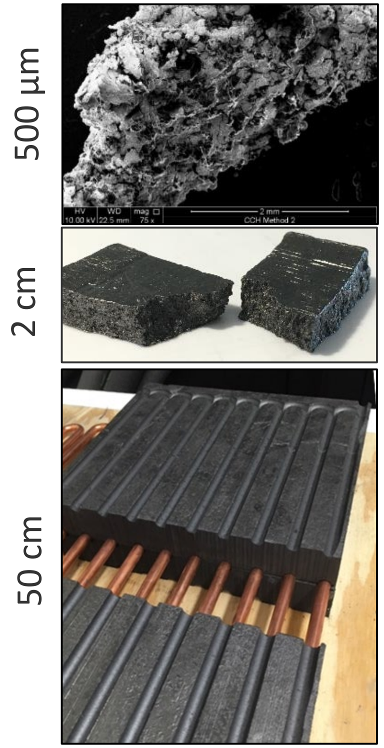
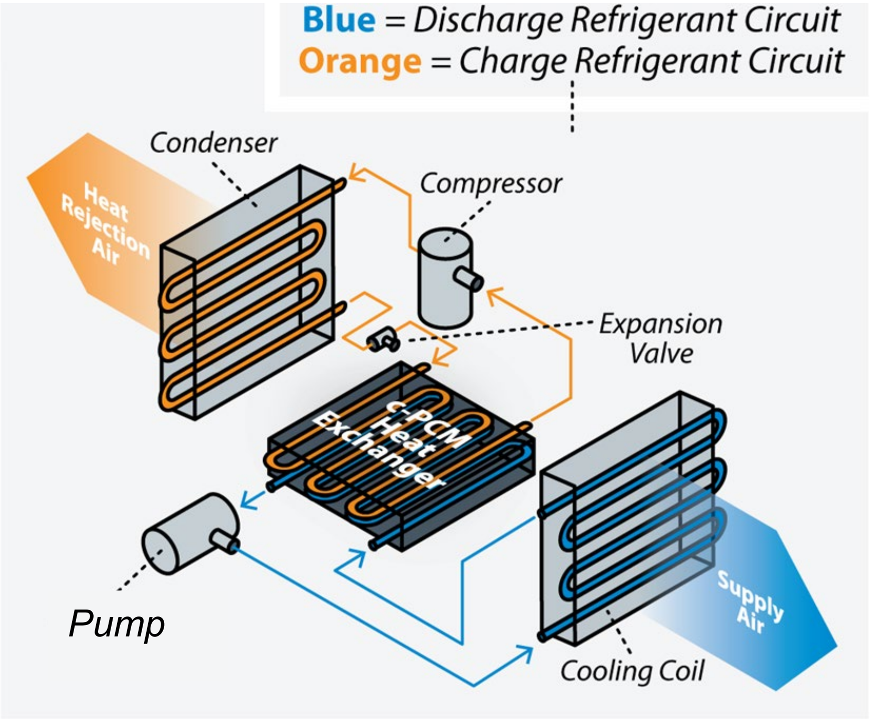
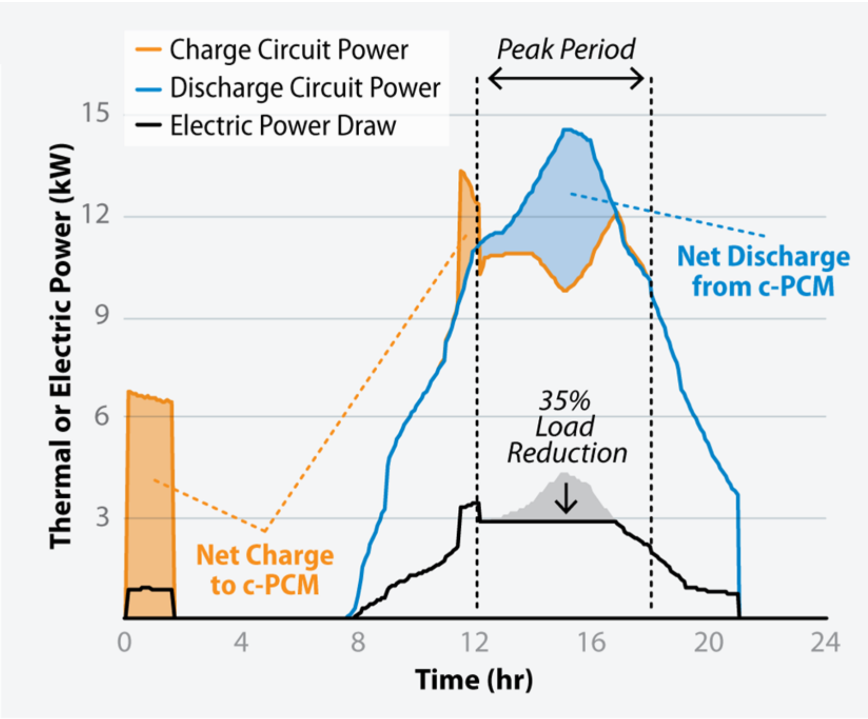
An air conditioner with composite phase change material (FY19 Technology Commercialization Fund project)

Composite phase change material:







NREL
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Project Summary

Timeline:

Start date: 2018 December

Planned end date: 2021 June

Key Milestones

1. Experiments complete on 5-ton system prototype; 06/30/2020
2. Experiments complete on next-generation thermal storage prototype; 06/30/2021

Budget:

Total Project $ to Date:

- DOE: $500,000
- Cost Share: $550,000

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Key Partners:

NETenergy
Emerson
Trane Technologies

Project Outcome:

This project will develop prototypes of a new hybrid air conditioner with embedded thermal energy storage.

It focuses on packaged air conditioners, which has limited thermal storage options despite it being the largest space cooling market in the US.

The goal is to develop an affordable and cost-effective thermal storage technology that enables load flexibility and reduced carbon emissions.

Team

NREL



Dr. Jason Woods (PI) **Dr. Allison Mahvi** **Dr. Anurag Goyal**


Eric Kozubal **Dr. Wale Odukomaiya**

Materials characterization
Thermal storage design/modeling
Laboratory characterization

NETenergy


Dr. Said Al-Hallaj **Mike Pintar**

Material synthesis
Thermal storage sub-system build
Commercialization

Emerson


Dr. Rob Comparin **Dr. Juan Catano Montoya**

Vapor-compression components build
Market analysis
Manufacturing cost analysis

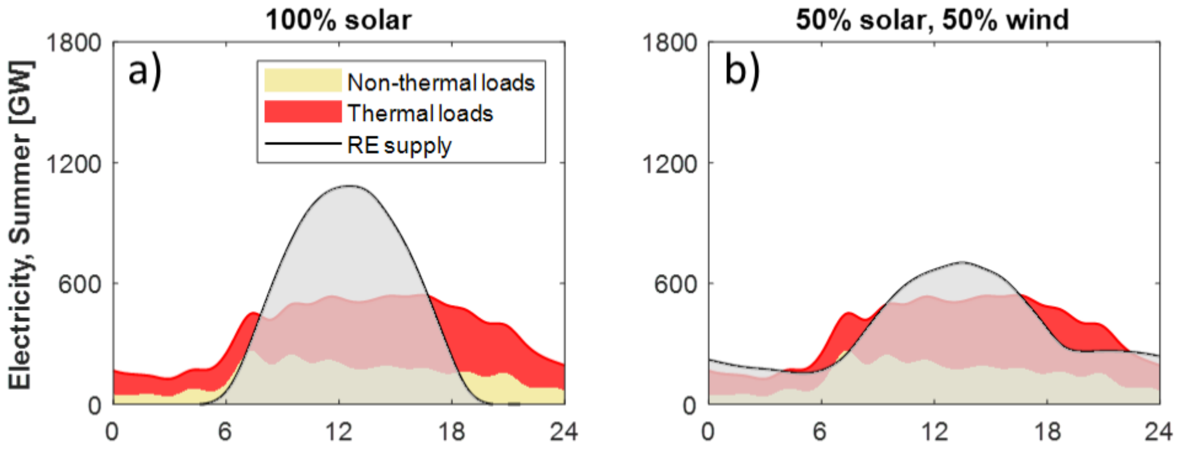
Trane


Manlio Valdez **Scott Smith**

Support on vapor-compression build
Support on market analysis

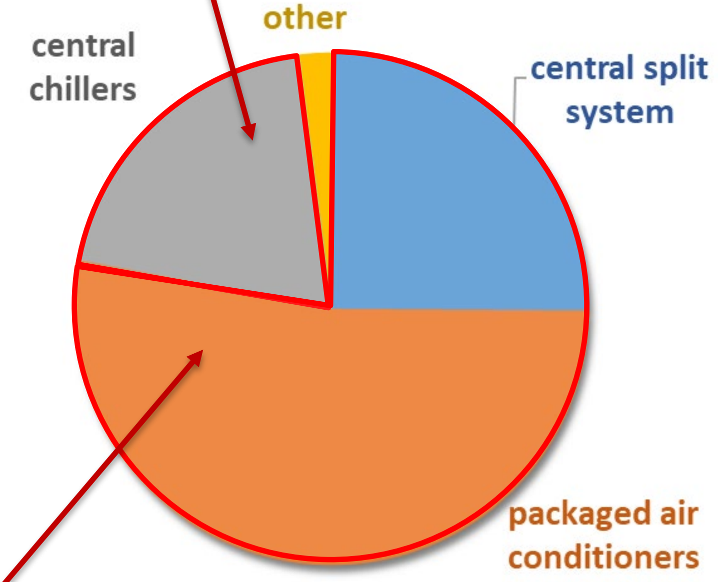
Challenge

- 77% of electricity is used at buildings
  - 50-60% of that is for thermal loads
    - Much of this is mismatched with renewable-electricity generation



US electricity generation for a 100% renewable grid compared to building thermal and non-thermal loads.

Existing ice and chilled water storage are often cost-effective for these applications



Fraction of US commercial floorspace cooled by HVAC type [1]

There's no available solution for split and packaged systems (>80% of US floor space).

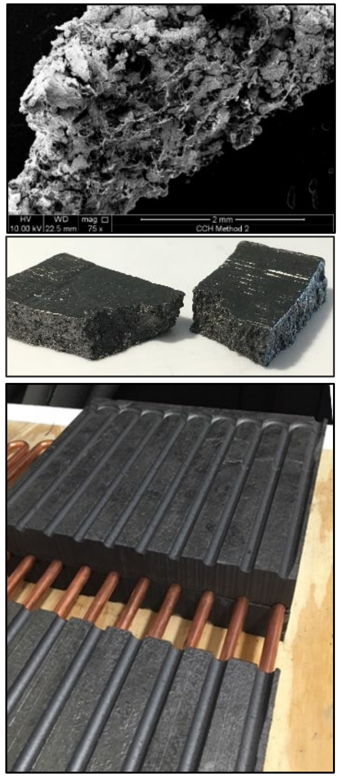
[1] *US EIA, 2012. Commercial Building Energy Consumption Survey, Table B41. Cooling equipment, floorspace.*

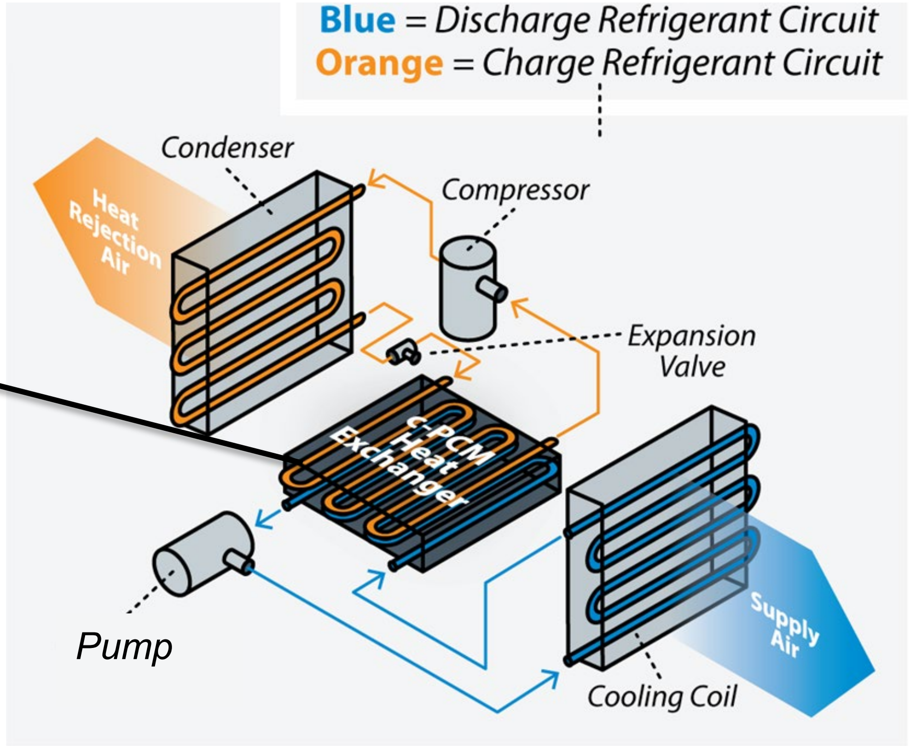
Approach

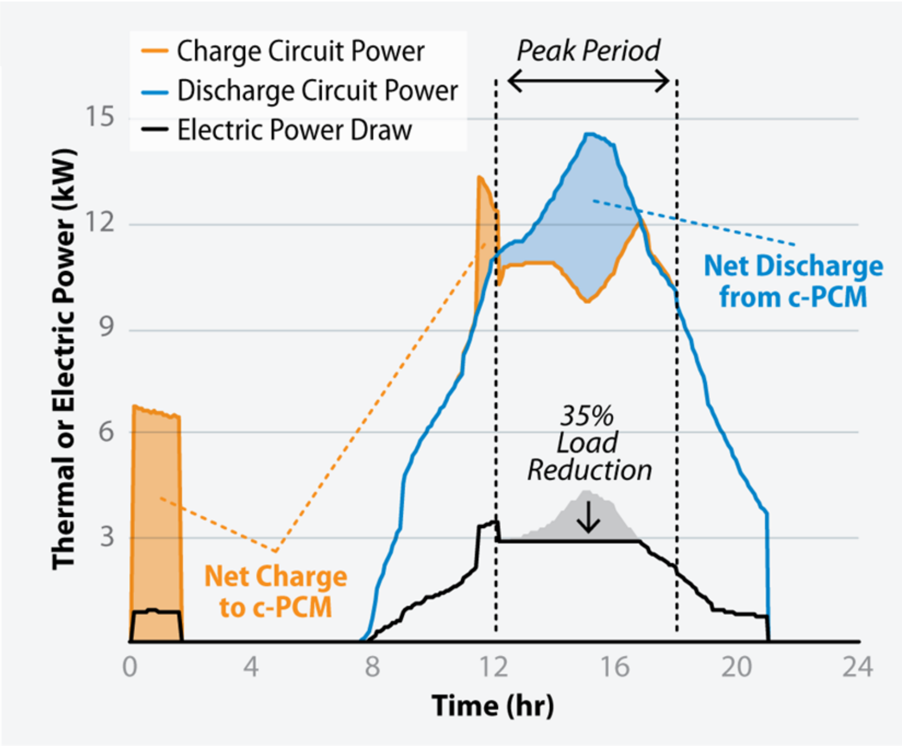
A “hybrid” air conditioner where the thermal storage shaves the peak cooling demand, while the compressor operates at a reduced capacity.

<u>Composite phase change material</u>:

500 µm
2 cm
50 cm





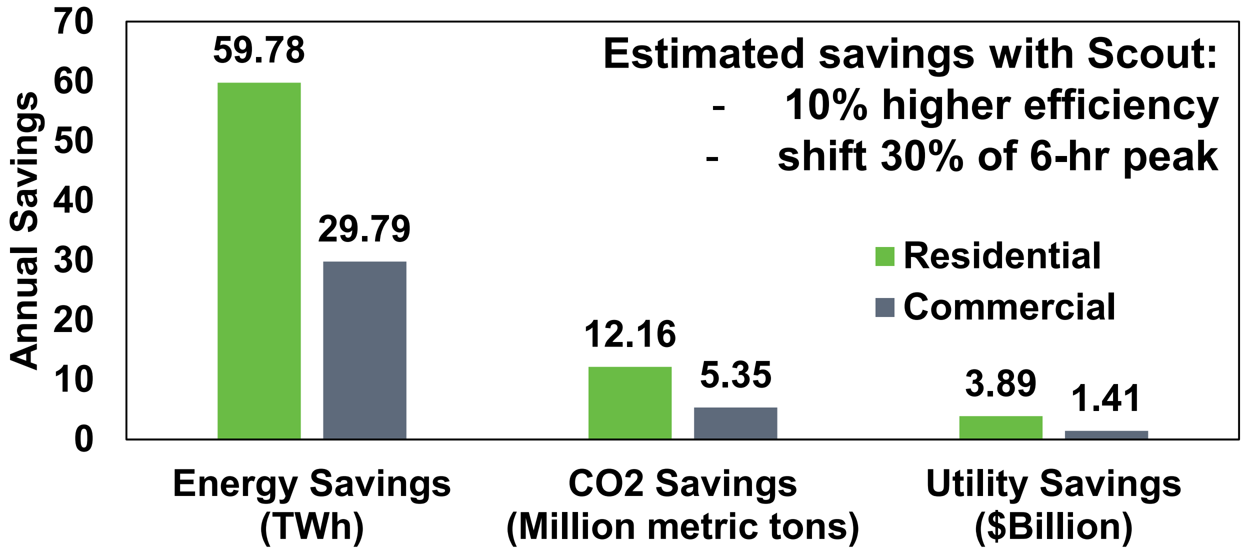


Impact: Creating a packaged air conditioner with TES that can succeed in the market

	Rooftop unit integrated ice system (previous state-of-the-art)	Proposed hybrid air conditioner integrated with c-PCM heat exchanger
Initial Cost	**5x higher cost** than standard RTU	**50% higher cost** than standard RTU
Weight	**2,700 kg** in separate box	**350 kg** added to RTU
Performance relative to baseline non-TES air conditioner		
Electric demand (kW)	**90% lower**	**35%–45% lower**
Electricity use (kWh)	**10% higher**	**10% lower**

Previous approaches are way too heavy and expensive for packaged systems, which condition >80% of US floor space.

Significant potential energy, CO_2, and monetary savings.



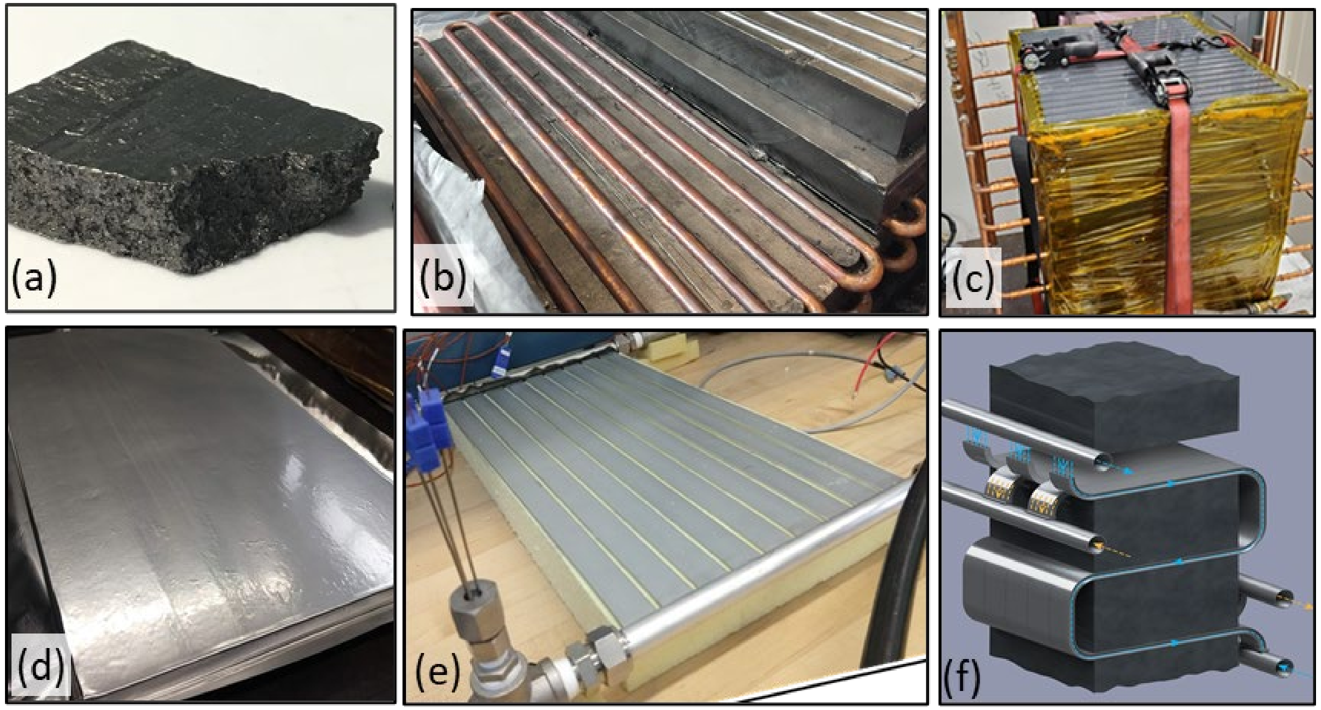
Progress

<u>Modeling, design, and experiments:</u>

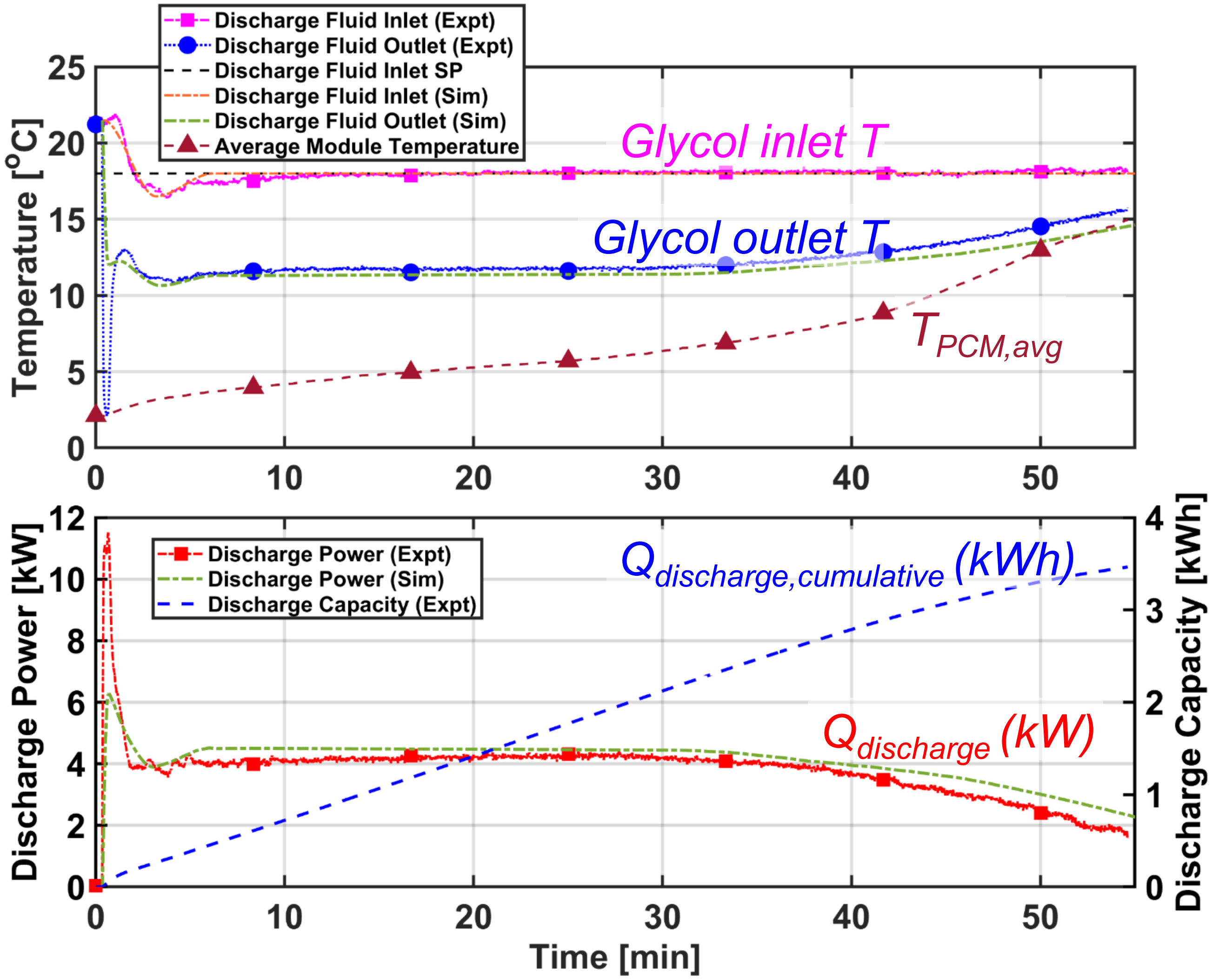
- TES sub-system: 1st generation, 1 tonh, glycol-glycol
- Air conditioning system: 1st generation TES, 6-tonh, refrigerant-glycol
- TES sub-system: 2nd generation, 1/10th tonh, glycol-glycol

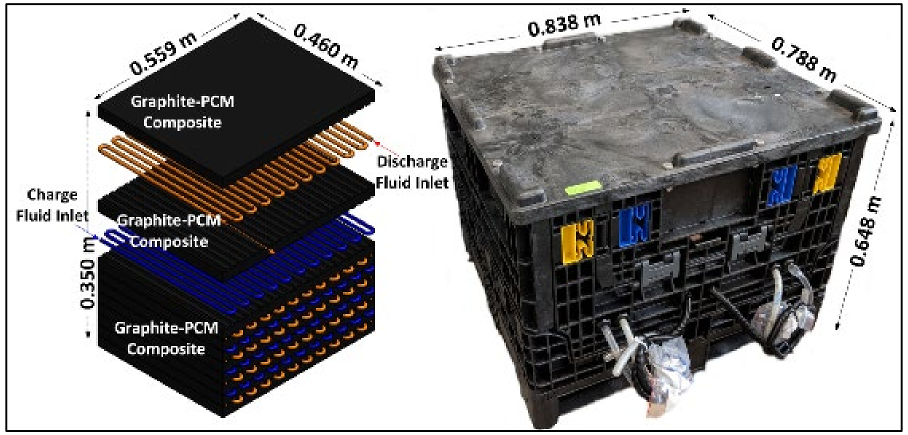
1st generation TES

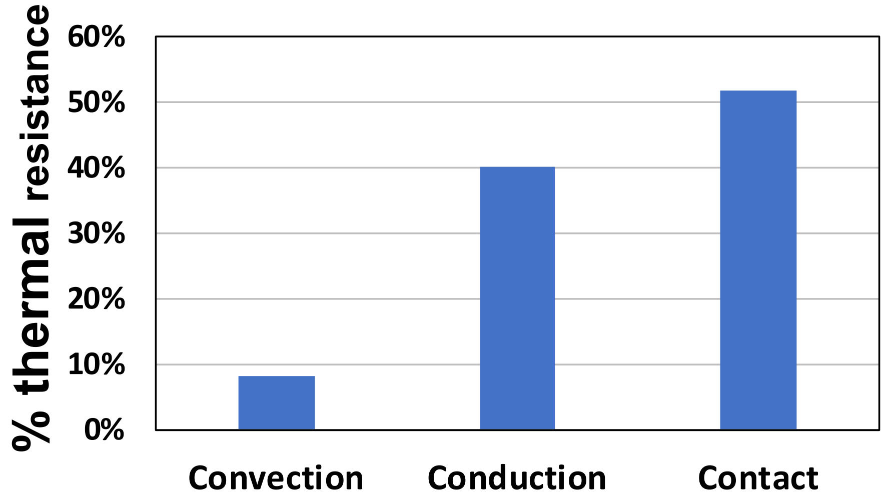
2nd generation TES



Progress: 1st generation, 1 tonh prototype







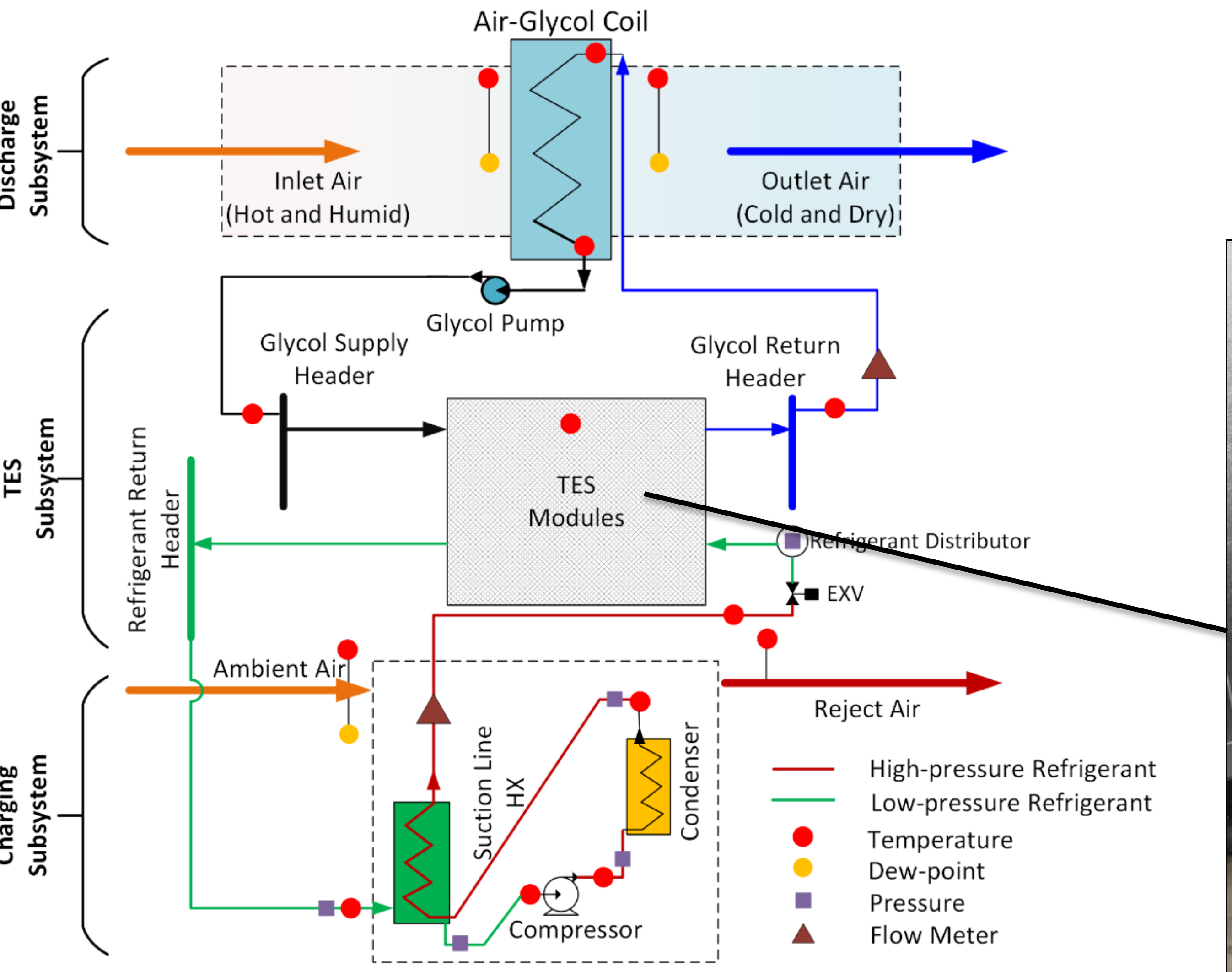
Finite-volume numerical model used to estimate contact resistance. Estimated at >50% of the overall resistance.

Progress: 1st generation, full-system

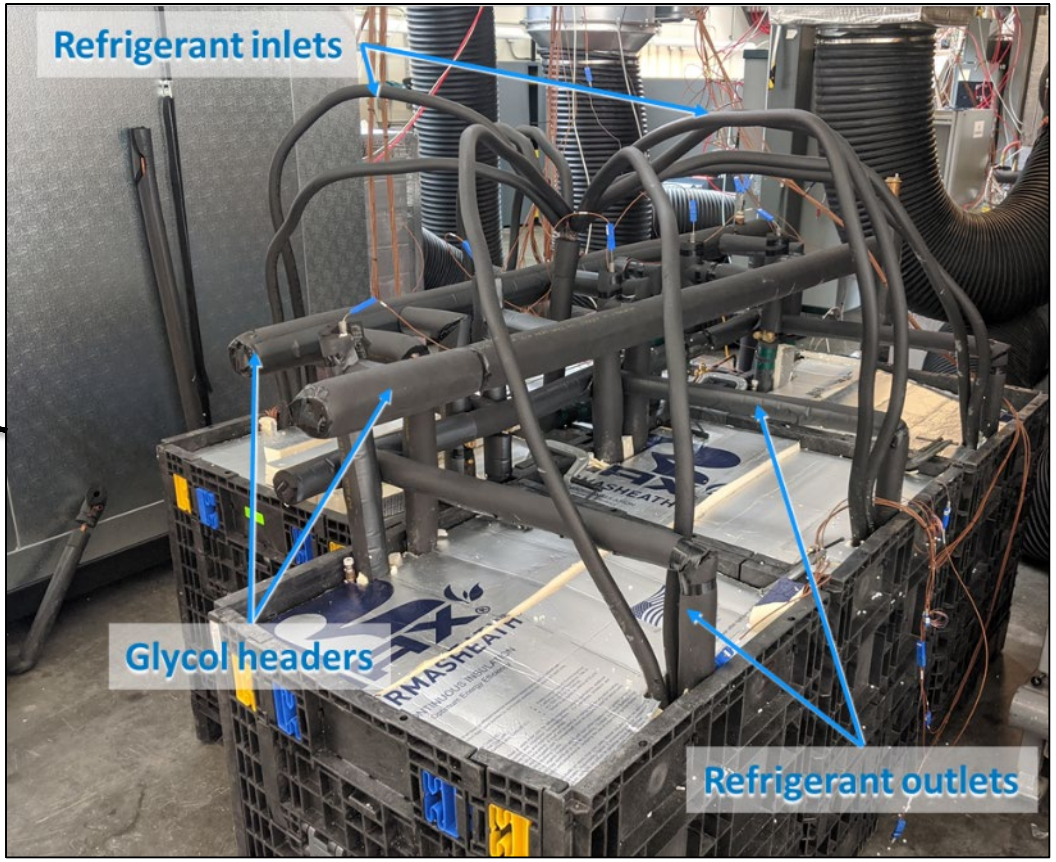
Charge subsystem – Condensing unit from Trane, modified by Emerson

Discharge subsystem - Built by Emerson

Progress: 1st generation, full-system



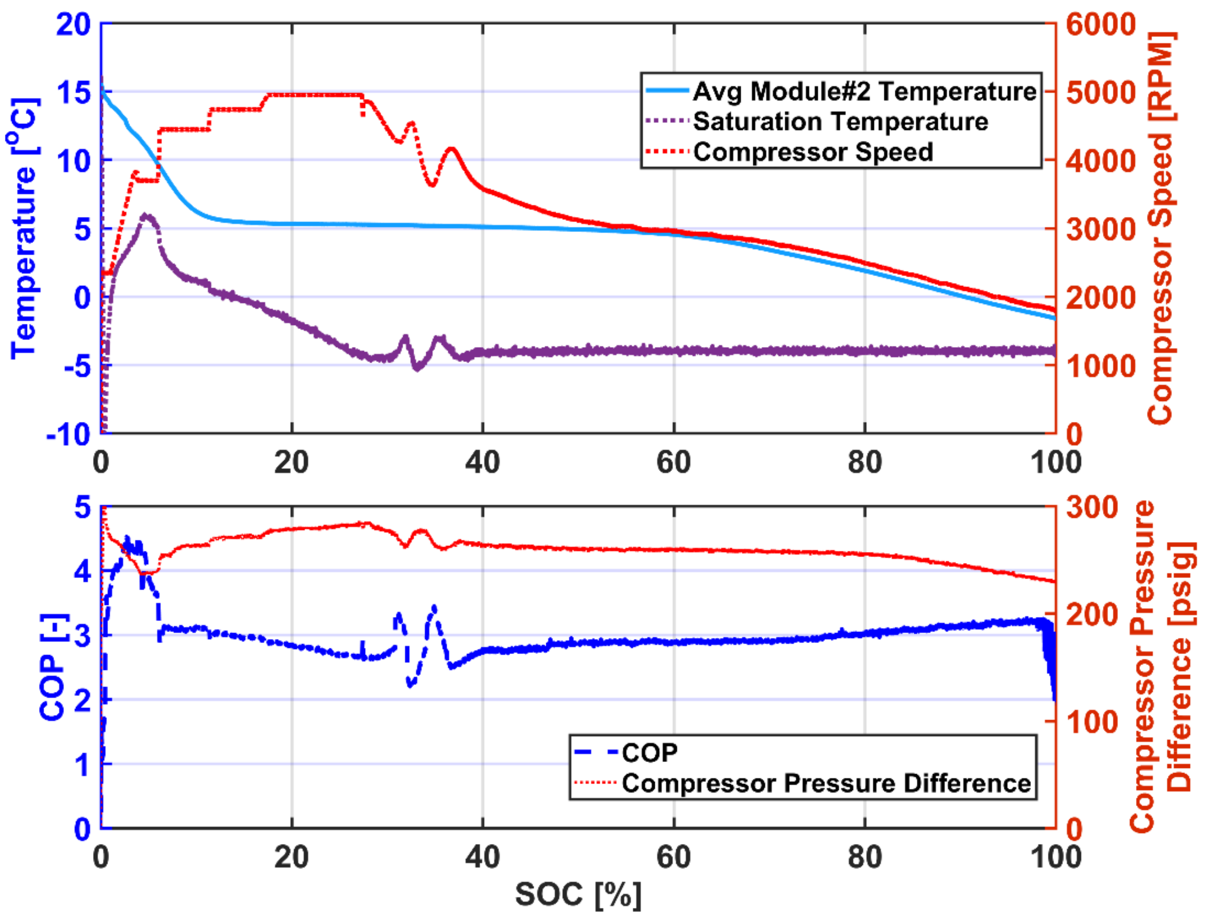
System installed at NREL ~ November 2019, with support from Emerson team



Progress: 1st generation, full-system

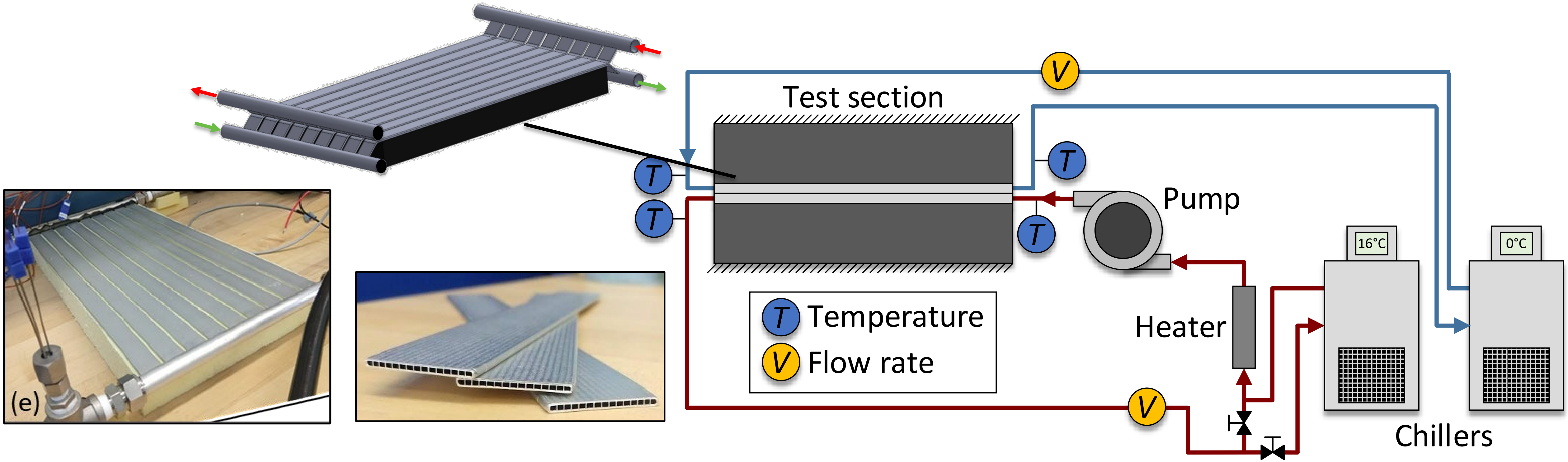
Key findings:

- Controls were effective at modulating charge/discharge and keeping superheat at TES outlet near 0 °C (suction-line HX ensures adequate superheat into compressor).
- PCM leak observed due to expansion on solid-liquid phase change.
- Contact resistance a critical problem with serpentine design.
- Need to eliminate refrigerant migration at end of charge cycle, which leads to self-discharge of TES.

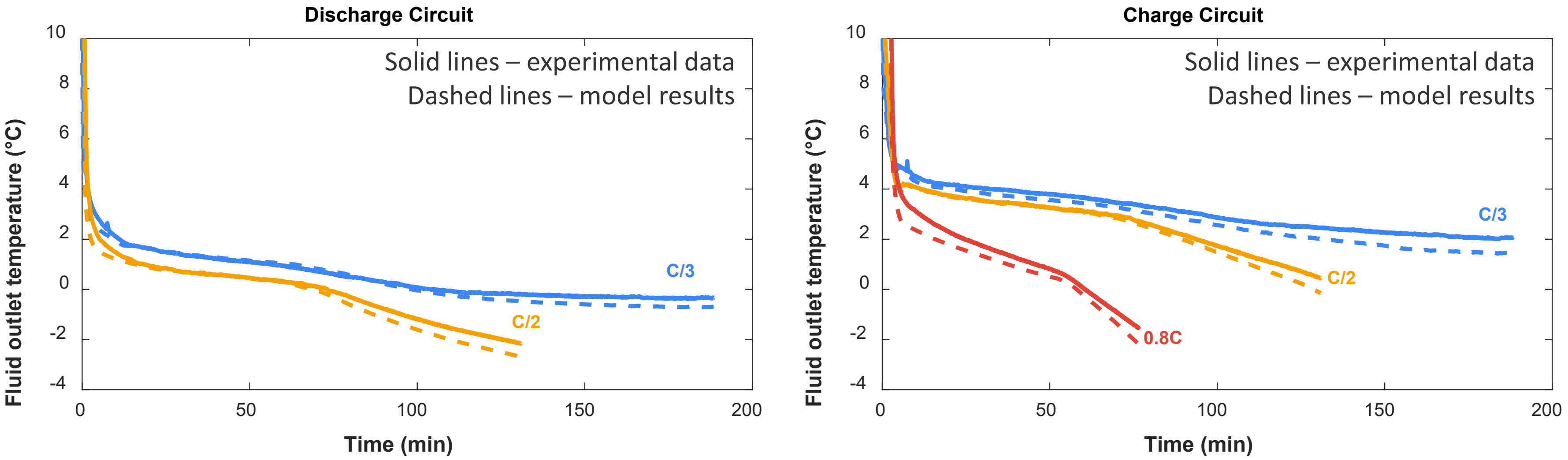


Progress: 2nd generation, 1/10th tonh

Material	Cycling performance – mass loss
Aluminum foil	0.7% decrease after 1 cycle
Mylar film	4.3% decrease after 2 cycles
Sealed Mylar bag	0% decrease after ~60 cycles

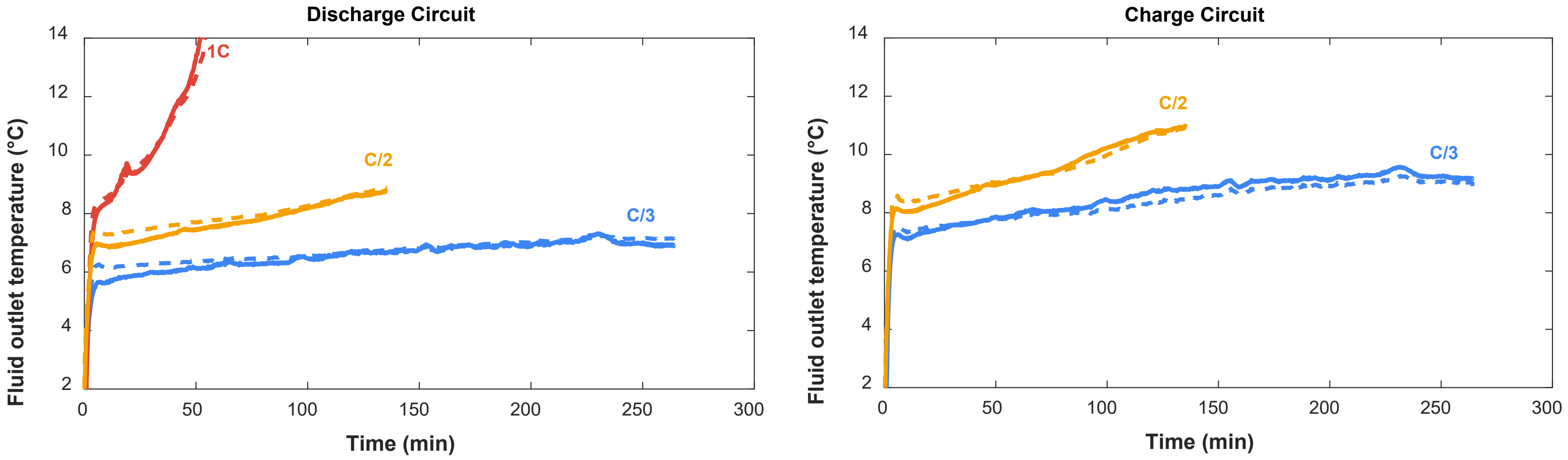


Progress: 2nd generation, 1/10th tonh



Net charging

Avg error = 0.34 ºC
Max error = 1.16 ºC



Net discharging

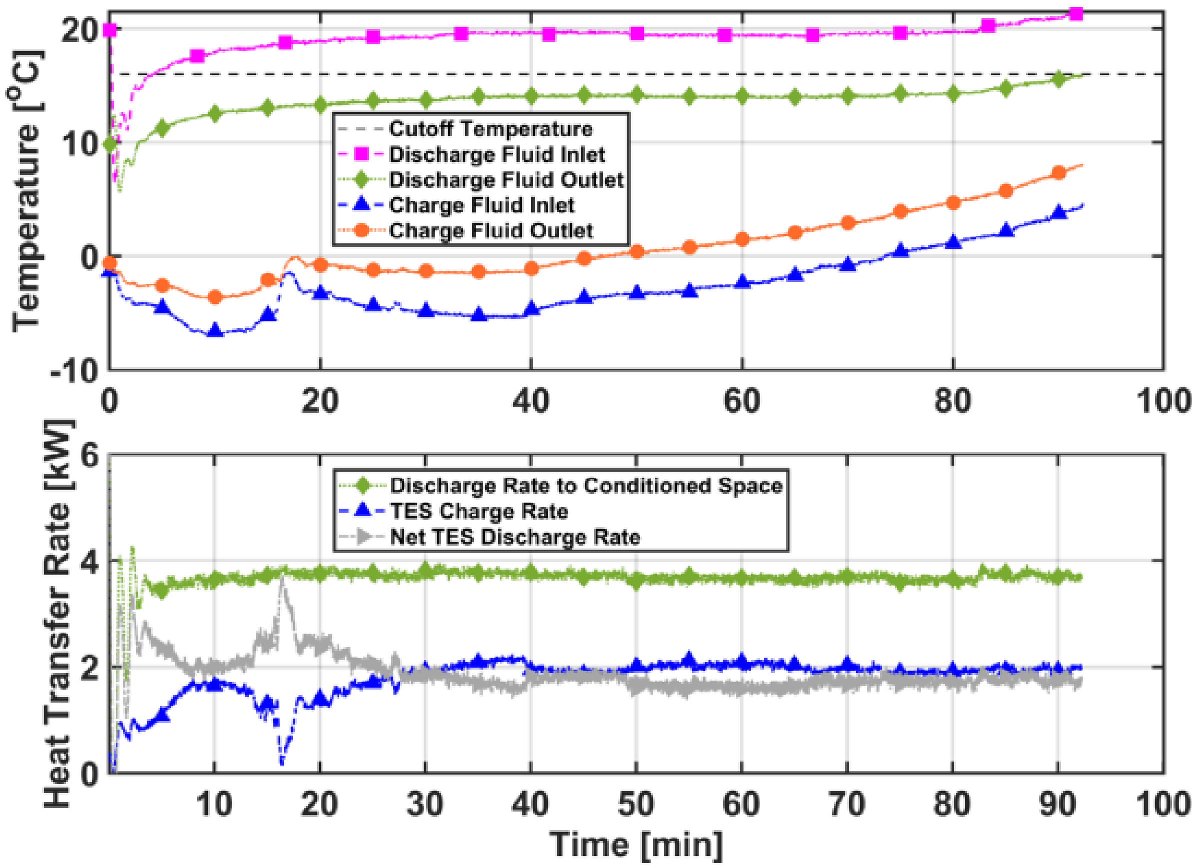
Avg error = 0.22 ºC
Max error = 0.67 ºC

Woods, J., A. Mahvi, A. Goyal, E. Kozubal, A. Odukomaiya, R. Jackson. Rate capability and Ragone plots for phase change thermal energy storage. Nature Energy. 6(3) (2021) 295-302.

Progress: 2nd generation, 1/10th tonh

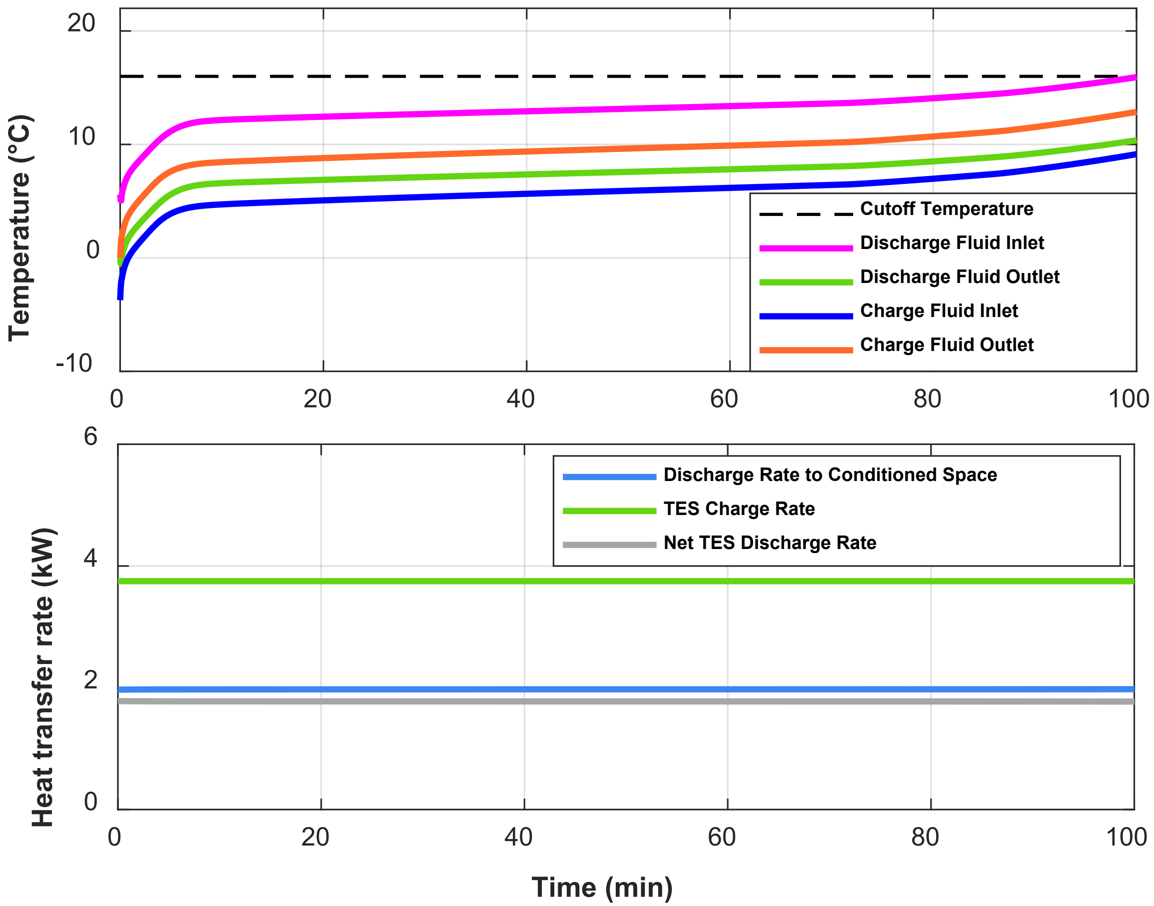
1st generation – Copper tube

Experimental data from Goyal et al. (2021)



2nd generation - Microchannel

Results using current microchannel model

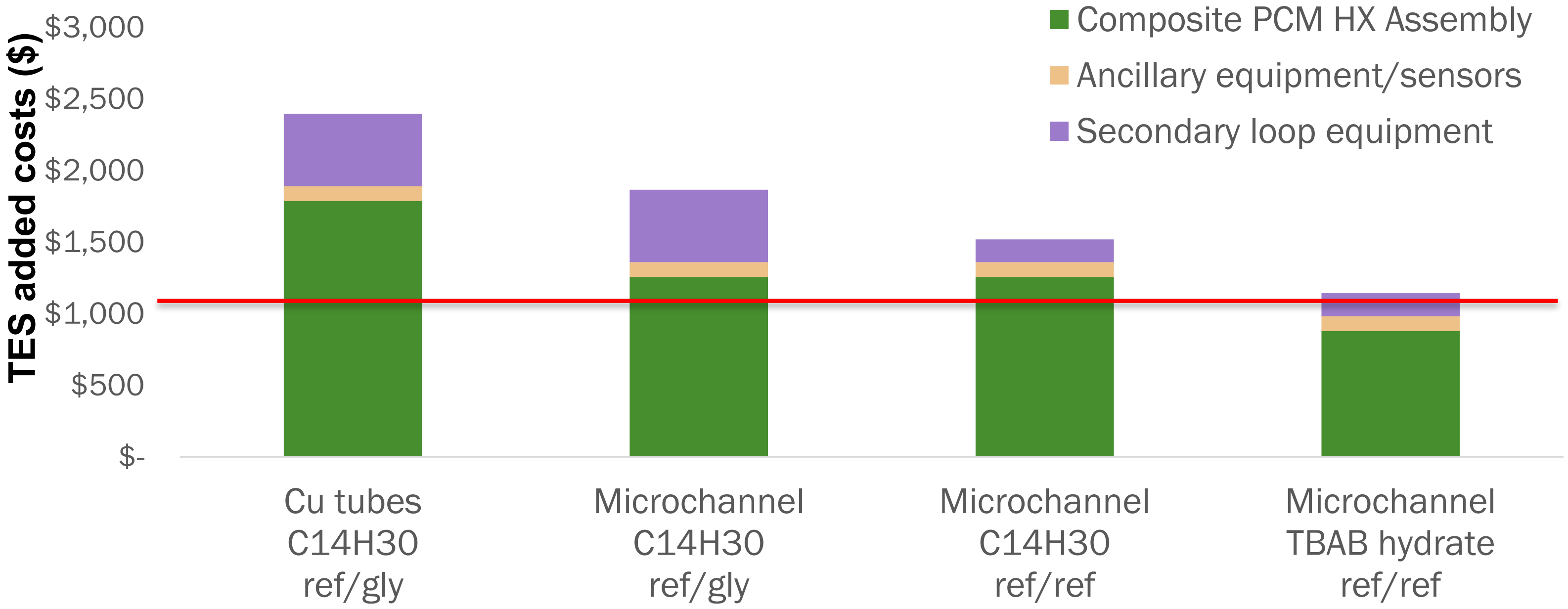


Goyal, A., E. Kozubal, J. Woods, M. Nofal, S. Al-Hallaj. Design and performance evaluation of a dual-circuit thermal energy storage module for air conditioners. Applied Energy. 292 (2021) 116843

Progress: Energy and demand savings point to manufacturing cost targets

Climate	TES design	PCM T_t	Fixed-speed peak power	TES hybrid peak power	kW % change	Fixed-speed energy	TES hybrid energy	kWh % change
			kW reduction			kWh reduction		
		°C	kW	kW	%	kWh	kWh	%
Los Angeles	Serpentine	4.5	5.59	2.9	-48%	34.8	33.1	-5%
	Microchannel	4.5		2.4	-57%		28	-20%
	Microchannel	10.0		2.4	-57%		26.4	-24%
Baltimore	Serpentine	4.5	4.87	3.1	-36%	38.4	40	4%
	Microchannel	4.5		2.5	-49%		33	-14%
	Microchannel	10.0		2.4	-51%		29.9	-22%

Added costs for 5 tonh storage
In a 5-ton system



cost target to achieve 3-yr payback with existing utility rates

* This considers only the building owner's costs; it does not include utility incentives or other benefits to the utility.

Stakeholder Engagement & next steps

- **Trane and Emerson: Customer discovery workshop**
    - Focus on installers, building managers – make sure this technology looks familiar
    - Approach companies with large national accounts (i.e., that own a lot of buildings)
- **Exelon corporation (electric utility)**
    - NETenergy working with Exelon electric utilities for future demonstration in their territory

Next steps

- **Scale-up of 2nd generation thermal storage design**
- **Integration of scaled-up 2nd generation design with vapor compression air conditioner for laboratory experiments and eventual field demonstration**
- **Development of technology that uses the c-PCM for cooling and heating**

Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: NREL received $500,000 from DOE Office of Technology Transitions in December 2018. NETenergy provided $175,000 in cost share (funds to NREL) and NETenergy, Emerson, and Trane provided $425,000 of in-kind cost share.

Variances: The project was completed as planned.

Cost to Date: All funds have been spent

Budget History					
Start date: Dec. 2018 FY 2019 (past)		FY 2020 (past)		End date: June 2021 FY 2021 (current)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$500,000	$165,000	$0	$245,000	$0	$140,000

Project Plan and Schedule

Project start: December 2018
Project end: June 2021

Completed work
Future work

Completed milestones	
FY19Q1	Composite PCM experimental results
FY19Q2	Experimental results on composite PCM heat exchanger
FY19Q3	Progress update on HVAC system design
FY19Q4	System built and integrated with system-scale composite PCM HX
FY20Q1	System installed and commissioning of 5-ton prototype
FY20Q2	Progress update on 5-ton system experiments
FY20Q3	Report on system experiments
FY20Q4	Experimental data on next-generation HX prototype
FY21Q1	Draft article on next-gen TES prototype, experiments and modeling
FY21Q2	Building model and analysis for updated system design
FY21Q3	Final Report for Project TCF-18-15537