Design and Integration of Thermochemical Energy Storage (TCES) into Buildings for Load Shedding/Shifting

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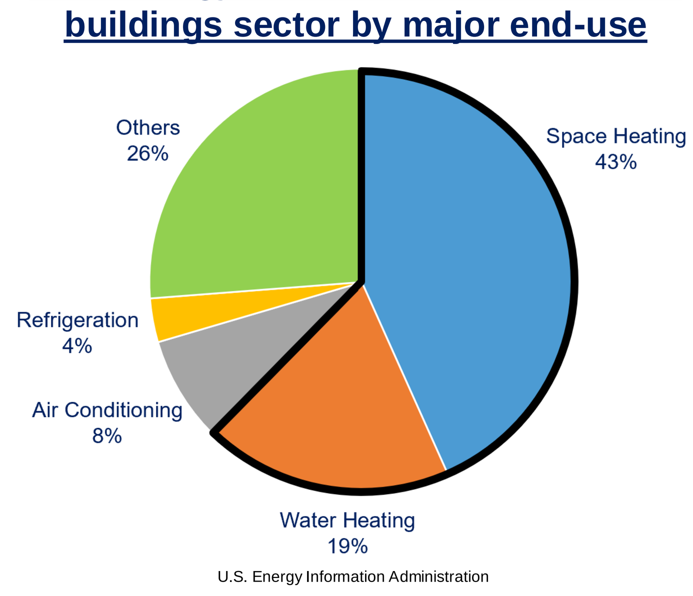
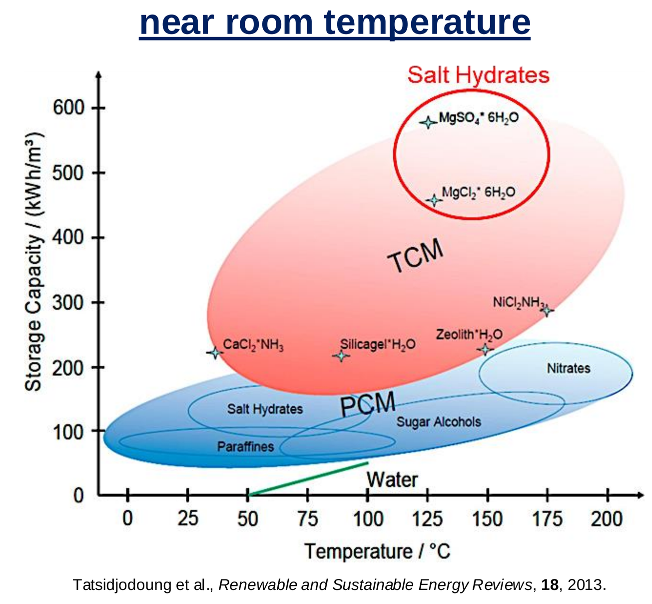
Thermochemical Energy Storage

In the United States, the buildings sector accounts for over half of the primary energy consumption. Space conditioning and water heating are the dominant end-uses, which necessitates decarbonizing these thermal loads. Low-temperature thermochemical energy storage (TCES) can address the intermittency associated with renewable electrification of heat.

2020 energy use in the U.S. residential buildings sector by major end-use



Energy storage capacity of materials near room temperature



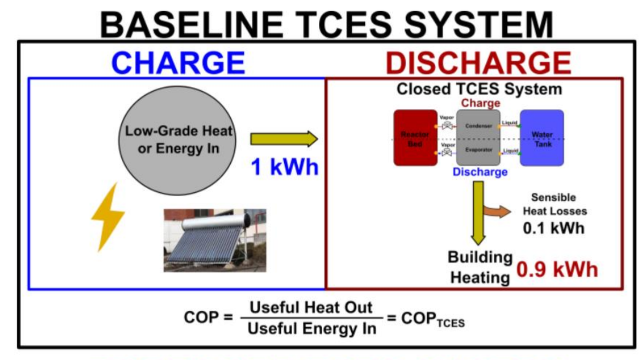
Project Goal and Research Objectives

The overall goal is to develop a proof-of-concept closed loop TCES reactor using stable salt hydrate composite materials that can be integrated with a residential heat pump. The TCES can store off-peak grid electricity or utilize otherwise wasted heat from HVAC to load shift thermal end-uses in buildings or for peak load shaving at a low levelized cost of storage.

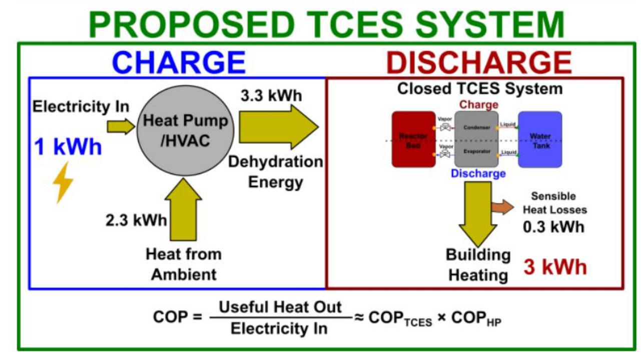
This is achieved with the following objectives:

1) Design salt hydrate composites with enhanced structural stability that achieve high energy density, fast reaction kinetics, and maintain hygrothermal stability.
2) Develop a benchtop TCES packed bed reactor with water vapor in a closed loop that outputs heat at >35°C during winter and cooling at <20°C during summer with an overall energy storage density of 200 kWh/m³.
3) Demonstrate a proof-of-concept TCES unit integrated with a residential heat pump that delivers at least 40% of the building thermal load using a simple controls strategy.

BASELINE TCES SYSTEM



PROPOSED TCES SYSTEM

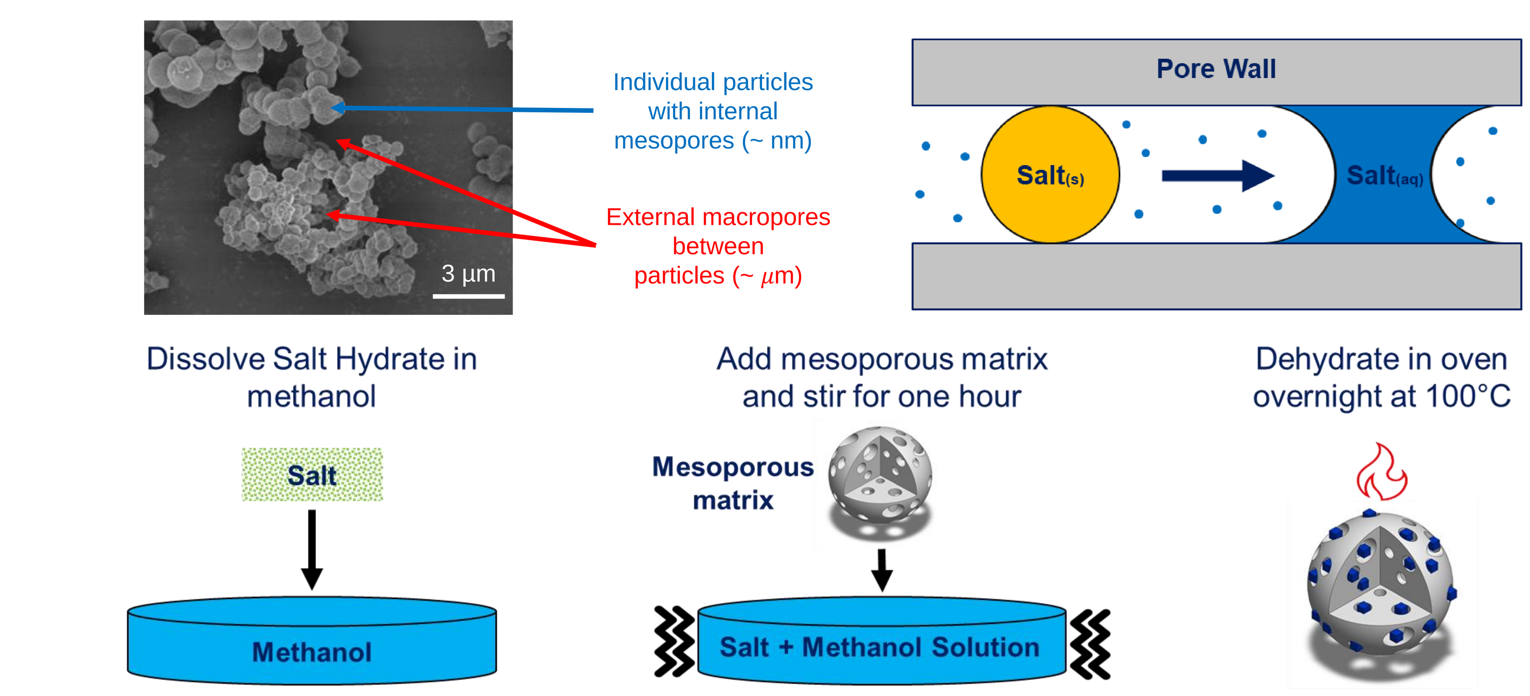


Objective 1: Materials Development

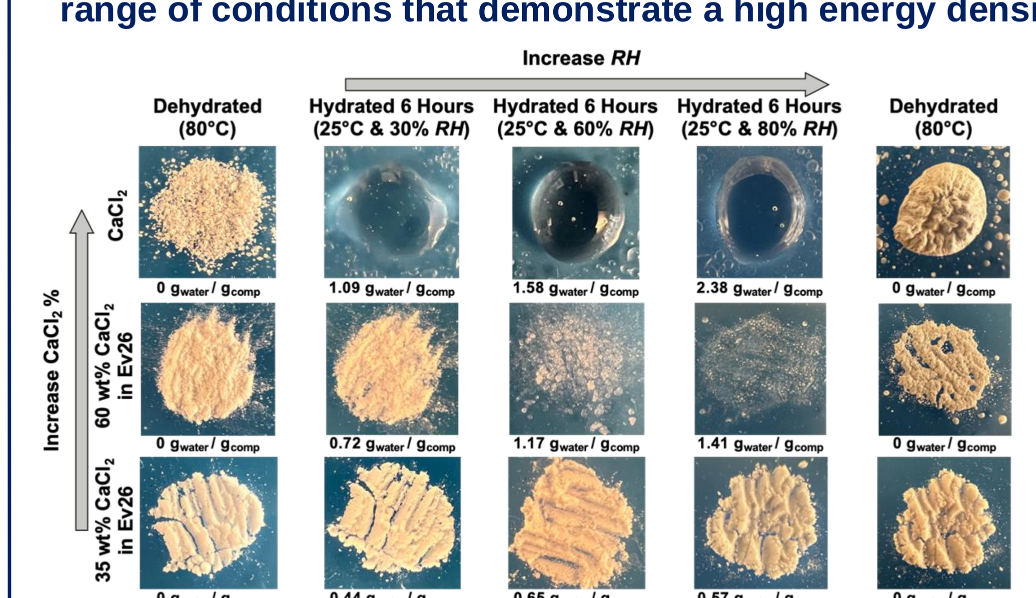
To achieve reversible reactions, hygrothermal stability and kinetics are the key material-level parameters that dictate reactor-level performance metrics such as thermal power output (heat duty), temperature lift, and energy density. This work develops salt composites with improved stability, permeability and thermal conductivity.

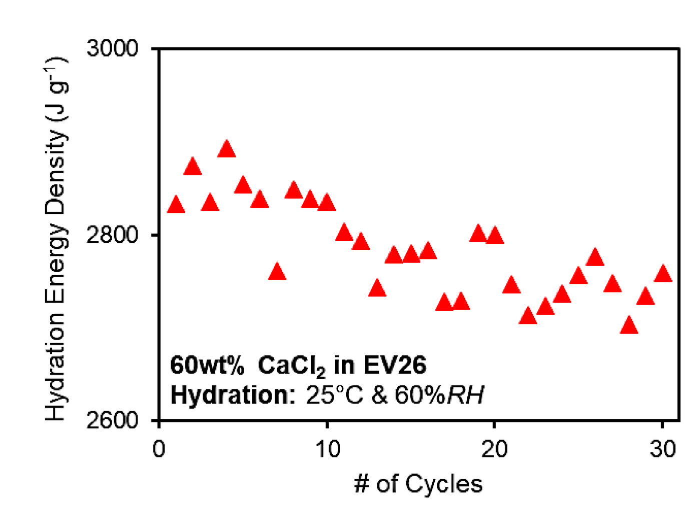
Composite Synthesis and Characterization

Nanoconfinement of salt in mesopores: Salt hydrate ($CaCl_2$) particles are confined within a mesoporous matrix (~nm) using a wet impregnation fabrication process. The synthesis uses commercially available matrix materials (silica), common solvents (methanol), and can be scaled up to kg-scale batches. Capillary attraction within the mesopore prevents salt leakage and agglomeration during hydration, while macropores (~μm) allow for water vapor diffusion.



Stable salt composites with minimal salt leakage and/or agglomeration are achieved across a range of conditions that demonstrate a high energy density and reversible cycling (>30 cycles).



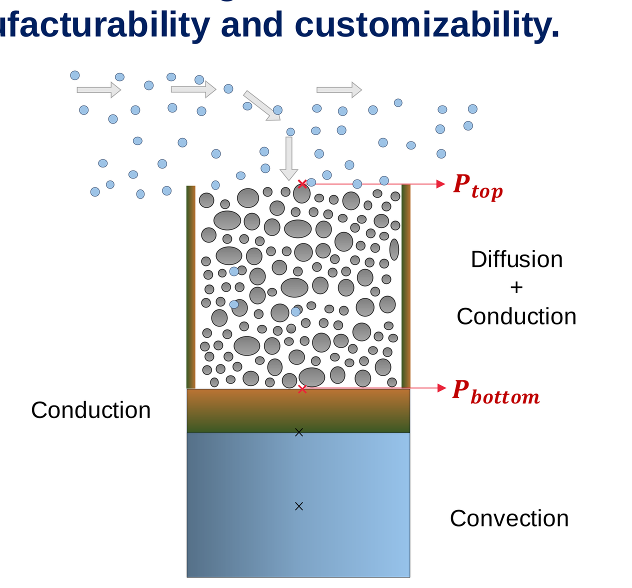


Objective 2: Reactor Design

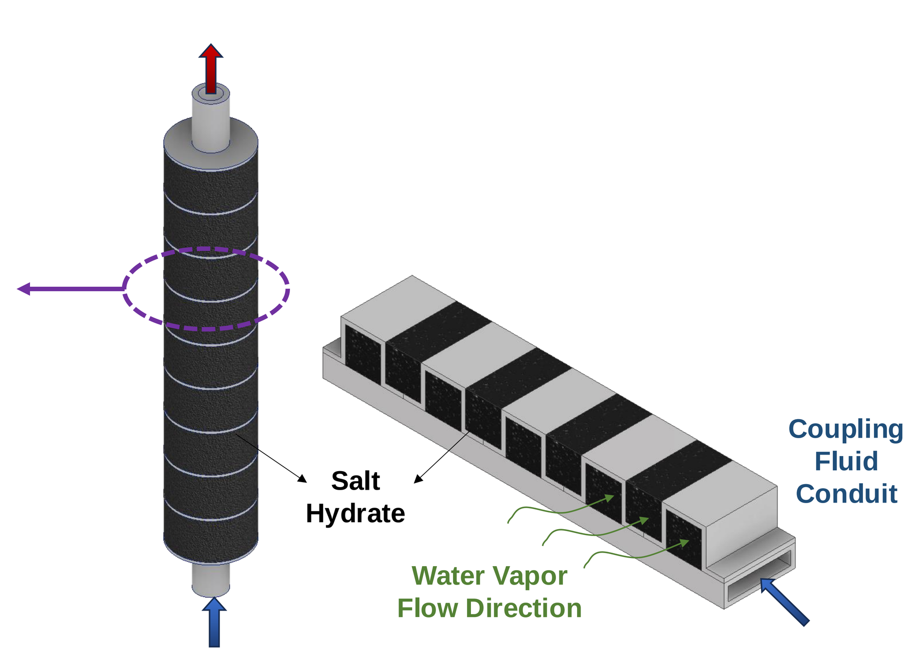
TCES reactor design is inherently more complex than other storage technologies (phase change and sensible heat materials) because it involves internal heat and mass transfer, as well as heat transfer between the coupling fluid and the storage material.

Modeling of the Salt Bed

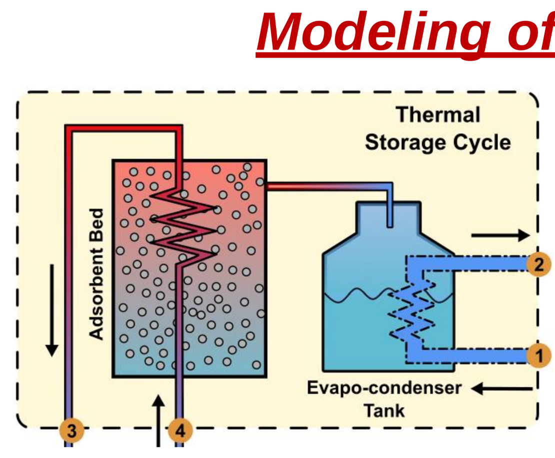
Heat and mass transfer resistances across the salt hydrate are the biggest challenges associated with the design process. High thermal resistance and potentially poor contact between salt hydrate pellets and the coupling medium lead to unused salt (inactive storage). Therefore, 2D heat and mass transfer equations are solved to enable more effective designs, such as rectangular channel and circular fin-tube geometries given the ease of manufacturability and customizability.



Analysis on a representative segment



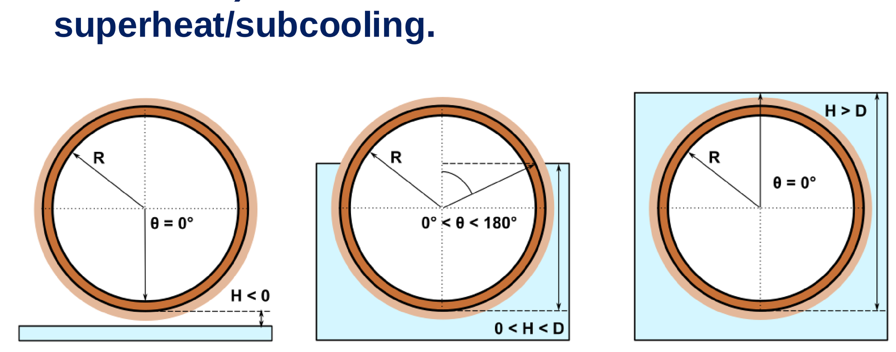
Modeling of the Evapo-Condenser



A single component is used for both the condensation (during charging) and evaporation (during discharging) process. The evapo-condenser also serves as a storage tank for the water (closed loop).

Detailed modeling of the phase change process as the water liquid level rises and falls allows for optimal sizing of the component.

Low-pressure phase change of water (~800-2000 Pa) is modeled at low wall superheat/subcooling.



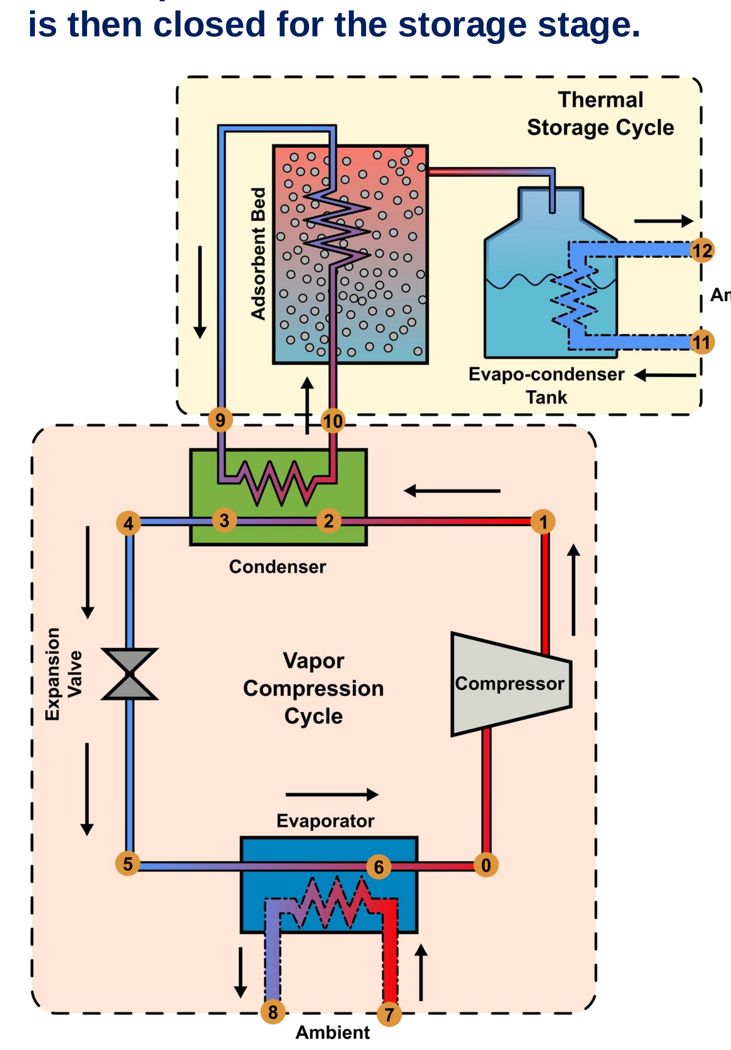
Capillary assisted evaporation model

Objective 3: System Integration

With a stable composite material and closed loop reactor design from Objectives 1 and 2, the TCES unit is integrated with an off-the-shelf heat pump for load shifting/shedding to achieve a low carbon emissions technology solution and cost savings to the end-user.

Charging

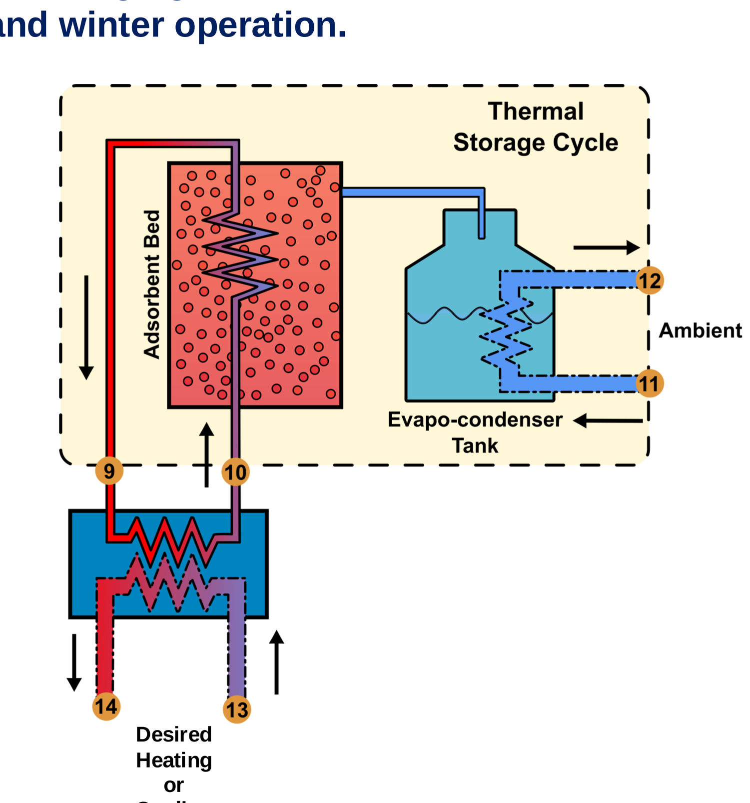
Charging is done during periods of high renewable electricity generation, low electricity cost, or low electricity demand. Heat rejected from the condenser of the heat pump is used to dehydrate the salt (endothermic reaction). The valve between the evapo-condenser tank and the salt bed is then closed for the storage stage.



Discharging

During periods of low renewable electricity generation, high electricity cost, or high electricity demand, the TCES is passively discharged. Water is evaporated from the evapo-condenser and the vapor reacts with the stored salt to hydrate it (exothermic reaction).

The integrated TCES-heat pump system can provide both heating from the salt bed, and cooling from the evaporator during discharging. This allows for both summer and winter operation.



Acknowledgements

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