following attributes: Energy density > 200 kWh/m^3, thermal reliability > 90% after > 200 cycles, cost <$15/kWh



Stats

Performance Period: 10/1/2020—9/30/2023

DOE budget: $2,400K Cost Share: $600K

Milestone 1: Down selected the most promising thermochemical materials with charging temperatures below 100ºC and energy densities above 500 kWh/m^3 after cycling. March 2021

Milestone 2: Synthesized and optimized composite TCM comprising a porous support matrix and an inert binder to achieve thermal reliability >90% after 2000 cycles, with energy densities> 250kWh/m^3. Sep 2022

Milestone 3: Develop a reactor prototype and demonstrate reactor level performance with the following attributes: Energy density > 200 kWh/m^3 , thermal reliability > 90% after > 200 cycles. (in Progress) June 2023

Team and Partners

Lawrence Berkeley National Lab (LBNL)

NETEnergy, LLC

University of California, Berkeley (UCB)

National Renewable Energy Laboratory (NREL)

University of Auckland, New Zealand

Team

Materials selection, optimization and characterization
Materials and Reactor level Modeling
Reactor Design and Prototype development

Sumanjeet Kaur (PI)
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System level modeling and techno-economic analysis

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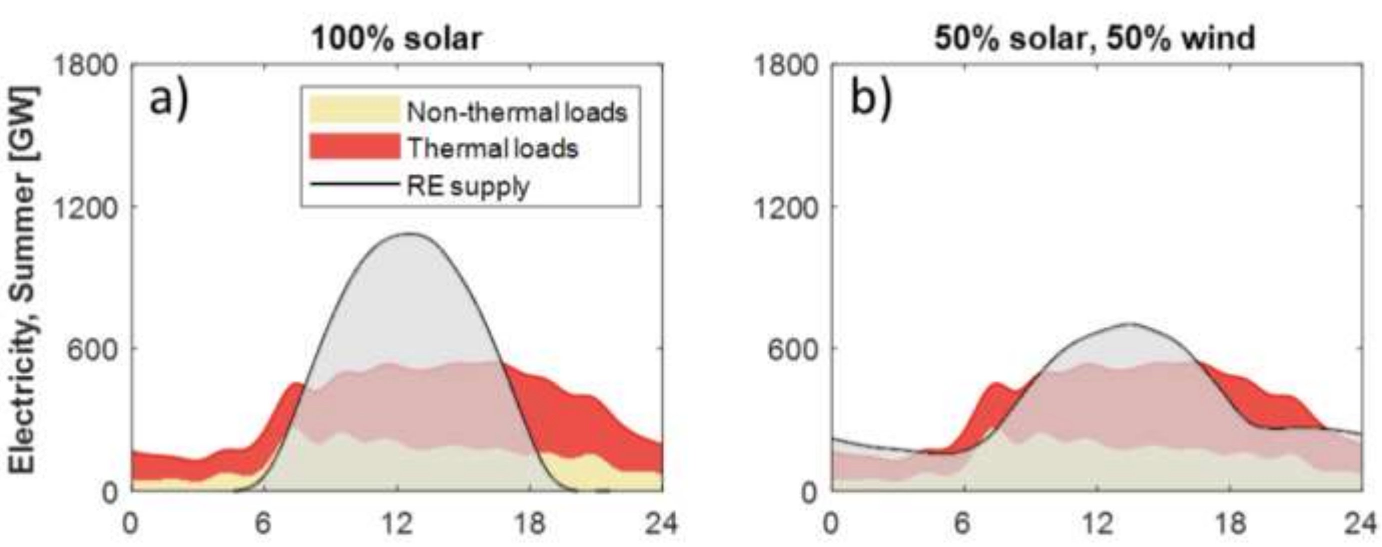
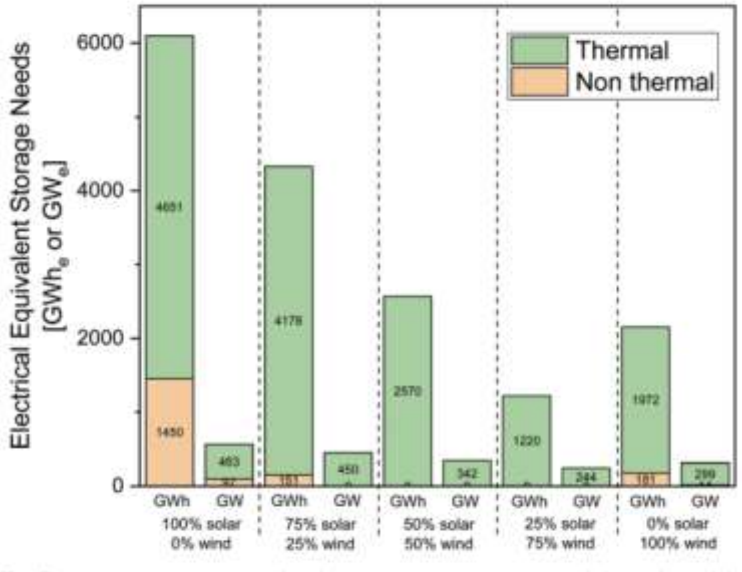
NREL

Problem

- Buildings dominate primary energy and electricity use in the United States and most of the world.
- When disaggregated into individual end-uses, **thermal loads dominate** and are also a major contributors in CO_2 emissions.



U.S. commercial and residential building electricity demand, overlaid with 100% RE supply profiles.

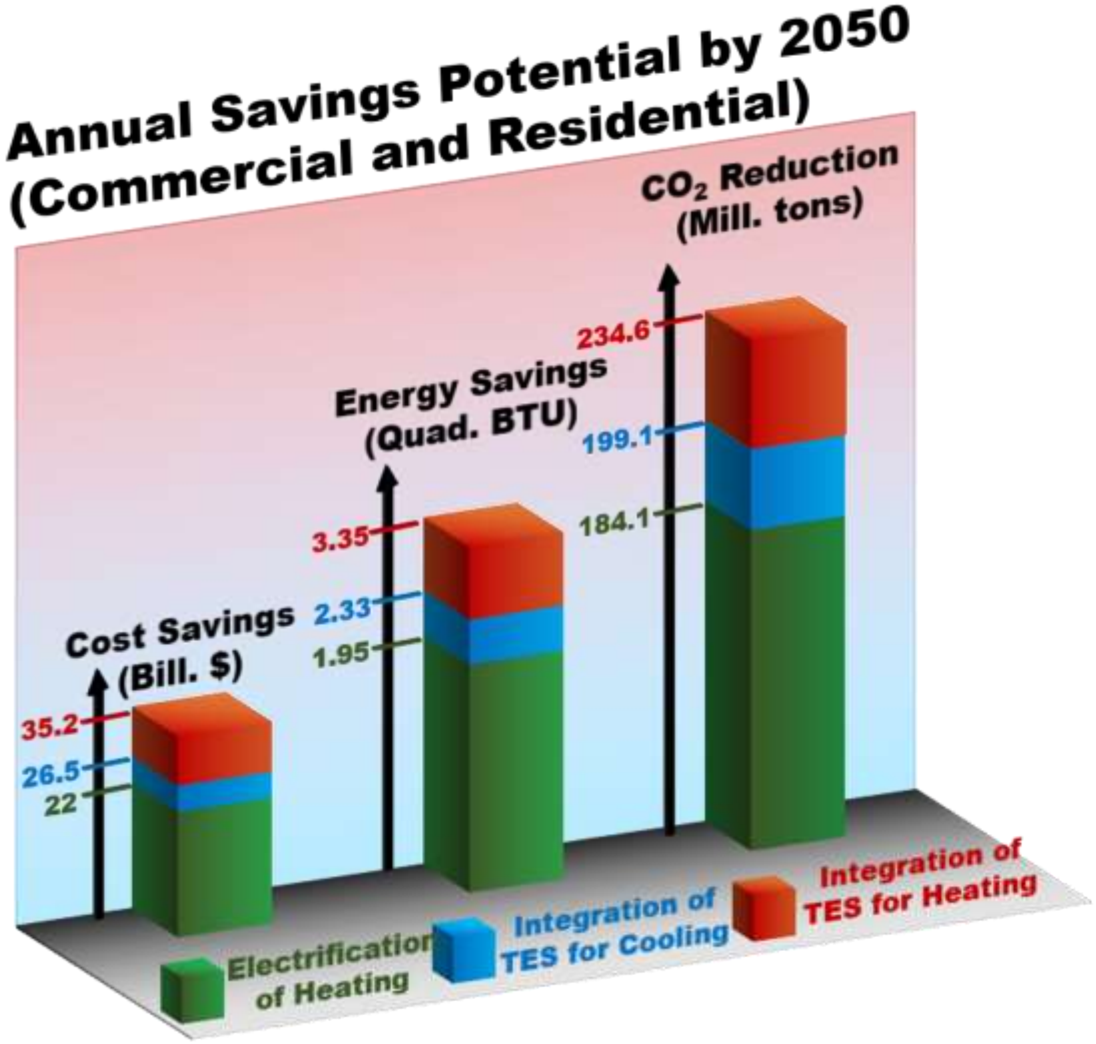


Energy storage required to support commercial and residential buildings in the United States for a 2050

NEED: Cost Effective Thermal Energy Storage

DOI: 10.1039/D1EE01992A (Perspective) *Energy Environ. Sci.*, 2021, **14**, 5315-5329

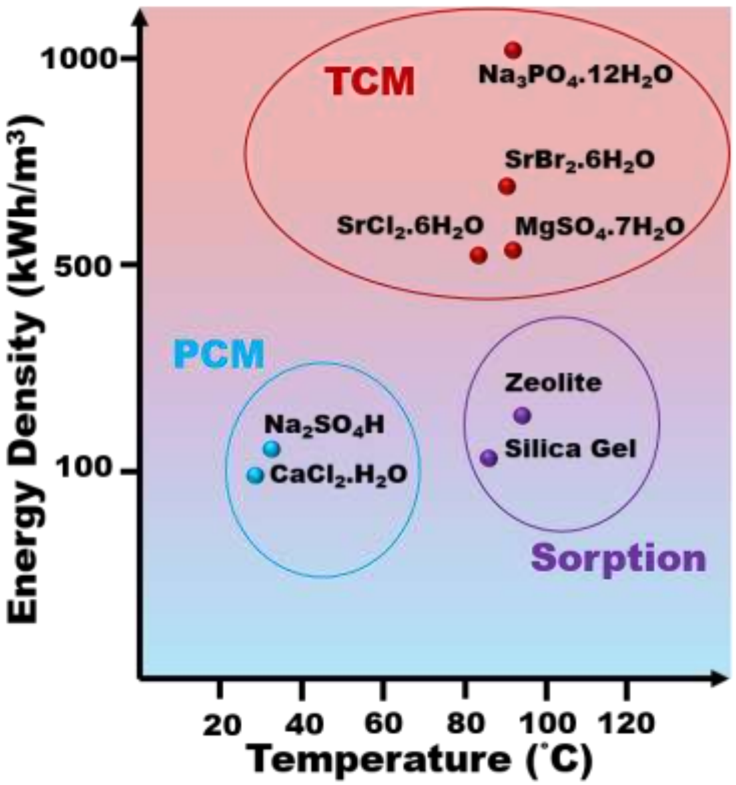
Impact

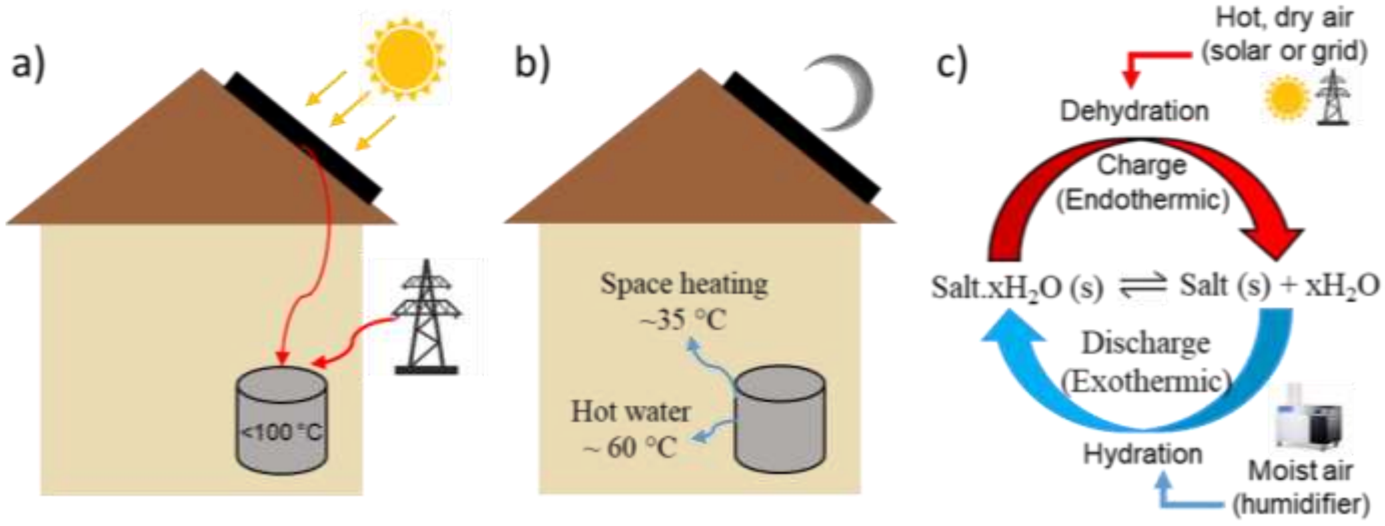


- Our group has conducted preliminary analysis for heating and cooling in residential and commercial buildings using NREL's Scout tool for TCM-heat pumps hybrid systems.

- As shown in Figure, preliminary results indicate a potential annual savings of the hybrid system: \$35.2 Billion, 3.35 Quadrillion BTUs and 234.6 Million tons reduction of CO_2.

Approach: Thermal Energy Storage for on-site Storage





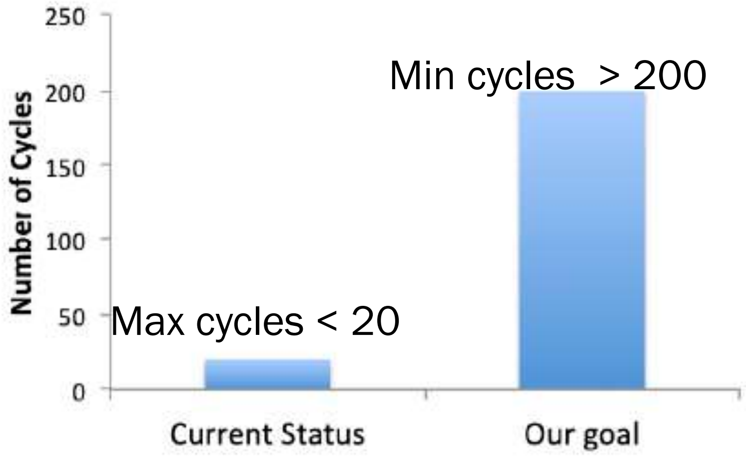
a) TCMs can be charged using solar energy or grid electricity. b) Energy stored in TCM can be discharged at desired T for thermal end-uses. c) Reversible solid-gas reactions (salt hydrate) in an open system.

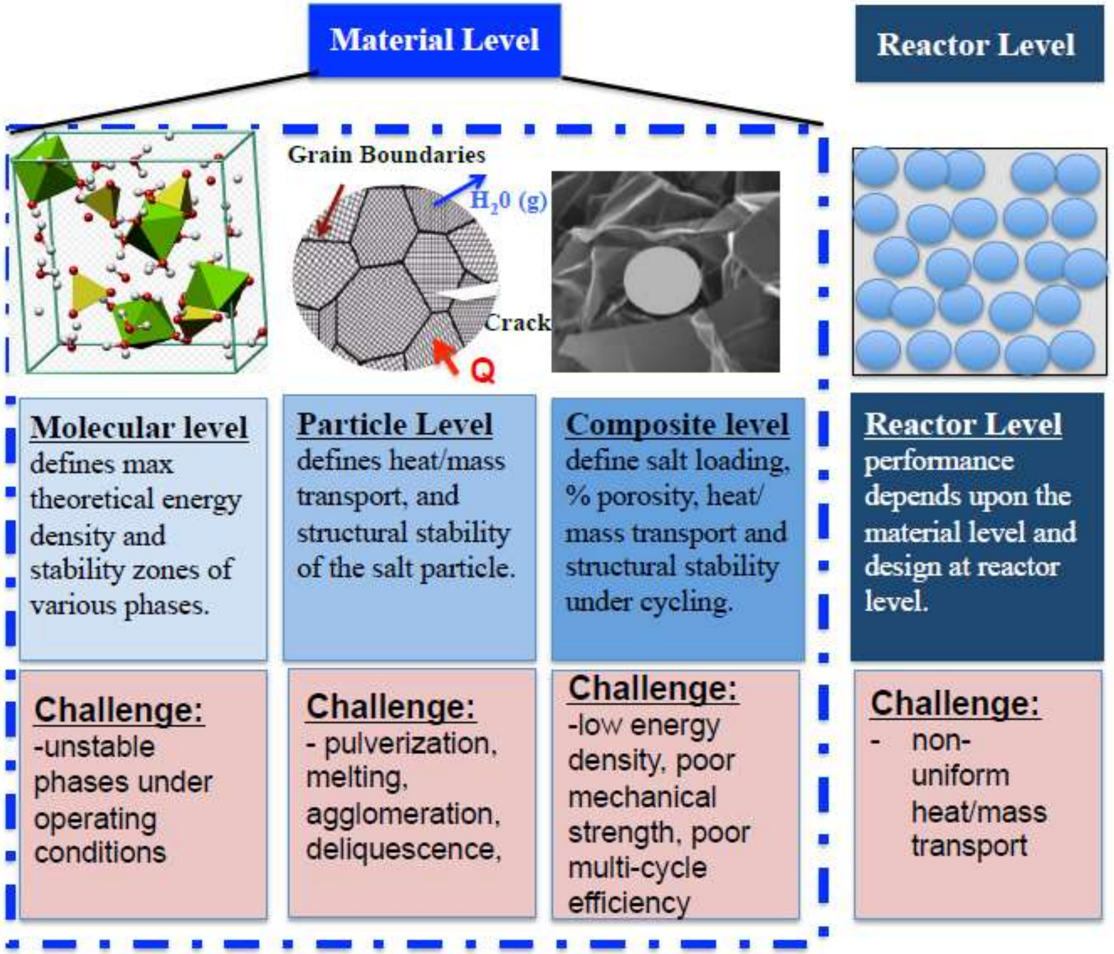
- Phase Change Materials (PCMs) and sorption-based storage have energy density in the ranges of ~100 kWh/m^3
- Thermochemical Materials (TCMs), comprising a reactive pair of inorganic salt and water vapor, have higher theoretical energy densities of ~500 kWh/m^3 and negligible self-discharge **as energy is stored in chemical bonds, making them *uniquely suited as compact, stand-alone solutions for daily-seasonal energy storage in buildings***

Approach: Bottom-up Optimization from Material to Reactor Level

State of the art: Poor Multi-cycling Performance for TCMs

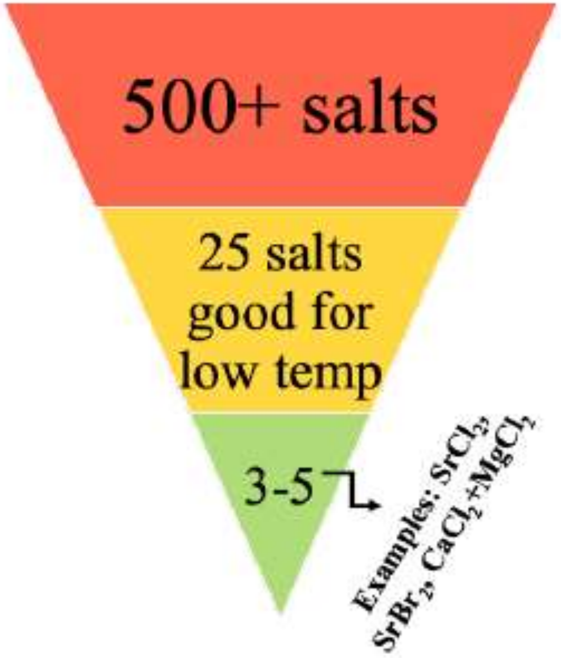
- TCMs suffer from instabilities at the material (salt particles) and reactor level (packed beds of salt), resulting in poor multi-cycle efficiency.
- So far the TCM based storage is optimized for seasonal: number of charge/discharge cycles per year to only *one* (charge in summer and discharge in winter). Has **high-levelized cost of storage.**





Our goal is to use bottom-up approach to design, optimize and develop TCM based thermal energy storage for buildings by addressing the chemical instabilities of the salt at material (and composite) level as well as optimizing the performance for heat and mass transport at reactor level.

Progress: Salt Selection and Characterization



Salt Selection Criteria:

- Non-toxic and non-flammable
- Charging temperature <100°C
- Fast reaction kinetics
- Energy density >500 kWh/m^3
- Deliquescence relative humidity (DRH) >40%RH to prevent over-hydration
- High cyclability
- $T_{melting} > T_{dehydration}$ to ensure solid stability
- Material cost <$2/kg

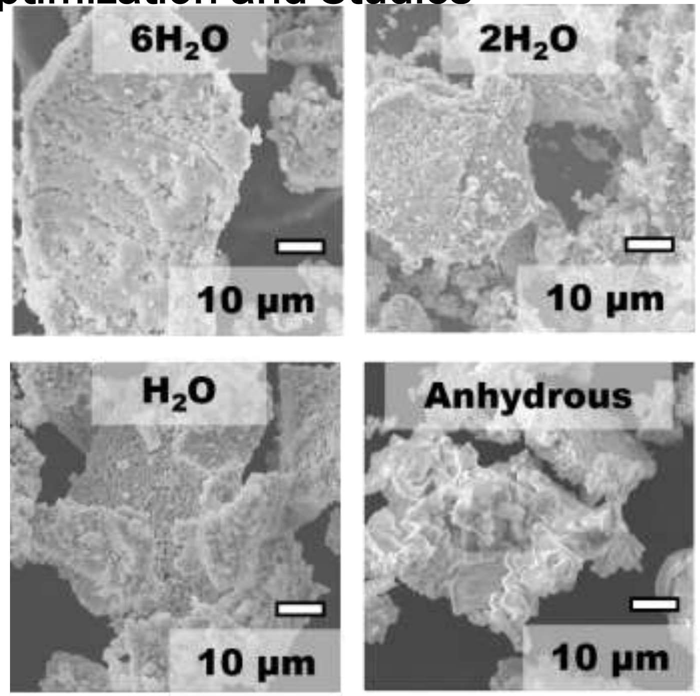
Example

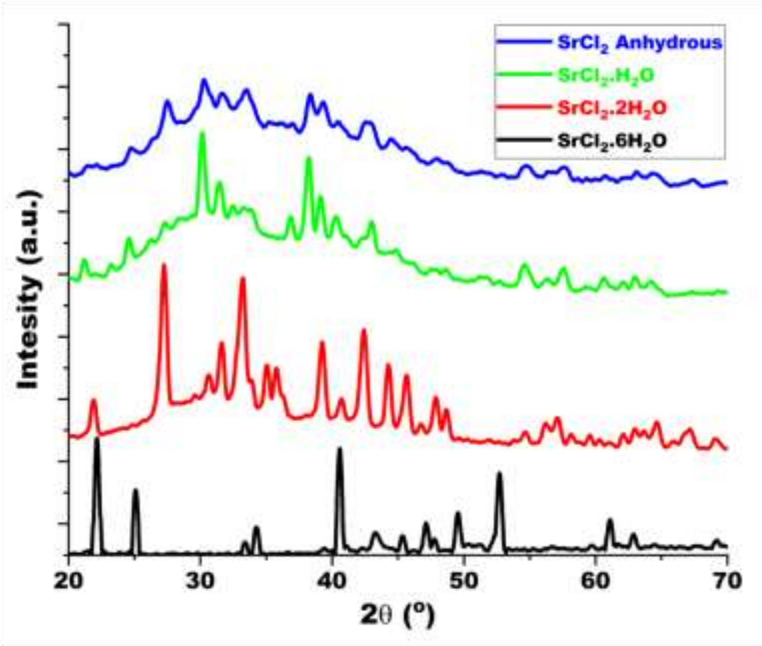
Salt	Dehydration temperature (°C)	Dehydration steps	Cyclability	Density of hydrated material (kg m^{-3})	Energy density (kWh m^{-3})	Energy of reaction (kJ mol$^{-1}_{salt}$)	Energy of reaction (kJ mol$^{-1}_{water}$)	Cost per kg (USD)	Cost of power (USD/kWh)	Comments
$SrCl_2.6H_2O$	42-50	$SrCl_2.6H_2O \rightarrow SrCl_2.2H_2O + 4\,H_2O$	Composite of $SrCl_2$ and pumice stable for 10 cycles in lab-scale reactor	1930	560 (130.7)	285 (65)	57 (13)	0.65 (anhydrous) 0.1 (hydrate)	0.35	• Reversible reaction achievable • Lower energy density than $SrBr_2$ unless dehydration temperature above 128 °C
	86	$SrCl_2.2H_2O \rightarrow SrCl_2.H_2O + H_2O$								

Clark, R. J. *et al*. **Experimental screening of salt hydrates for thermochemical energy storage for building heating application**. *Journal of Energy Storage* **51**, 104415 (2022).

Progress: Fundamental Analysis and Optimization

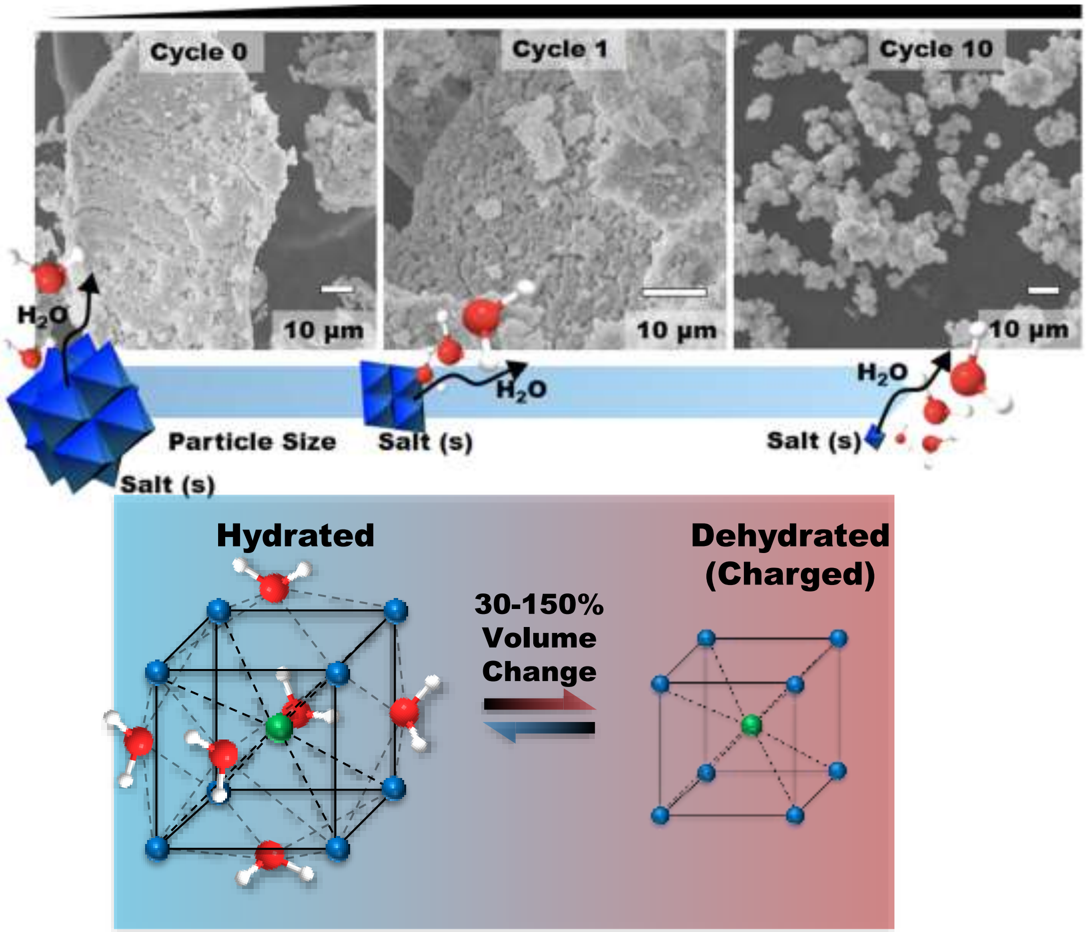
Materials Level Optimization and Studies



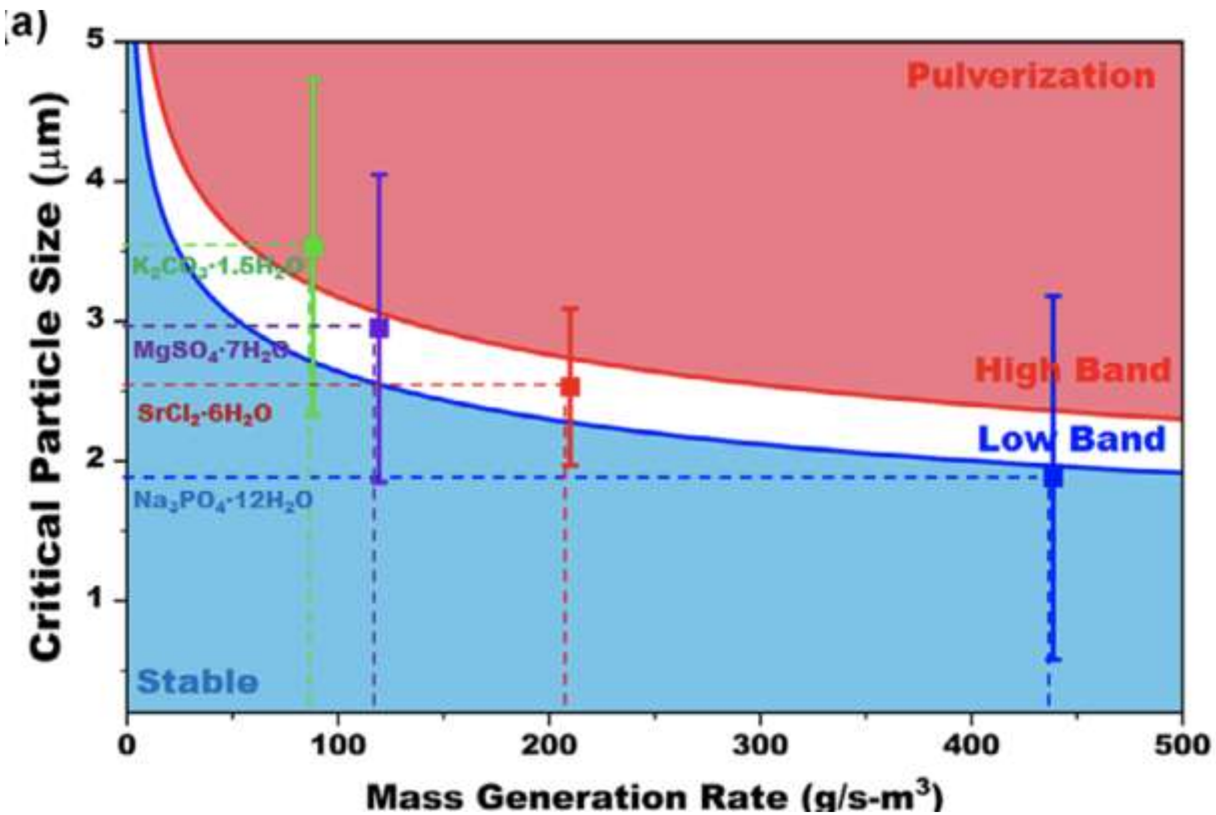


- Performance optimization are done from the materials scale where fundamental analysis are done to investigate morphological and kinetic behaviors of the salt hydrates.
- Key Findings: Optimal particle size required, understanding of ramp rate and depth of charge is critical.

SrCl2 – Particle size optimization



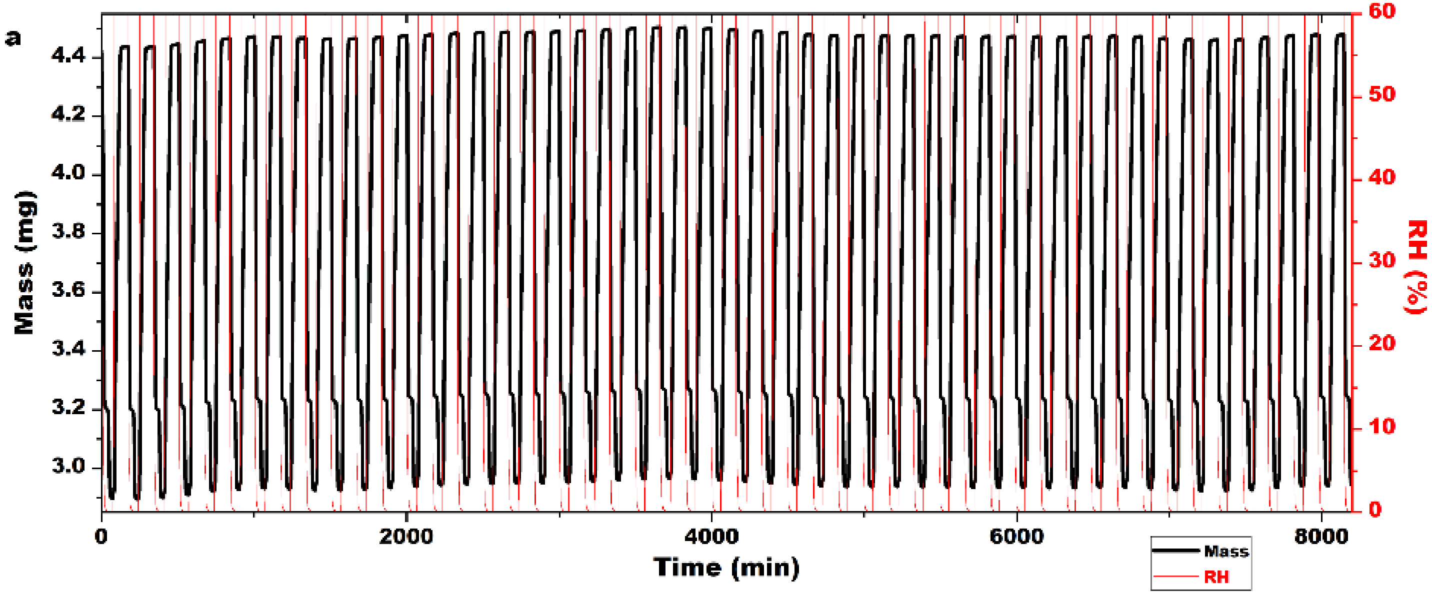
SEM image and illustration of the change in salt hydrate ($SrCl_2$.6H2O) morphology and size during cycling

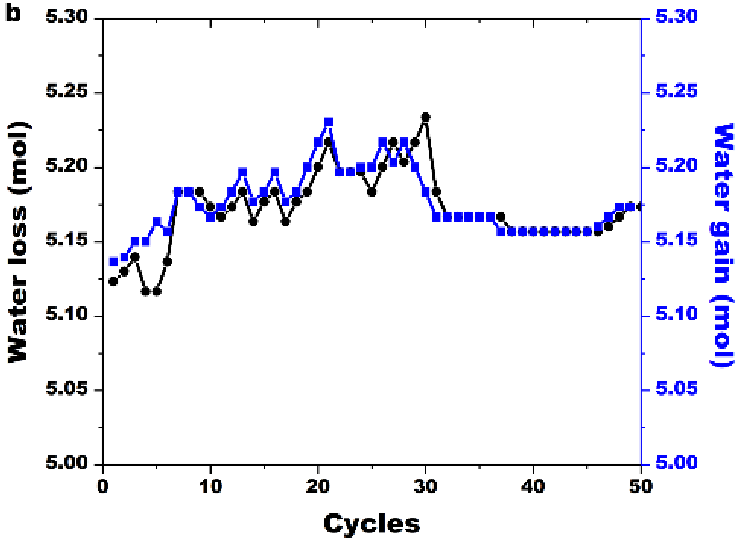


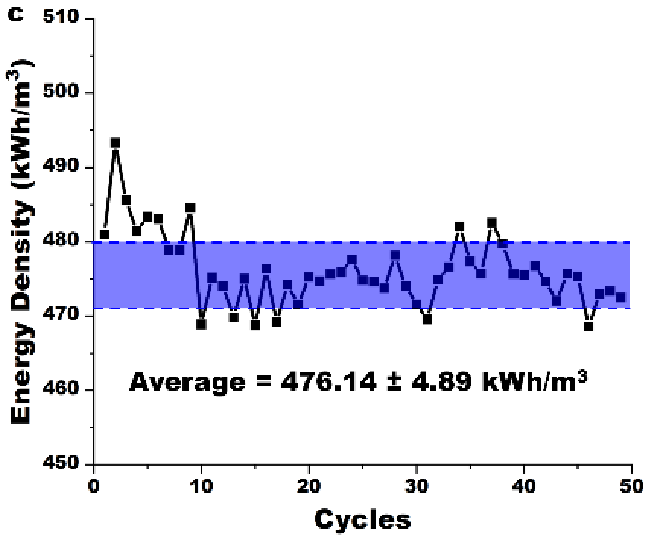
Model along with experimental data on the critical particle size of salt hydrates. Two set of material constant values were taken to represent the range of mechanical and intrinsic properties for various salt hydrates.

Martin, A., Lilley, D., Prasher, R. & Kaur, S. Particle Size Optimization of Thermochemical Salt Hydrates for High Energy Density Thermal Storage. *Energy Environ Mater* (2023) doi:10.1002/eem2.12544.

SrCl2 – From particle Level





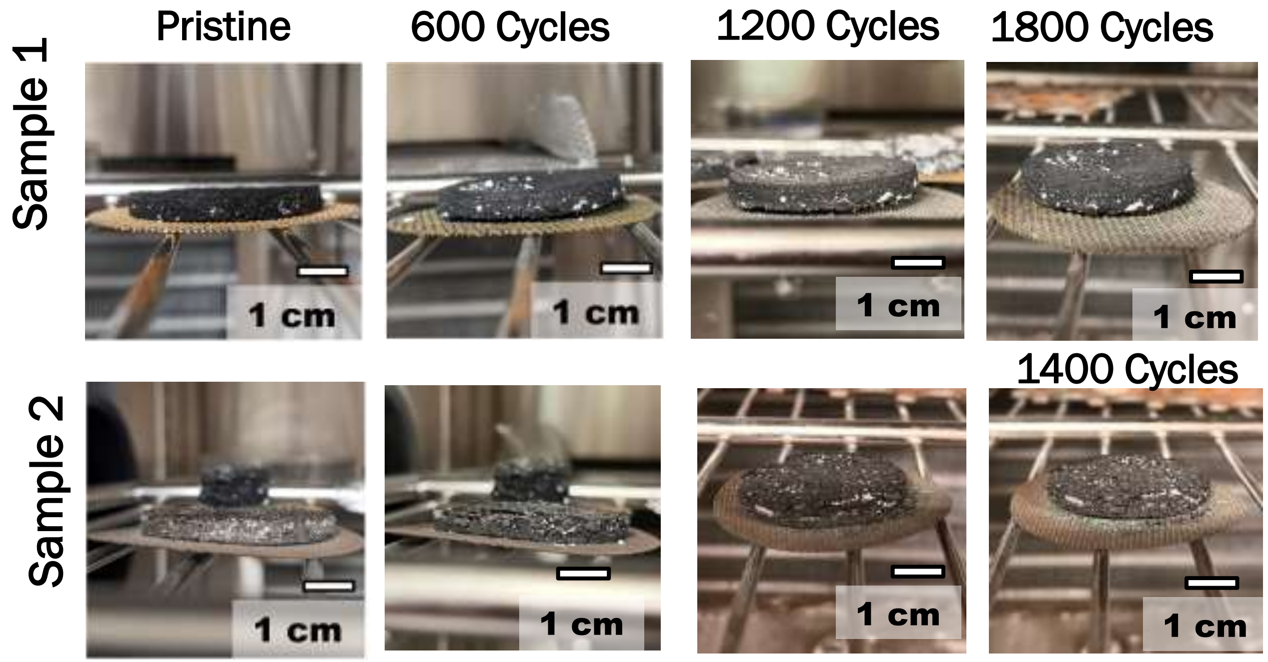


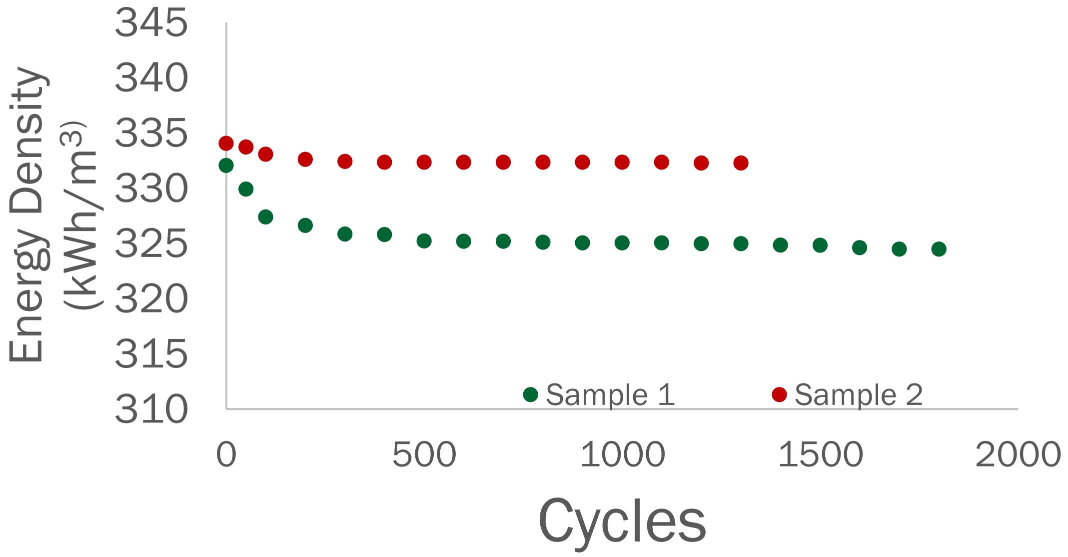
Cyclable at particle level when operated in the right parametric space ($6H_2O$ -$1H_2O$)

What happens as we scale it up? Also how do we scale it up?

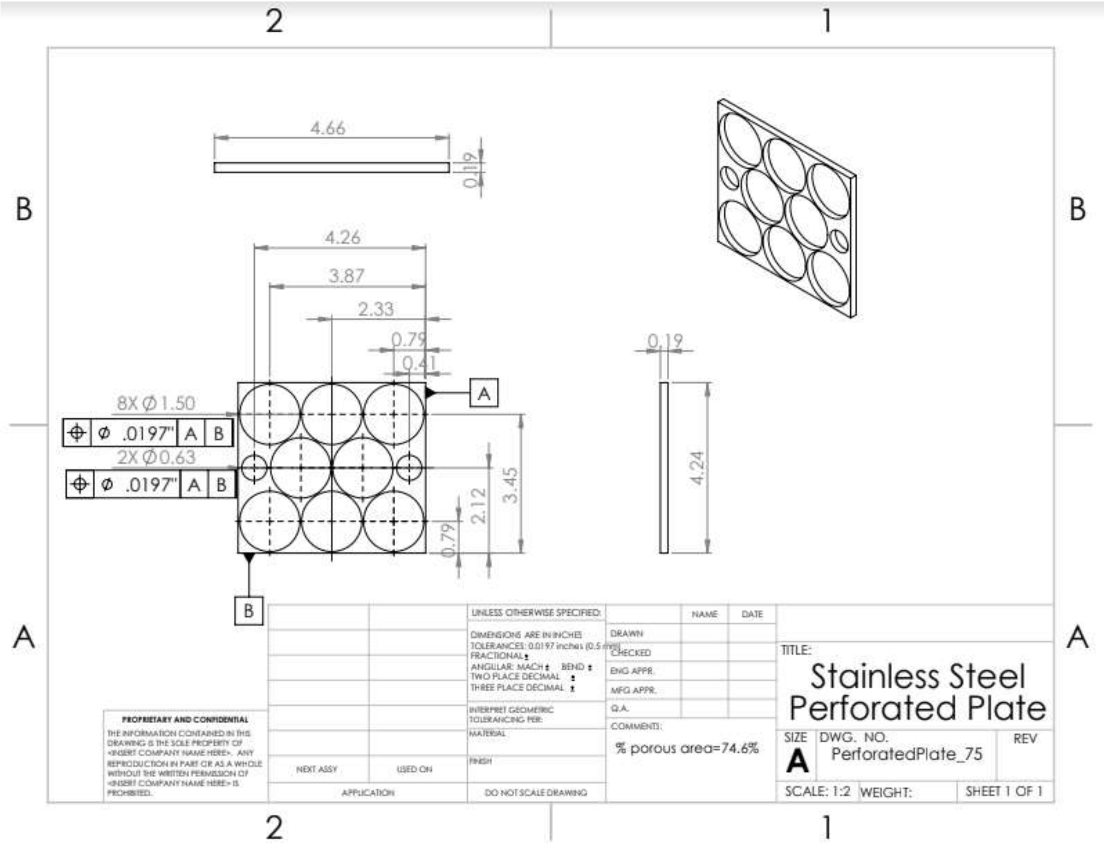
$SrCl_2$- Composite

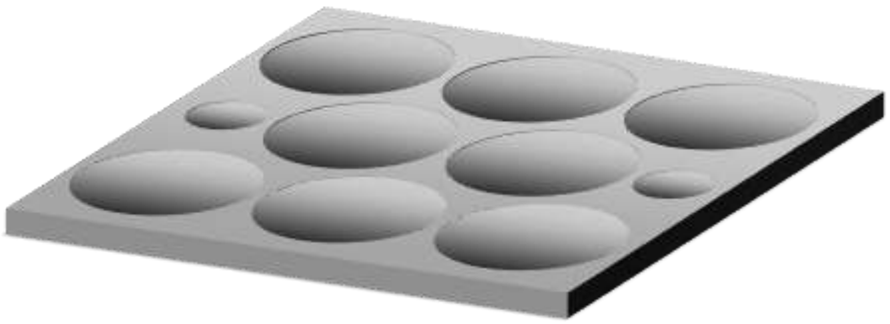
1. Significant volume changes during hydration-dehydration so needs a host matrix for mechanical strength – Composite
2. Typical wet method is used to make composites (Not conducive for all salts, less salt loading and could result in salt agglomeration)
3. Leveraging know how from battery research filed LBNL developed dry mixing composite recipe using binder 75wt% Salt hydrate (Record of Invention filed)





Reactor Design and Prototype Development at LBNL



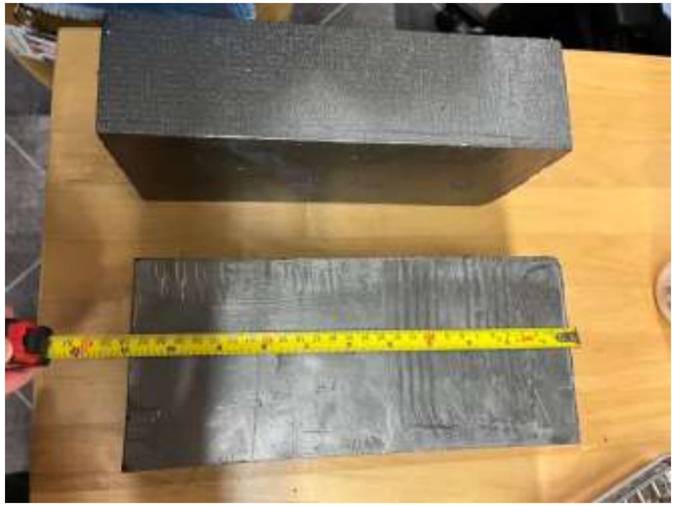


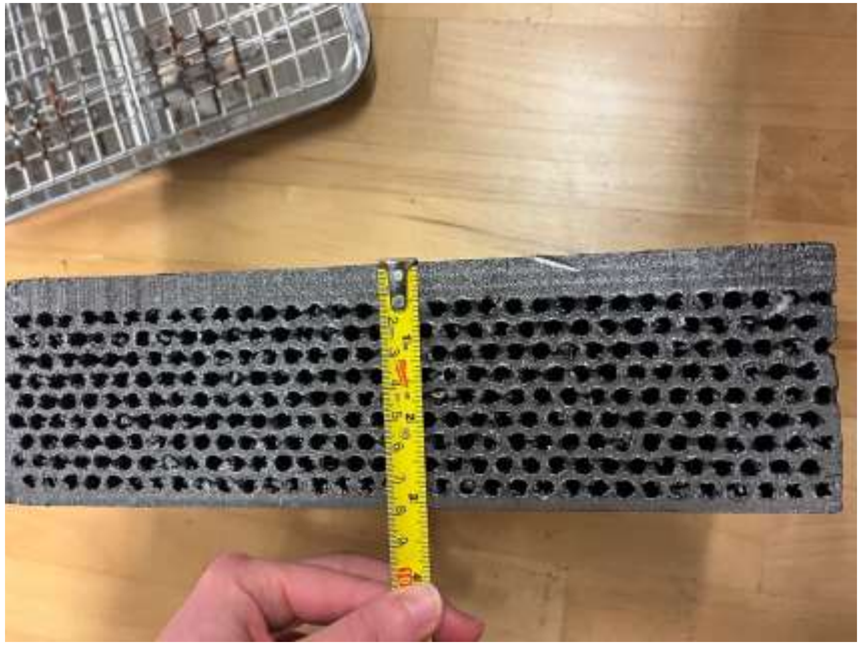
Each hole is filled with either 1.5-inch and 0.75-inch composite pellet respectively. The holes are made perfectly to house these pellets.

Calculated Energy Density per sheet = **0.746 x (average pellet energy density)**

Assuming we have perfect packing, we can have an average density of **~250 kWh/m^3** per sheet

NetEnergy Optimizing Another Salt Hydrate- $CaCl_2.6H_20$





Salt Hydrate:

$CaCl_2.6H_20$

Host:

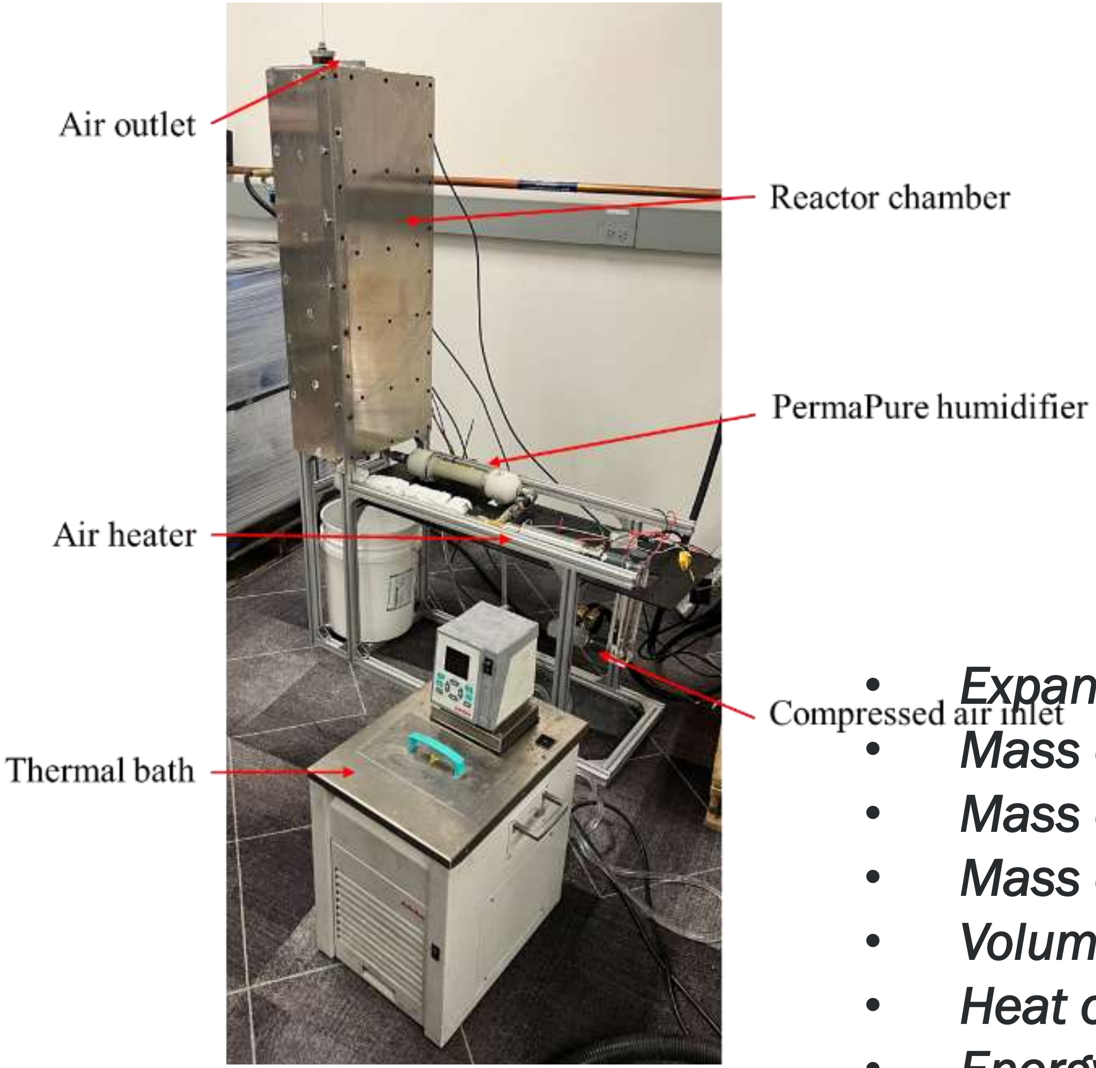
Expanded Graphite – Pre compressed Method used:

Wet Method

Benefit:

We are leveraging the existing product (pre compressed expanded graphite) of NetEnergy for TCM.

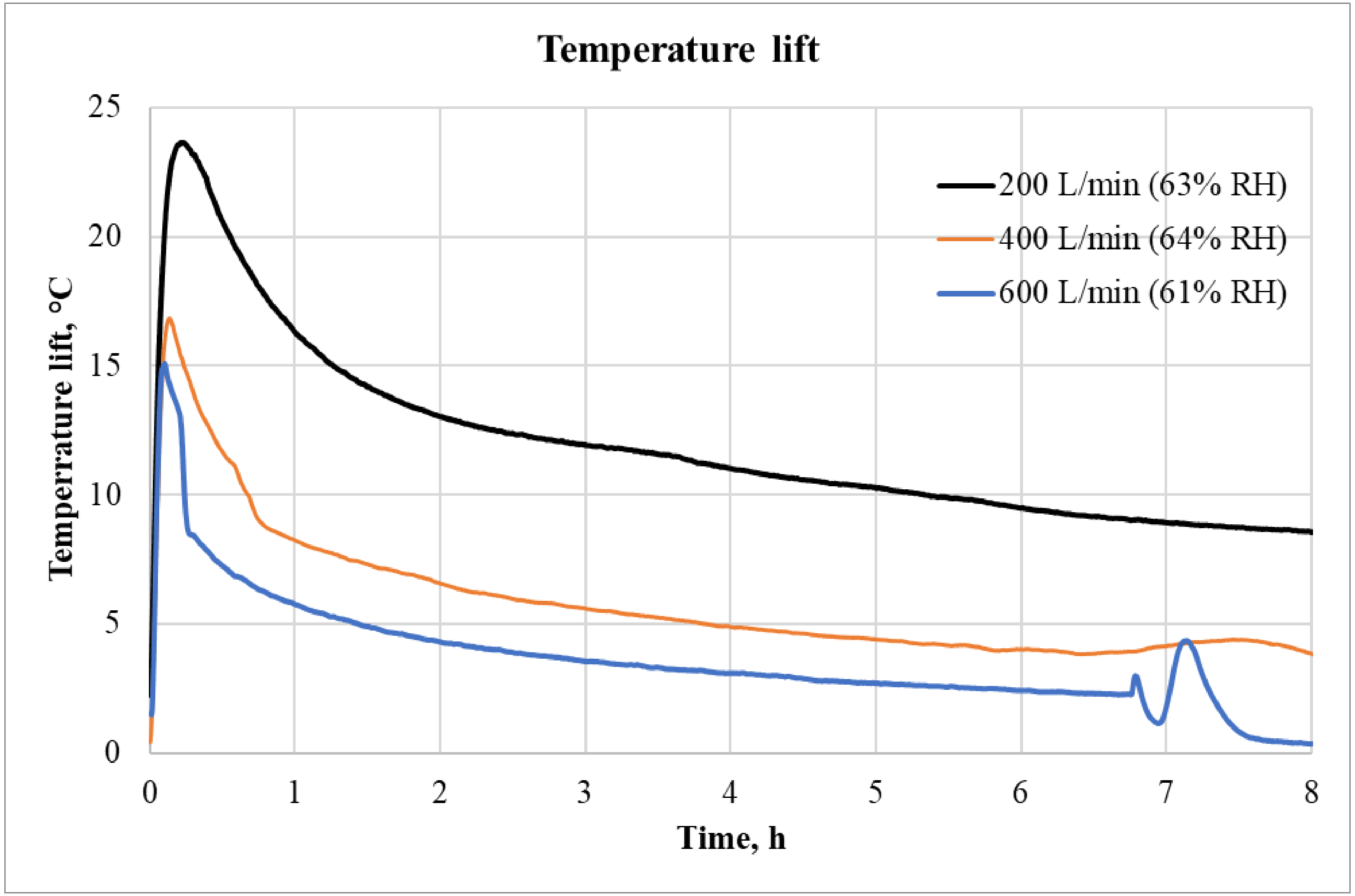
Reactor Prototype at NET Energy – Perforated brick design



- *Expanded graphite density: 100 g/L*
- *Mass of the block (graphite before soaking): 217.7 g*
- *Mass of the block after soaking and drying : 587.4 g*
- *Mass of anhydrous salt = 369.7 g*
- *Volume of the composite: 1,709,565 mm^3 or 0.001709565 m^3*
- *Heat of reaction =3200 kJ/kg*
- *Energy content = 3200 x 0.369.7 = 1183 kJ or 0.329 kWh*
- *Theoretical energy density = 0.329/0.001709565 = 192.5 kWh/m^3*

Results

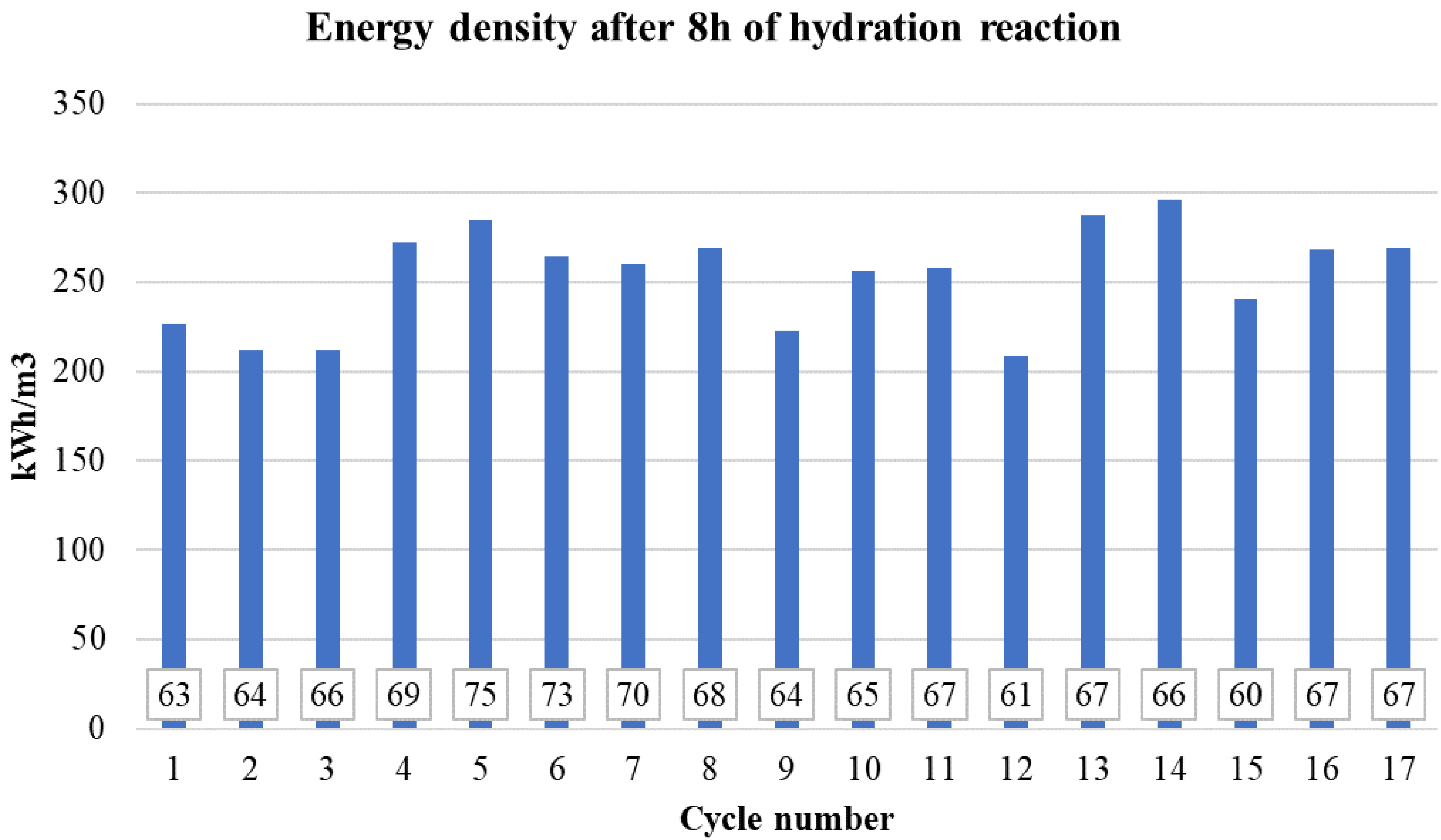
1. Temperature lift during 8h of hydration reaction



- 17 cycles total
- Majority at 400 L/min
- Showing the comparison between different air flow rates

Results

2. Energy density



- *Total energy density for 16-18h of hydration reaction is between 350 and 450 kWh/m3 (depending on RH)*

Stakeholder Engagement

Claus Daniel

Sr. Fellow and Innovation Theme Leader for Sustainability at Carrier

Juan Catano Montoya

Vice President Research at Emerson Commercial and Residential Solutions

Louis Storino

Principal Civil Engineer and Treasurer of Illinois Water Environmental Association (IWEA)

Warren C. Jones

Chief Executive officer at BluePath Finance LLC

Fy23

- Conduct comprehensive calculations of power and energy density of the storage system under different conditions for both reactors. Get data for at least 200 cycles in FY23
  - For LBNL Reactor
    - Finalize Reactor Design and build prototype
  - For NetEnergy Reactor
    - Conduct large number of cycles to insure thermal and mechanical stability of the graphite blocks
    - Further increase salt loading in the graphite blocks.
- Provide recommendations for future improvement to the existing system

Future -> Stor4Build

Continue this project with the aim to carry out first field demonstration of TCM based TES daily storage in 2-3 year time frame

Stor4Build
U.S. DEPARTMENT OF ENERGY

Learn more on Energy.gov

Accelerating the equitable growth, optimization, and deployment of cost-effective storage technologies for buildings

- Addressing the need for equitable solutions that ensure benefits of storage technologies are clear for all communities.
- 5-year goal is to implement a community-scale demonstration of technologies, which will serve as a foundation for large-scale deployments of thermal and battery energy storage and systems capable of satisfying both the heating and cooling needs in buildings.
- Multi-lab consortium 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) to Support equity-centric scaled adoption of building energy storage technologies and a market transformation to increase market viability.

Funded By: U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY | BUILDING TECHNOLOGIES OFFICE

Co-Directors: NREL Transforming ENERGY | BERKELEY LAB | OAK RIDGE National Laboratory

Supported By: ACEEE | Pacific Northwest

Thank You

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WBS #3.2.6.106 , FOA Project # 2090-1762

REFERENCE SLIDES

Project Execution

	FY2021				FY2022				FY2023			
Planned budget: Oct 1 2020												
Spent budget: Sep 30 2023												
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: : Selection of thermochemical salt hydrates												
Q2 Milestone: : Investigation and characterization of pristine salts												
Q3 Milestone: Characterization and Cycling												
Q4 Milestone: Conduct LCOS												
Q4 Milestone: Form TAC												
Milestone 5.1.1 Report on properties of graphite host matrix using various techniques. (Net Energy Inc + LBNL)												
Milestone 5.1.2 Report on properties of other host matrix such as vermiculite using various techniques. (Net Energy Inc +LBNL)												
Milestone 5.2.1 Down-select the most promising binders and demonstrate 5X better mechanical properties (failure stress) compared to non-binder composite after 50 cycles. (LBNL)												
Milestone 5.3.1: Report on the energy densities of various methods of salt impregnation in host matrix along with SEM imaging to show uniform loading of the salt (M18) (NREL, Net Energy Inc)												

Team

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System level modeling and techno-economic analysis

Jason Woods
NREL

Wale Odukomaiya
NREL

EERE/BTO goals

The nation's ambitious climate mitigation goals

Greenhouse gas emissions reductions

50-52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050

Power system decarbonization

100% carbon pollution-free electricity by 2035

Energy justice

40% of benefits from federal climate and clean energy investments flow to disadvantaged communities

EERE/BTO's vision for a net-zero U.S. building sector by 2050