Designing Thermal Energy Storage Devices using the Ragone Framework

Allison Mahvi and Jason Woods

Thermal Energy Storage Webinar

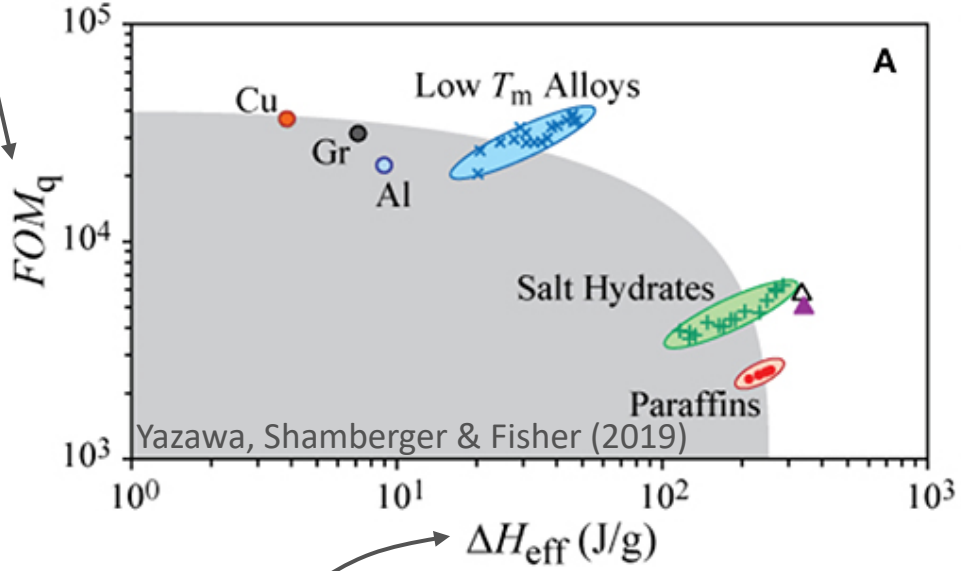
August 5, 2020

NREL/PR-5500-77581

This research has been submitted for publication
J. Woods *et al.* (2020), in review

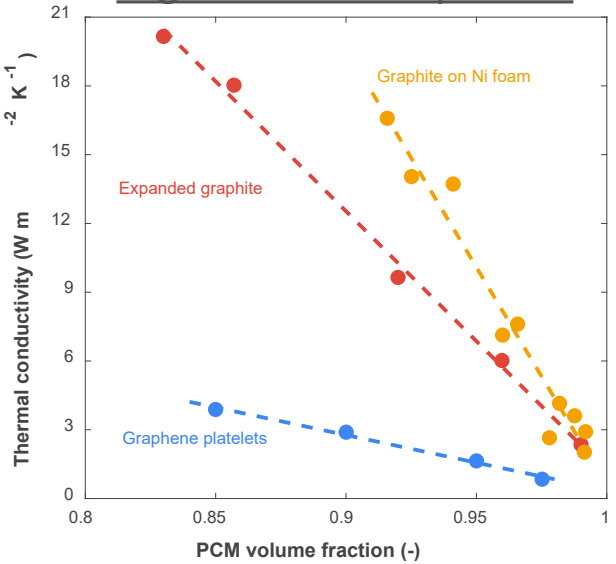
Past Work on Phase-Change Thermal Storage Materials

Proxy for power (function of **conductivity**, specific heat, **density**, **latent heat** and $\Delta T_{c\text{-}disc}$) $\sim\sqrt{k\rho L}$



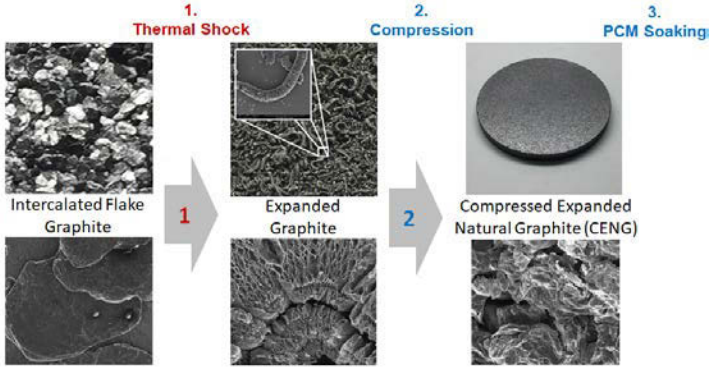
Capacity (function of **latent heat**, specific heat, and $\Delta T_{c\text{-}disc}$)

High *k* PCM composites



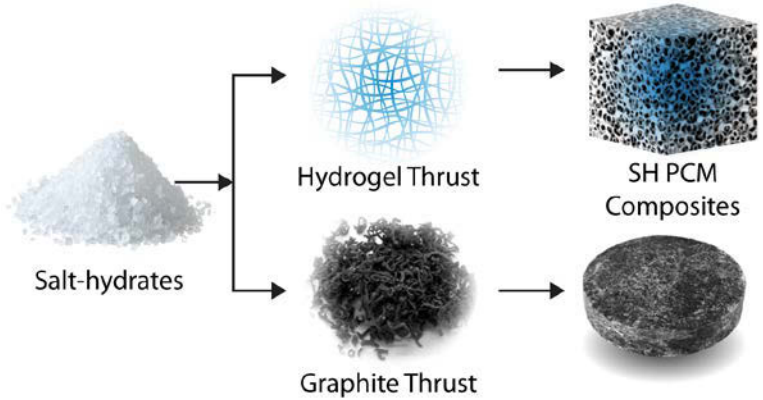
Phase Change Composites

Organic PCMs

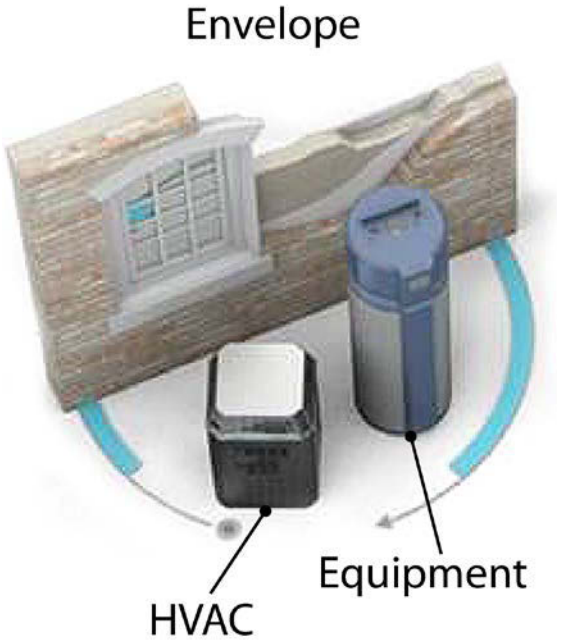


Alex Bulk *et al.* (NREL)

Salt Hydrates



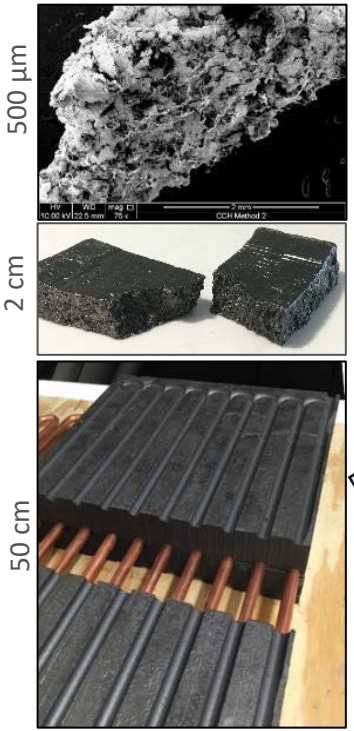
Adewale Odukomaiya *et al.* (NREL)



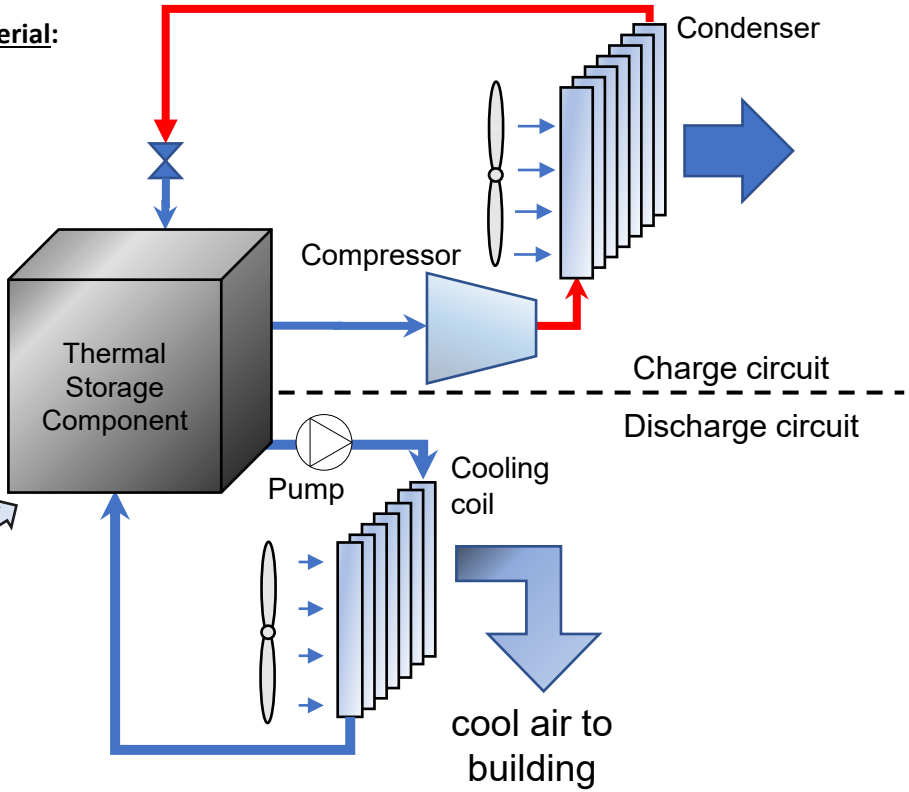
HVAC-Integrated Thermal Storage

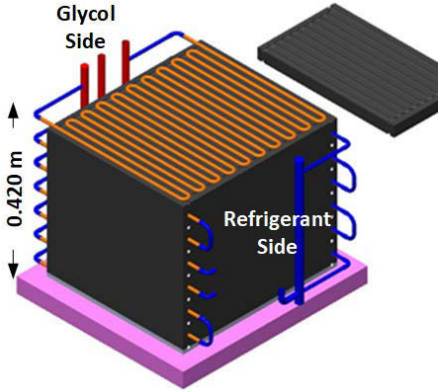
How should we design these components?

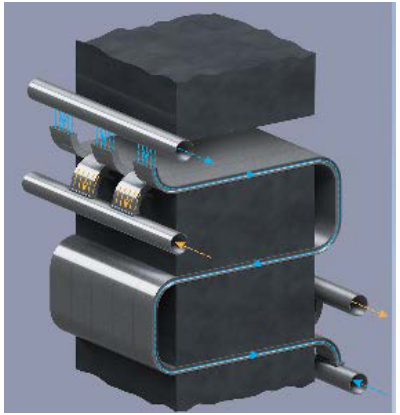
Phase-change composite material:



Anurag Goyal *et al.* (NREL)

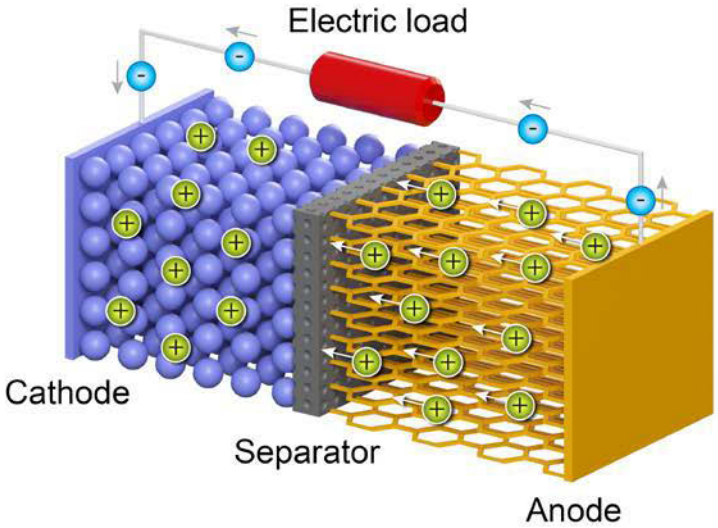




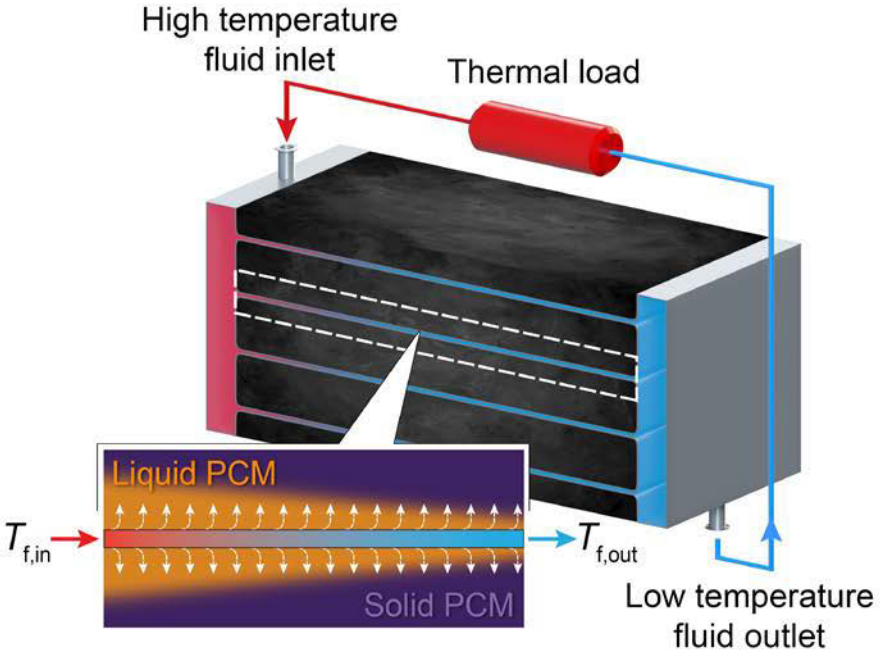


Electrochemical and Phase-Change Analogy

Electrochemical Storage

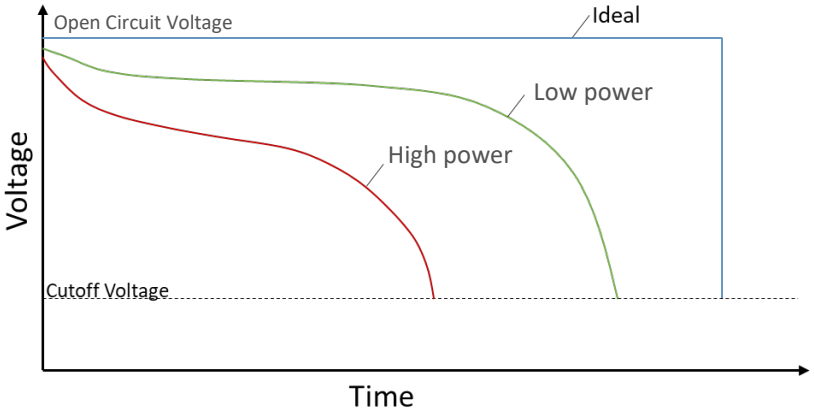


Phase-Change Storage

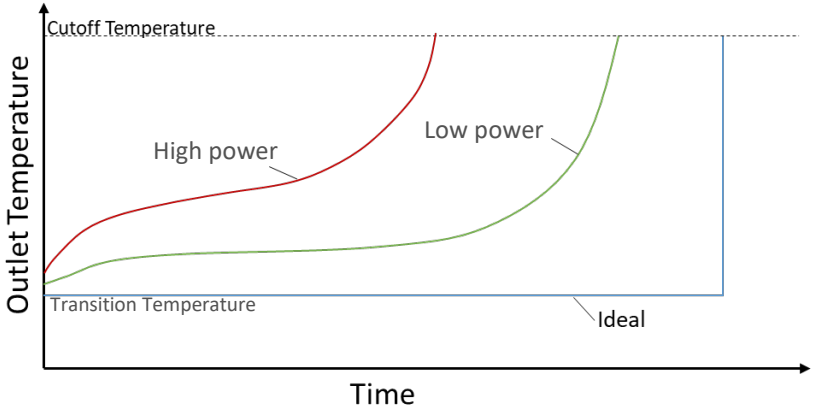


Electrochemical and Phase-Change Analogy

Electrochemical Storage



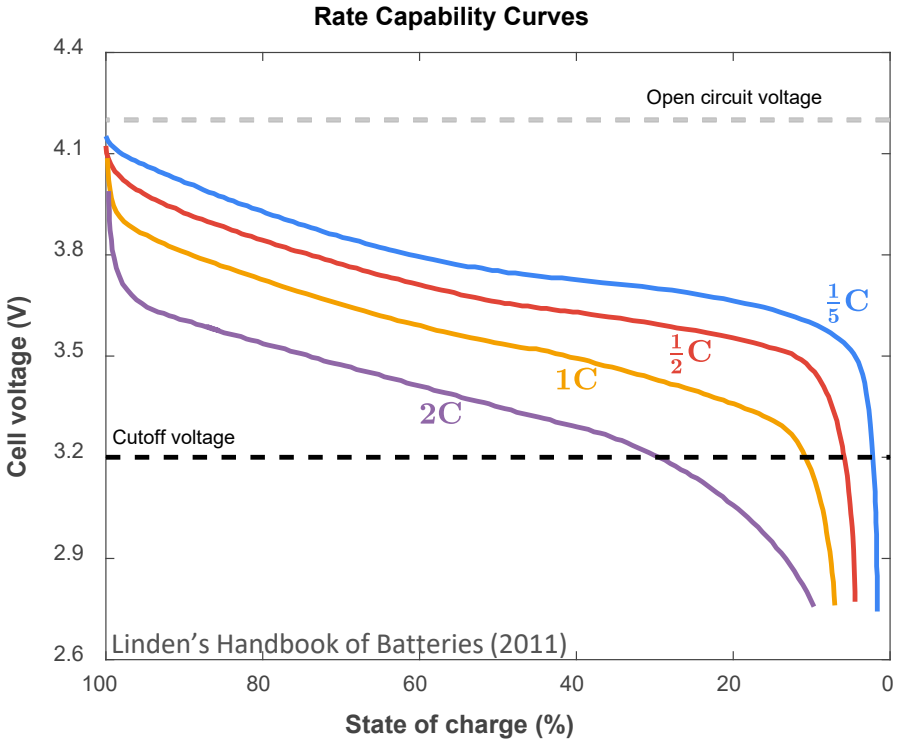
Phase-Change Storage

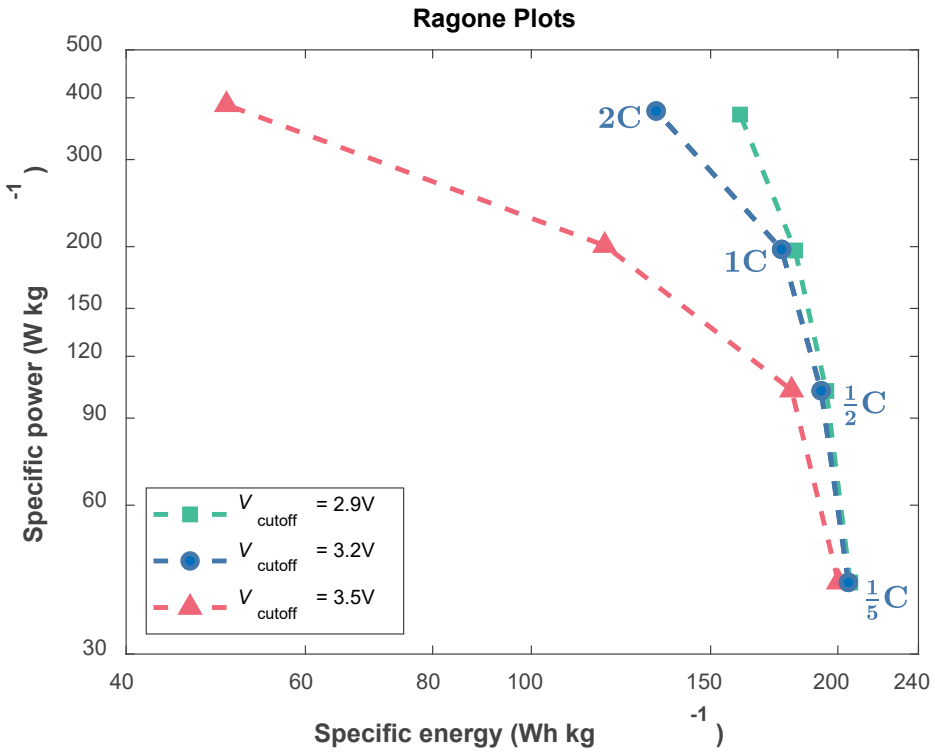


	Electrochemical storage	Phase-change thermal storage
Ideal output	Open Circuit Voltage (V)	Transition Temperature (K)
Actual output at constant current (or heat transfer rate)	$V = IR$ (V)	$T - T_t = \dot{q}R_{th}$ (K)

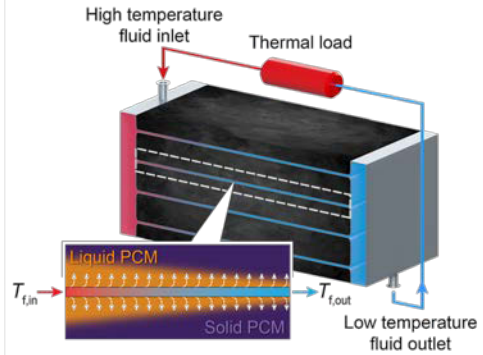
Rate Capability & Ragone Plots

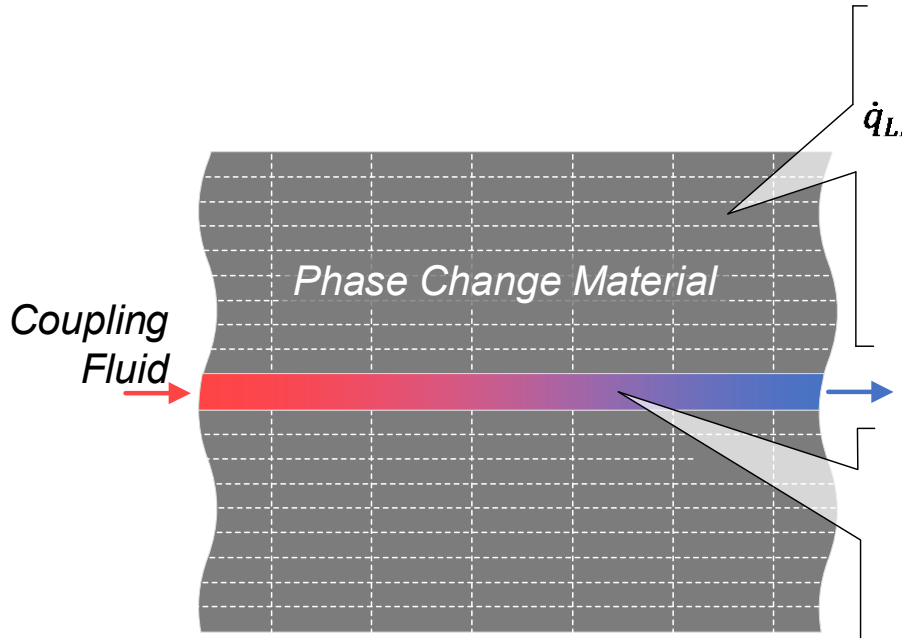
$LiCoO_2$/graphite lithium-ion battery

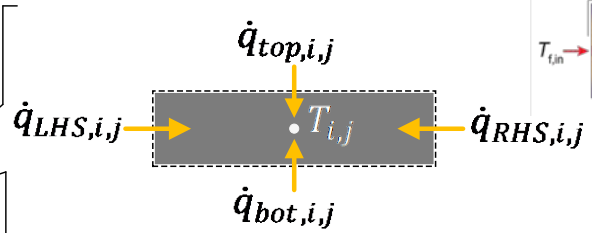




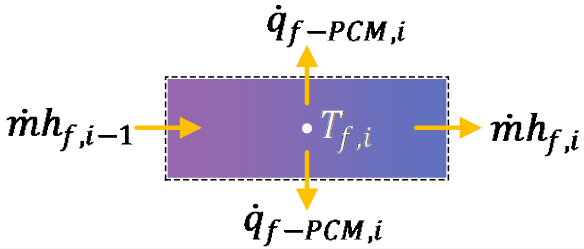
Heat Exchanger Model





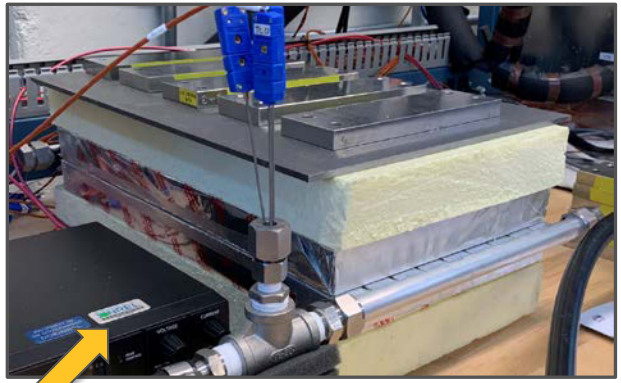


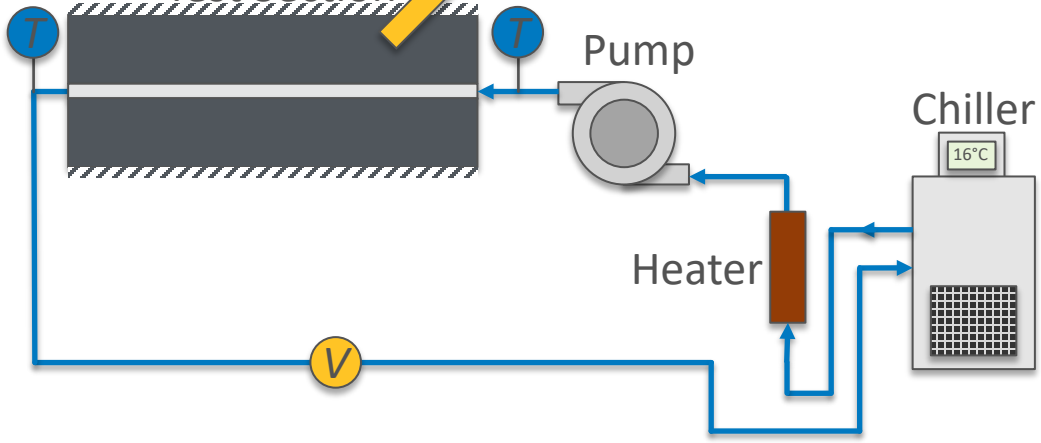
$$\frac{dh_{i,j}}{dt} = M_{node} \sum \dot{q}_{i,j}$$

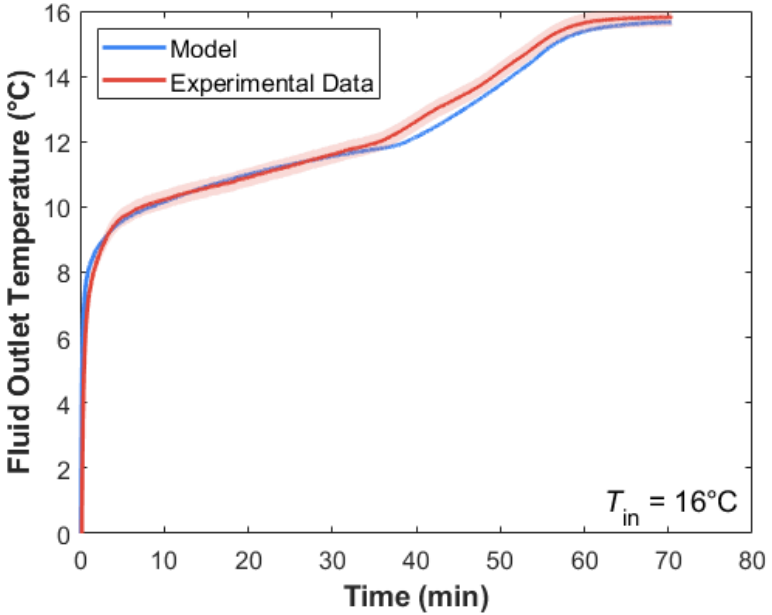


$$\left(\frac{dT_f}{dt}\right)_i = \frac{1}{M_f c_{p,f}} \left[\underbrace{\dot{m} c_{p,f} \left(T_{f,i-1} - T_{f,i}\right)}_{enthalpy\ carried\ by\ flow} + \sum \dot{q}_{f,i} \right]$$

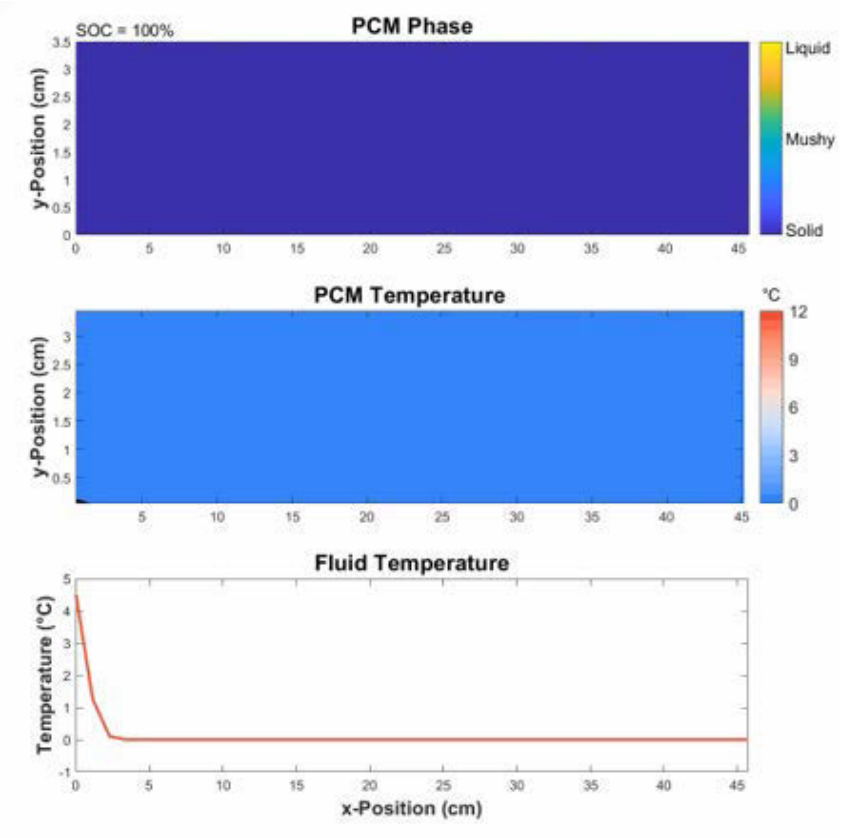
Model Validation

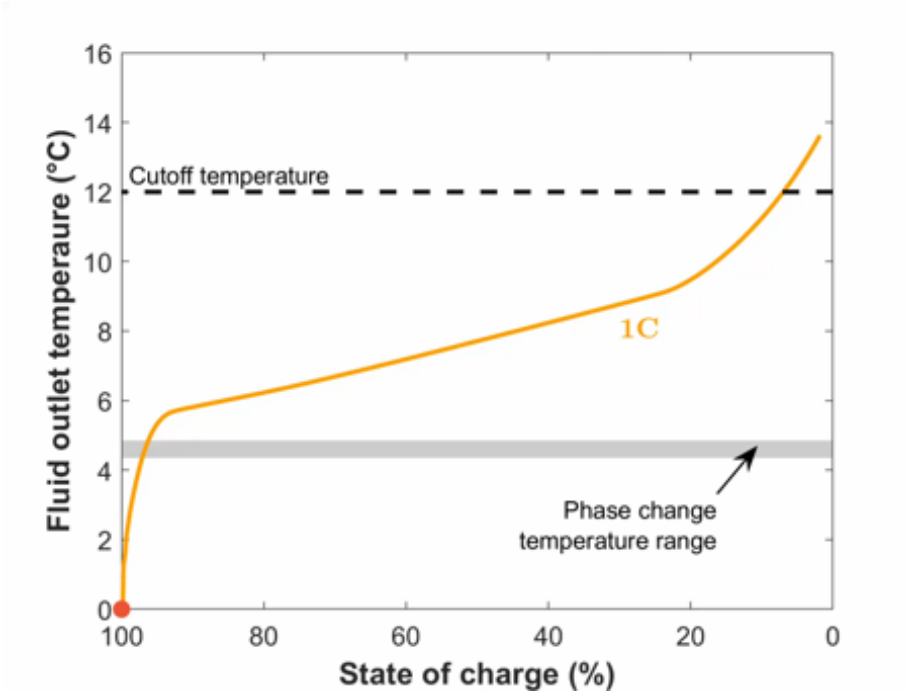




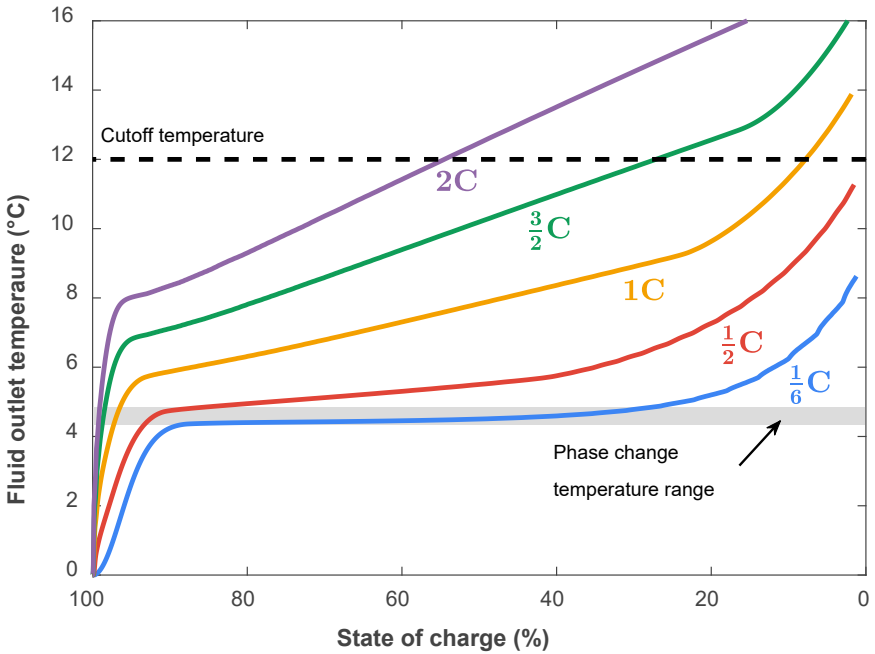


Thermal Battery Discharge (1C)





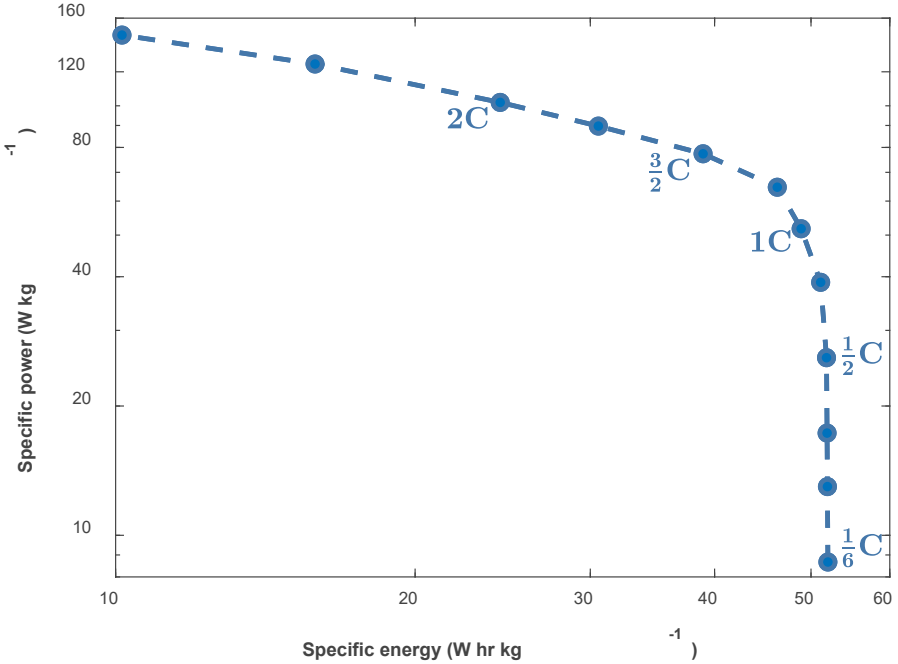
Constructing Ragone Plots



1) Generate the rate-capability curves at the desired power rate
2) Calculate how long the system can discharge before the outlet temperature is no longer useful (T_{cutoff})
3) Calculate the specific energy and power:

$$SP = \frac{\bar{q}_{f\rightarrow PCM}}{Mass} \qquad SE = \int_{t=0}^{t_{cutoff}} \frac{\dot{q}_{f\rightarrow PCM}}{Mass}\, dt$$

Constructing Ragone Plots

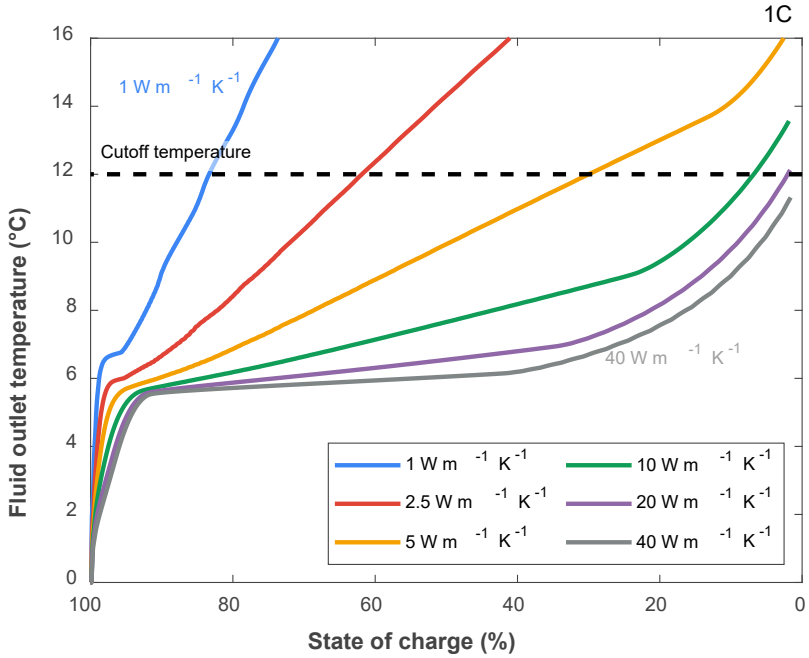


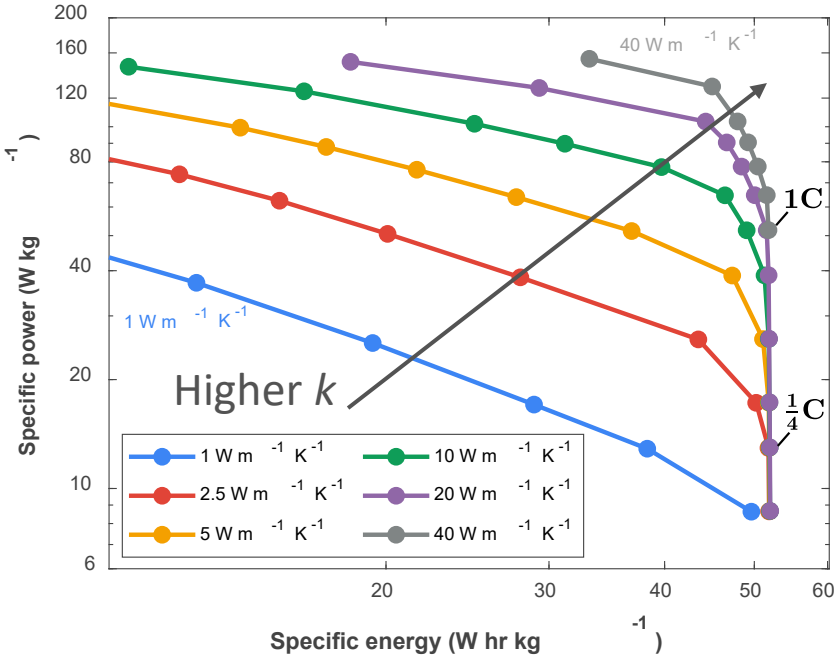
1) Generate the rate-capability curves at the desired power rate
2) Calculate how long the system can discharge before the outlet temperature is no longer useful (T_{cutoff})
3) Calculate the specific energy and power:

$$SP = \frac{\bar{q}_{f\rightarrow PCM}}{Mass} \qquad SE = \int_{t=0}^{t_{cutoff}} \frac{\dot{q}_{f\rightarrow PCM}}{Mass}\, dt$$

4) Plot the results on a log-log Ragone plot

Thermal Conductivity

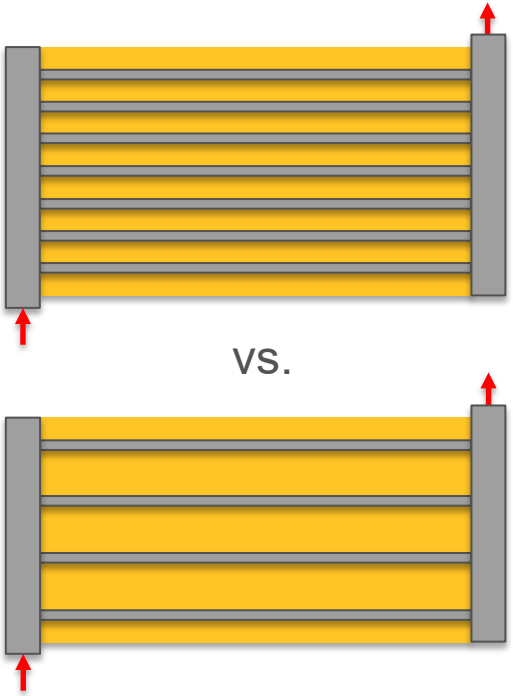


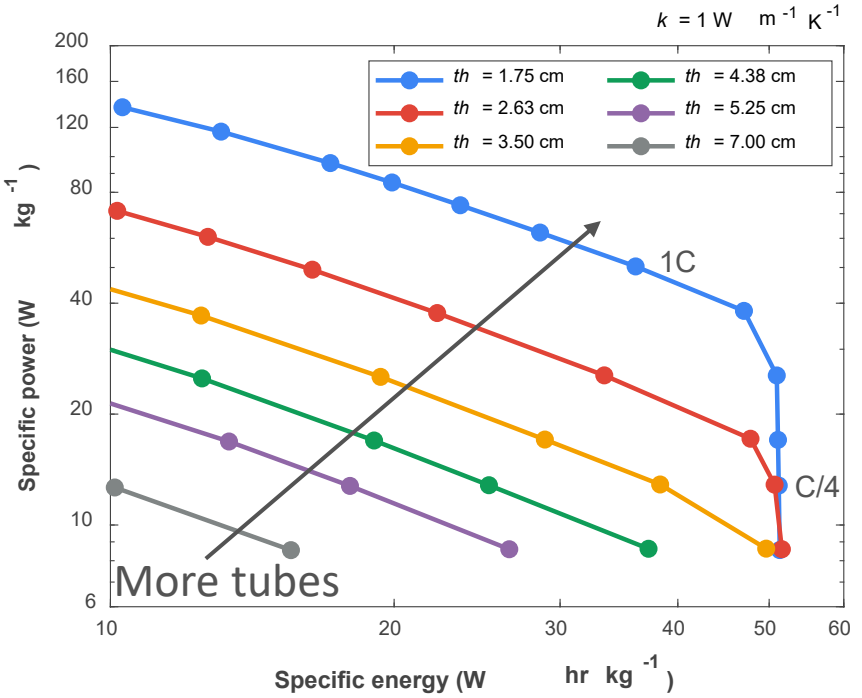


- Increasing thermal conductivity lowers fluid outlet temperatures (↑SE)
- Diminishing returns - low thermal conductivity can work fine at low discharge rates

How much does geometry matter?

Decreasing the number of tubes will lower total weight, volume and cost





Thicker PCM will increase the maximum resistances → Reduces performance

Conclusions and Future Work

- Leveraged battery research to develop rate capability and Ragone plots for thermal energy storage

<u>Can give insights into:</u>

- Component design
- Material targets for given application
- Storage efficiency and system operation

Thank you

www.nrel.gov

Allison.Mahvi@nrel.gov
Jason.Woods@nrel.gov

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Building Technologies Office. The views expressed in the presentation do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.