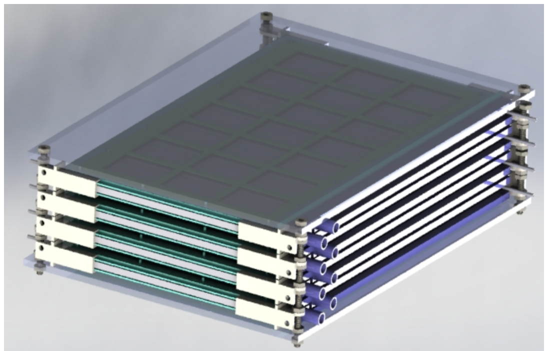
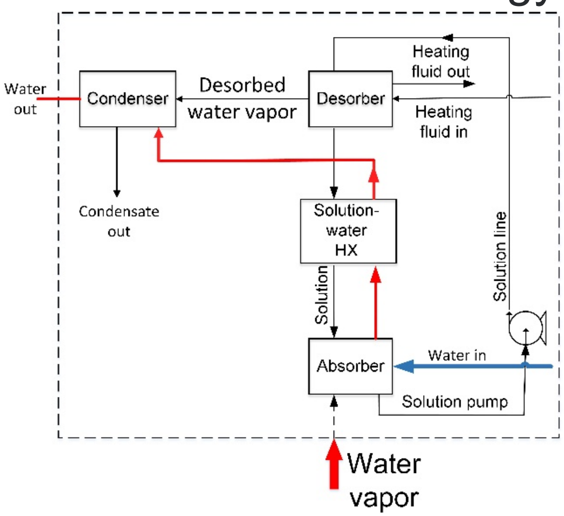
A Combined Water Heater Dehumidifier and Cooler (WHDC)

2017 Building Technologies Office Peer Review



Membrane Technology



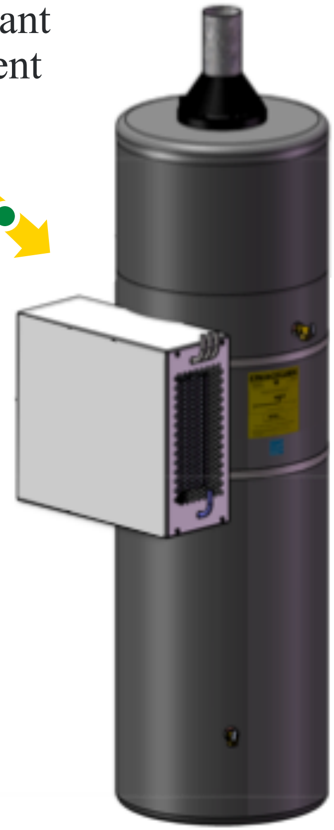
Novel Cycle Architectures

No desiccant entrainment

High air velocity

Four UF inventions

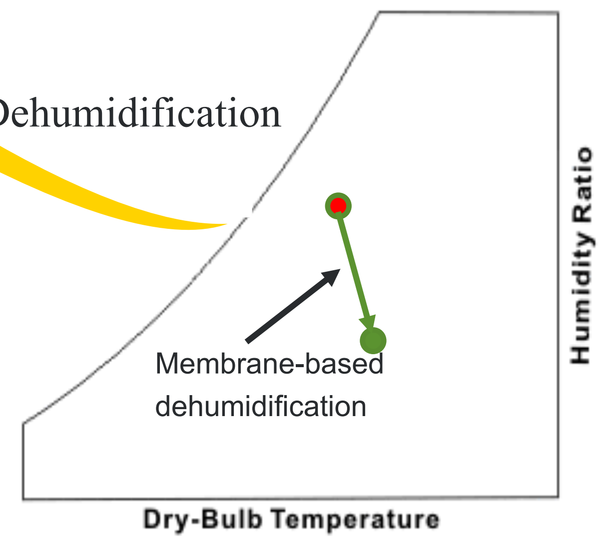
Compact size



Green fluids

No crystallization

Dehumidification



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University of Florida

Project Summary

Timeline:

Start date: 10/01/2014

Planned end date: 07/31/2017

Key Milestones

Proof-of-concept

COP=1.6 to support EF > 1; 9/30/2015

Budget:

Total Project $ to Date:

- DOE: $999,993
- Cost Share: $111,111

Total Project $:

- DOE: $999,993
- Cost Share: $111,111

Key Partners:

ORNL

Project Outcome:

- Develop a low-cost gas-fired water heat pump to meet the DOE MYPP 2020 target
  - Enabled by 4 inventions
- Double the energy factor (EF) from current 0.62 to 1.2
  - Major savings in water heating energy consumption in-line with the DOE 2030 goal of reducing building energy consumption by 50%
- Additional dehumidification benefits; relevant to >50% of installations (inside house and basement)

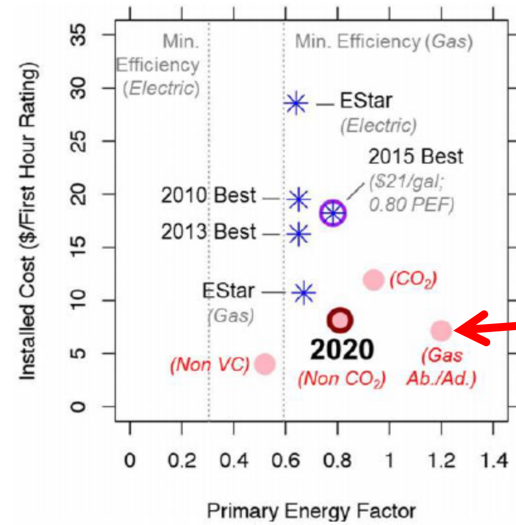
Purpose and Objectives

Problem Statement: >50% of water heaters shipped are gas-fired (~4 Millions/year)

- ➢ There is NO gas-fired water heat pump in the market

Target Market and Audience: A regional solution applicable to 3/5 of US climate zones: the mixed-humid, hot-humid and marine zones accounting for 54% of the US housing market

- ➢ Added dehumidification benefit for >50% of installations



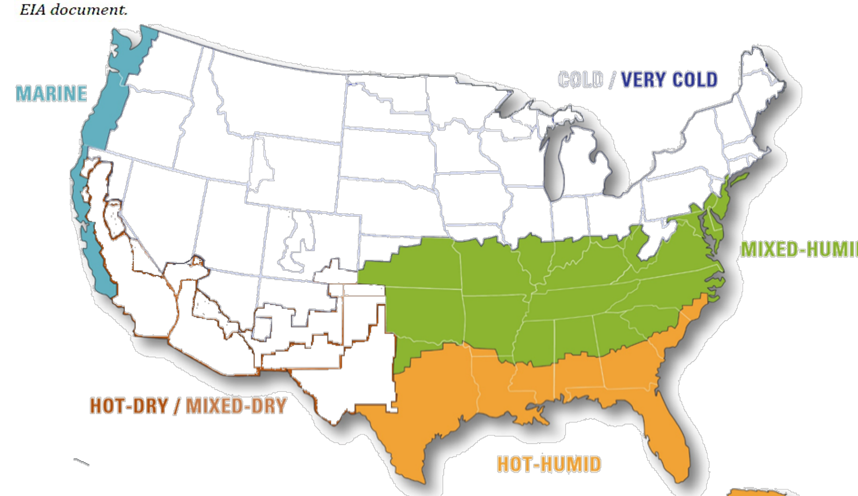
2020 R&D targets are shown for:

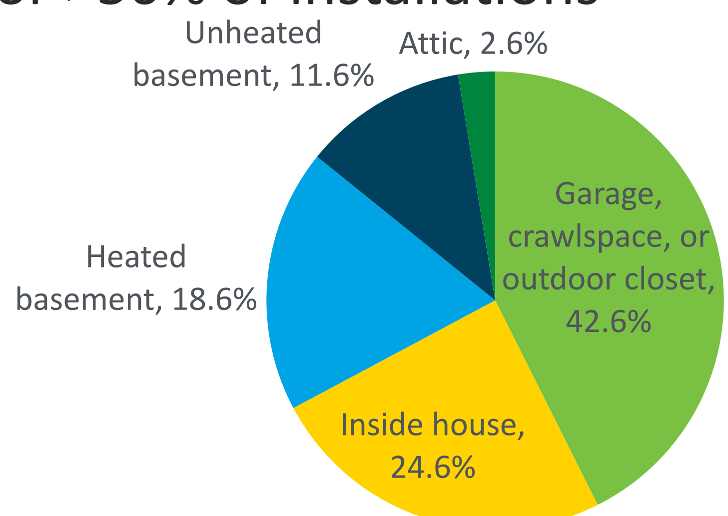
Electric
- Non-CO_2 vapor compression
- CO_2 vapor compression
- Non vapor compression

Gas-Fired
- Absorption/Adsorption

† Installed costs are generally taken from EIA, "Updated Buildings Sector Appliance and Equipment Costs and Efficiencies," April 2015 (available at https://www.eia.gov/analysis/studies/buildings/equipcosts/). Exceptions are made for equipment not described by this EIA document, or where more accurate recent market data are available.

* Baseline is assumed to be the 2013 Best in Market residential electric resistance water heater from the above EIA document.





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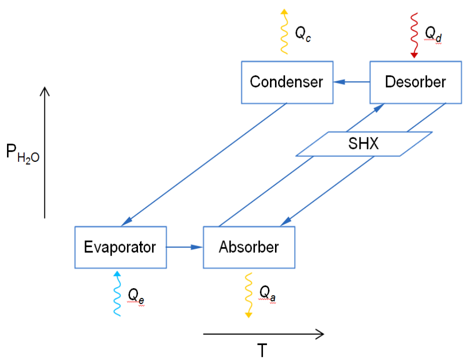
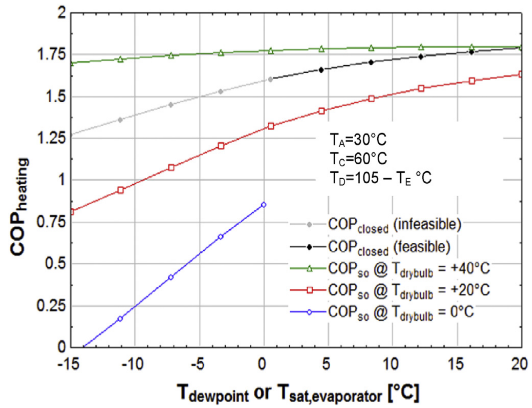
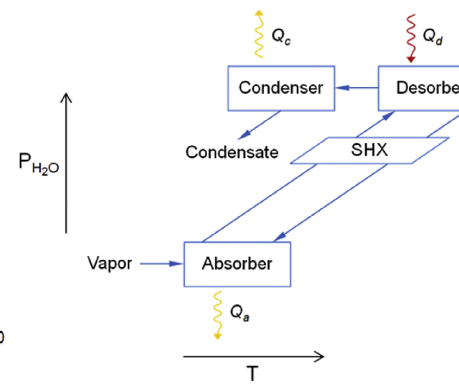
Approach: A New Class Absorption Cycle

Closed System

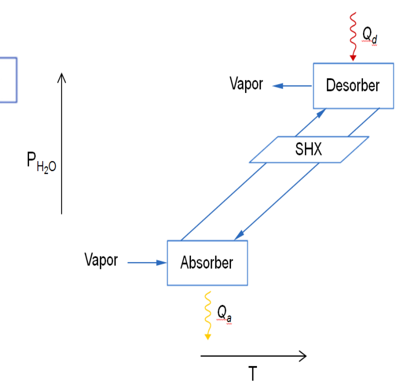




Semi-open System



Open System

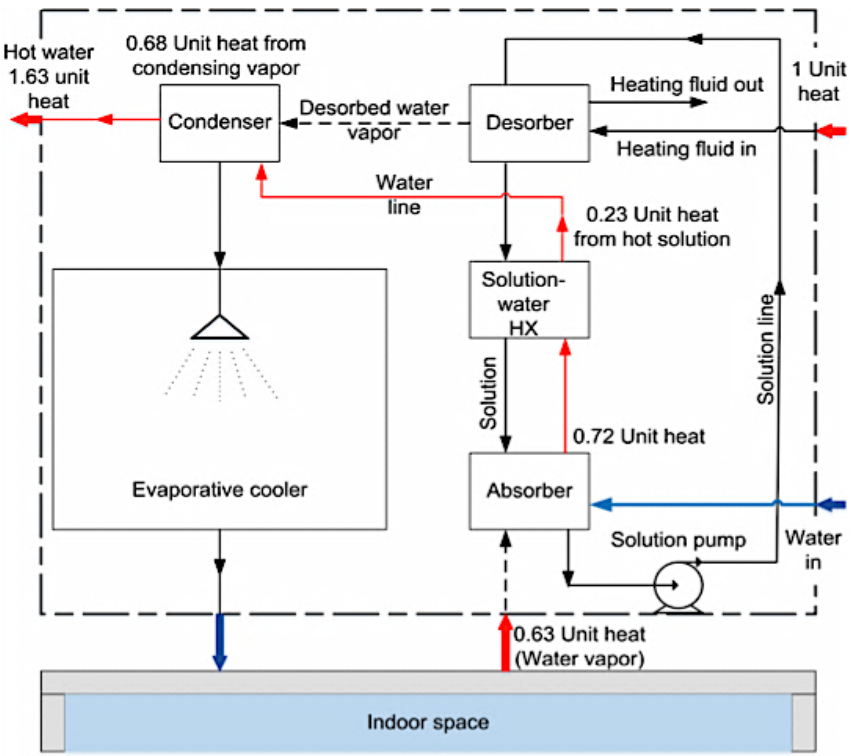


Component	Traditional closed sorption	Semi-open sorption
Vessel materials	Carbon steel	Polymer
Solution pump	Hermetic, with hydrostatic plus 1–15 kPa (0.15-2.17 PSI), variable head	Nonhermetic with constant hydrostatic head
Vacuum requirements	Periodic vacuum pumping	None
Vessel pressure rating	Must withstand full vacuum (34 ft)	Only hydrostatic pressure differentials (~2 ft)
Evaporator	Required	Not required

K. Gluesenkamp, D. Chugh, O. Abdelaziz, and S. Moghaddam, "Efficiency Analysis of Semi-Open Sorption Heat Pump Systems," Renewable Energy, 2016.

Approach: Novel WHDC Cycle

New Paradigm: latent and sensible heat communications with ambient



Water heater, dehumidifier, and cooling (WHDC) system

Cycle performance at different operating conditions			
Environment	Conditions	Water Heating Capacity (kW)	Thermal COP
Conditioned Space	23°C, 50%	3.22	1.63
Cold Basement	6°C, 80%	3.28	1.54
Humid Outdoor	35°C, 70%	3.78	1.72

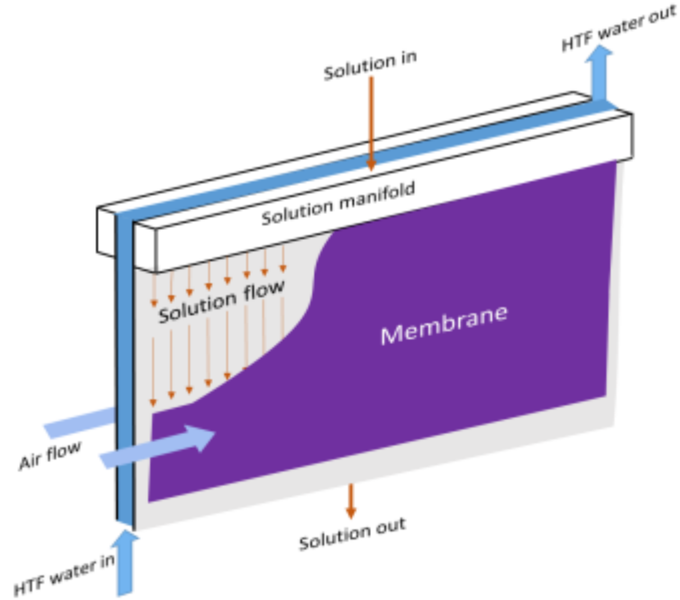
Key Issues:

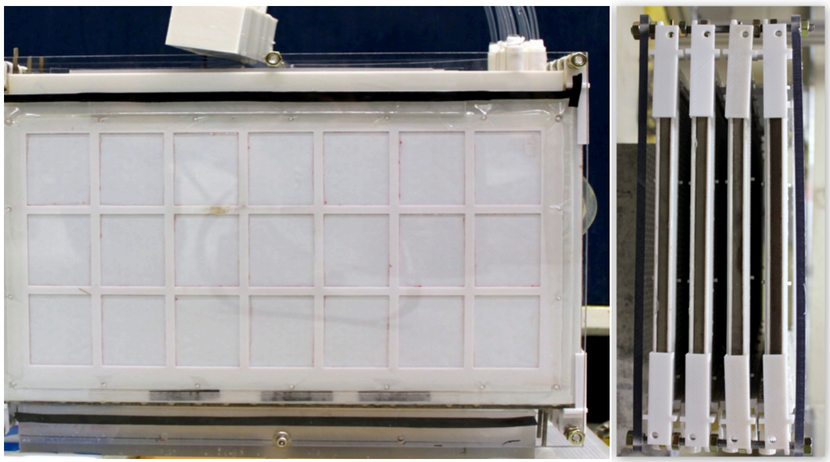
- Packed-bed liquid desiccant absorbers can NOT be used due to liquid entrainment and coupling of heat and mass transfer
- Crystallization of existing salts limits operation range and requires control equipment that increase cost
- Existing salts are corrosive

Approach: Enabling Absorber Technology

Membrane-based absorption technology:

- ➢ Liquid is fully contained within the system; enhances robustness
- ➢ Uniform distribution of an ultra-thin solution film
  - ✓ Enhances mass transfer from air but reduces heat transfer to air
- ➢ Absorber can be made entirely from polymers
- ➢ Enables a compact system for installation on the existing tanks





Fabricated absorber

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Approach: Enabling Liquids

Ionic liquids (salts that remain liquid at room temperature):

Crystallization issue is addressed

- ➢ Allows to increase temperature lift
- ➢ Eliminates need for control equipment and associated costs

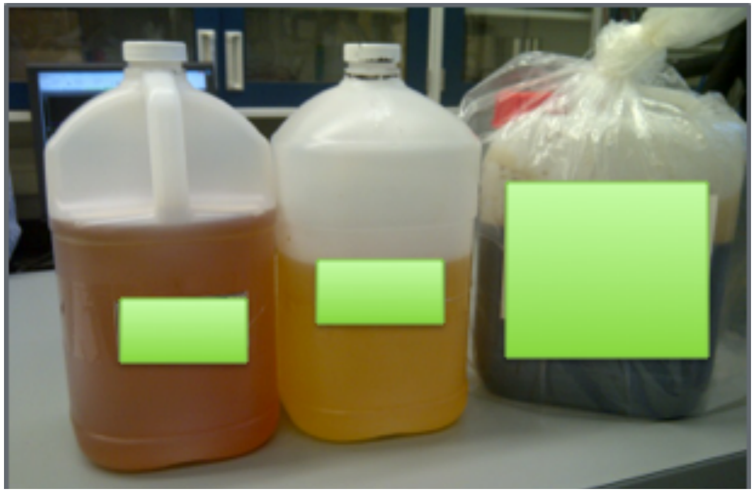
Properties can be tuned to enable different working conditions

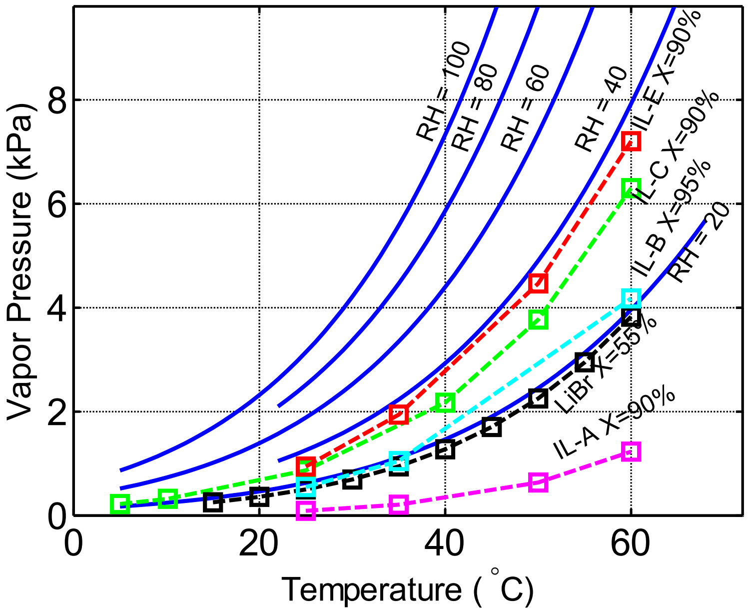
- ➢ This will revolutionize the absorption cycles and enables operation under conditions previously not possible

Low corrosion rate

Environment friendly (green liquids!)

- ➢ We dispose the liquid in lab sink





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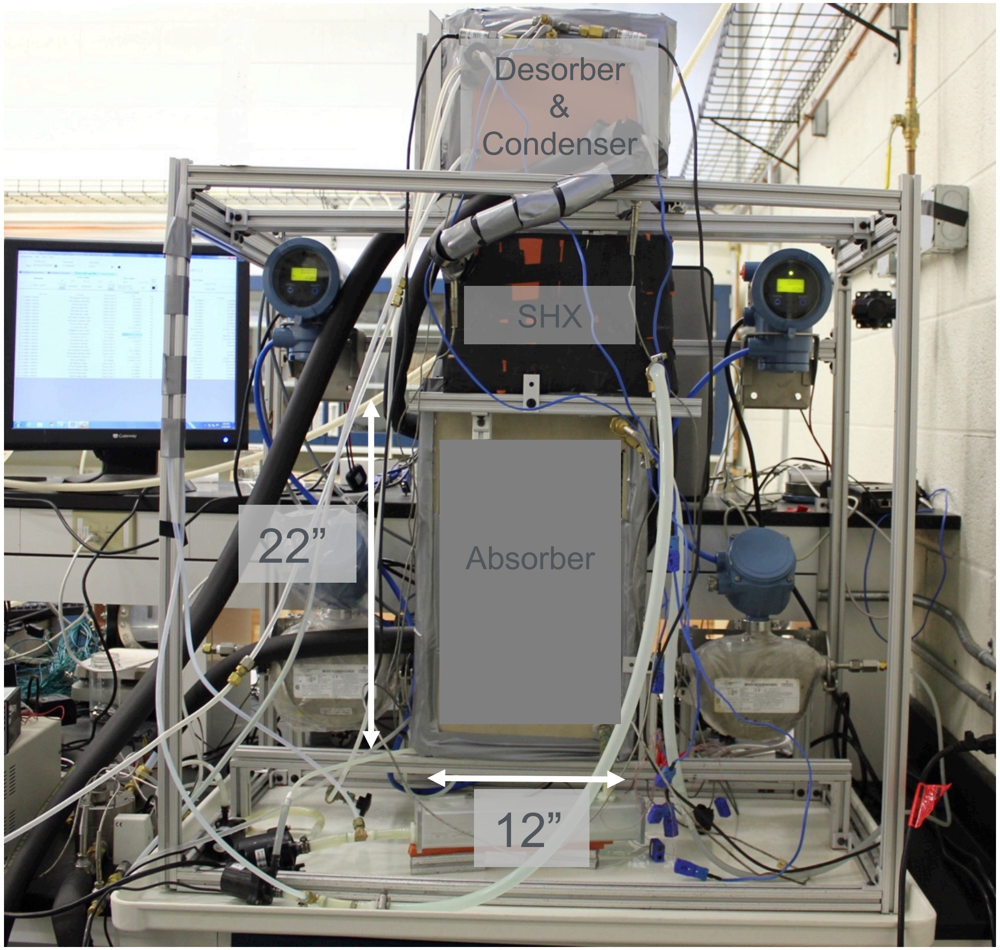
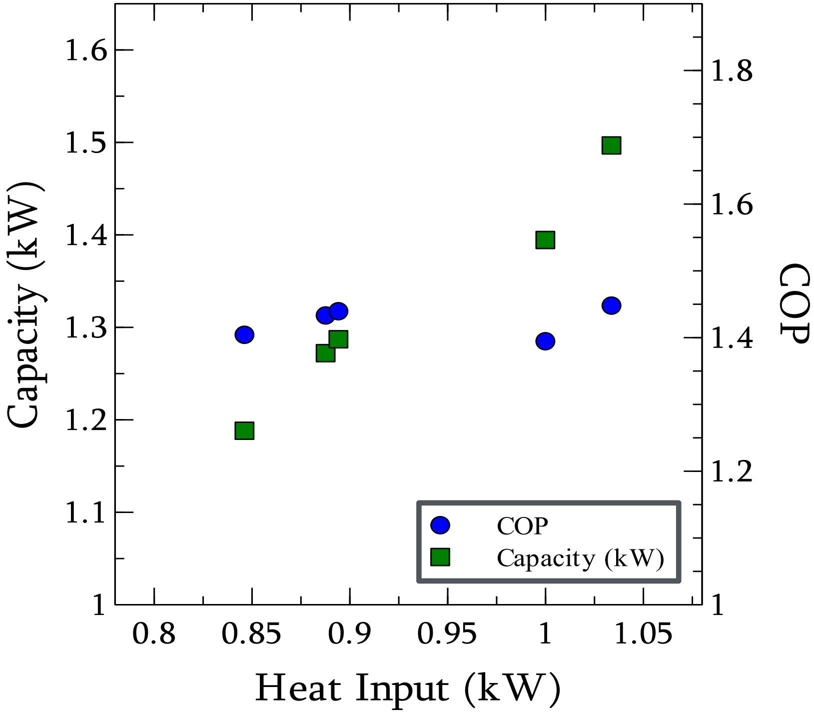
Progress and Accomplishments: 1st Gen. System

A demonstration unit was fabricated with LiBr solution (operated with hot oil)

- Required careful control to avoid crystallization
- Corrosion was a major issue, as expected





Performance of a LiBr system at 20-22 ° C and ~60% RH

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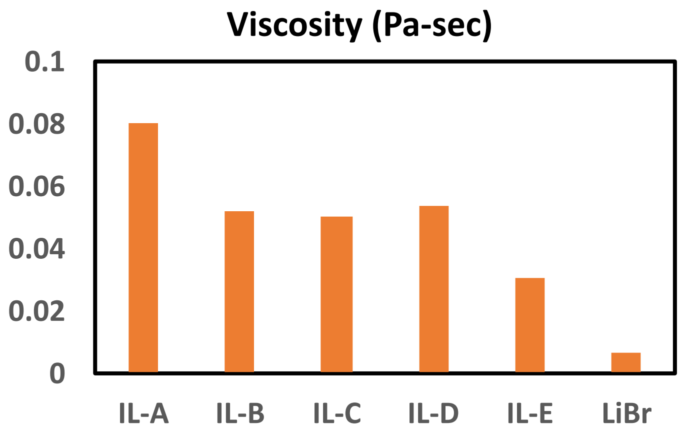
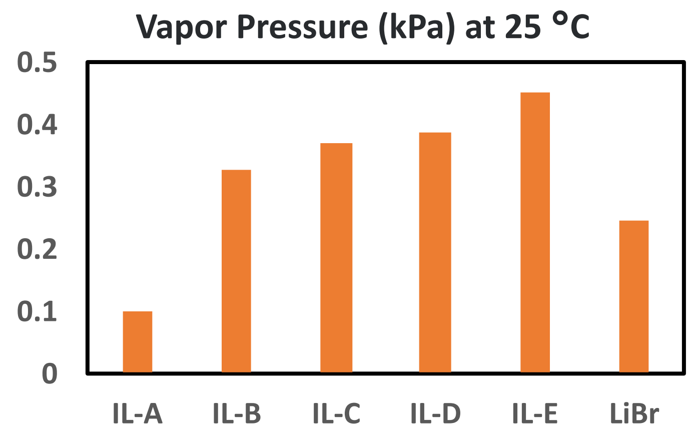
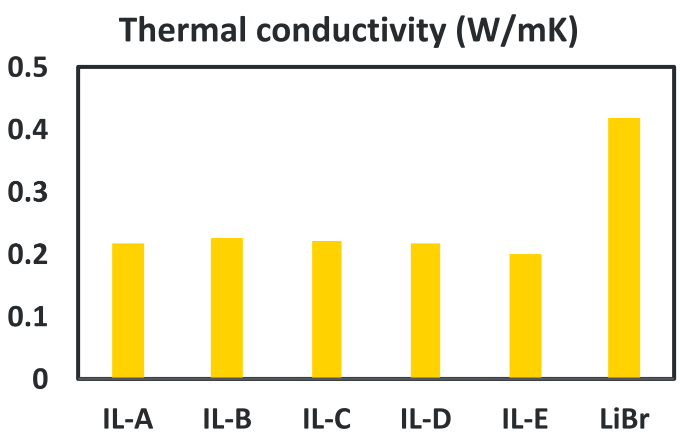
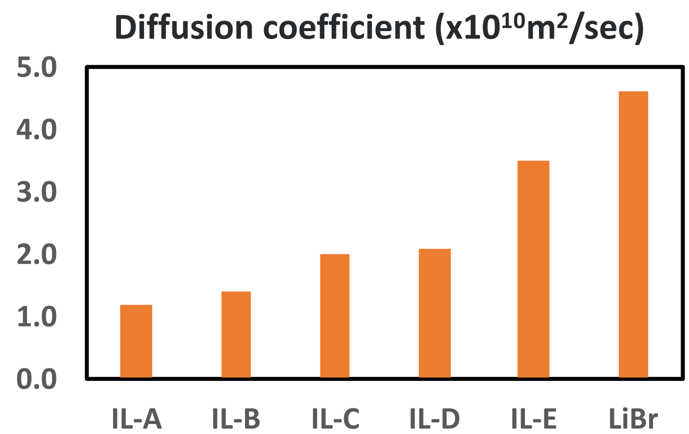
Progress and Accomplishments: Most Comprehensive Analysis of Ionic Liquids for Absorption Cycles

Developed extensive capabilities to measure P-T-X, thermal conductivity and capacity, heat of absorption, density, viscosity, mass diffusion coefficient (using PFG-NMR), and corrosion rate









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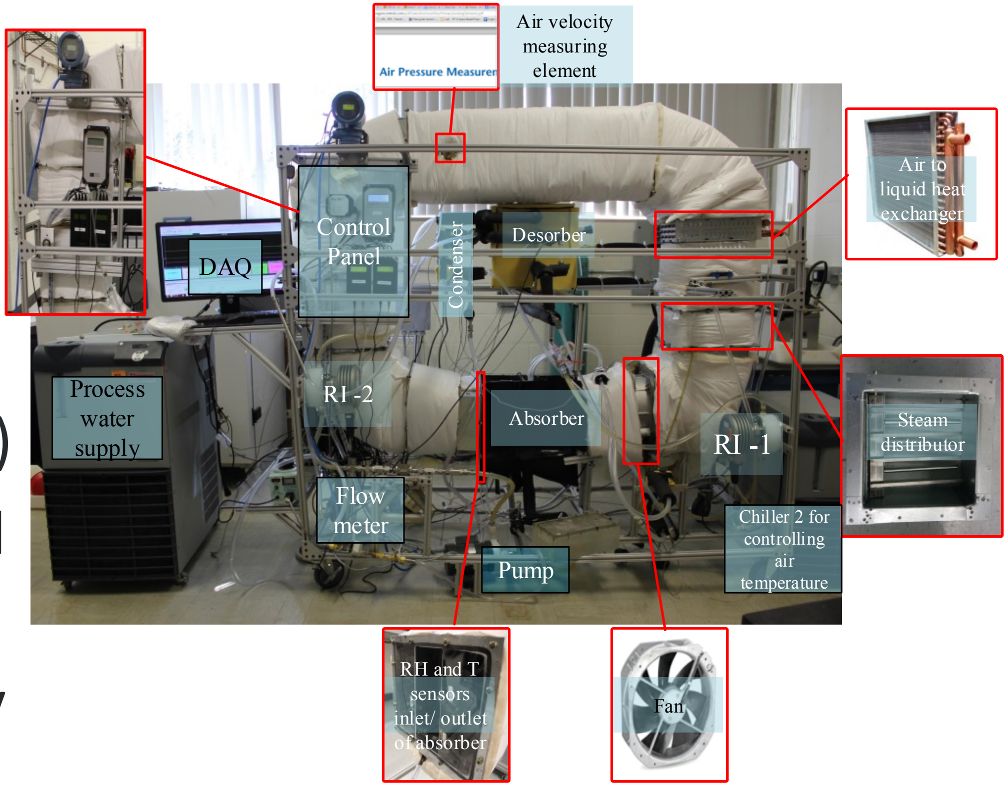
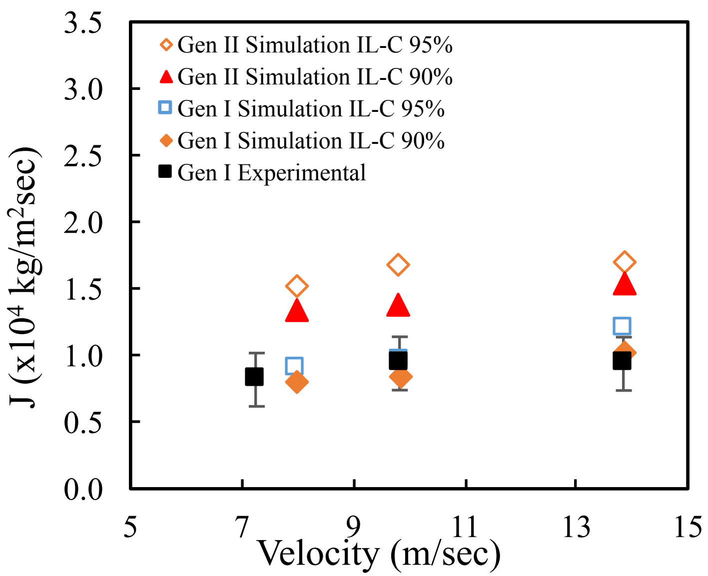
Progress and Accomplishments: 2nd Gen. System

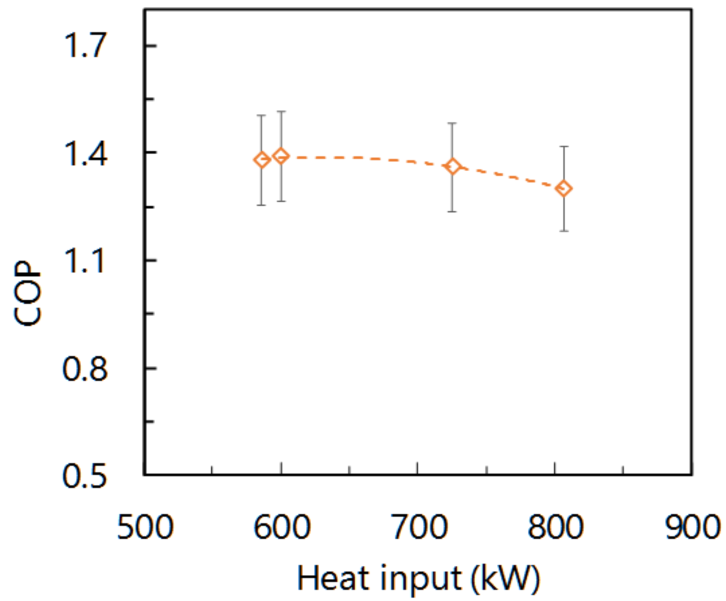
The system is equipped with

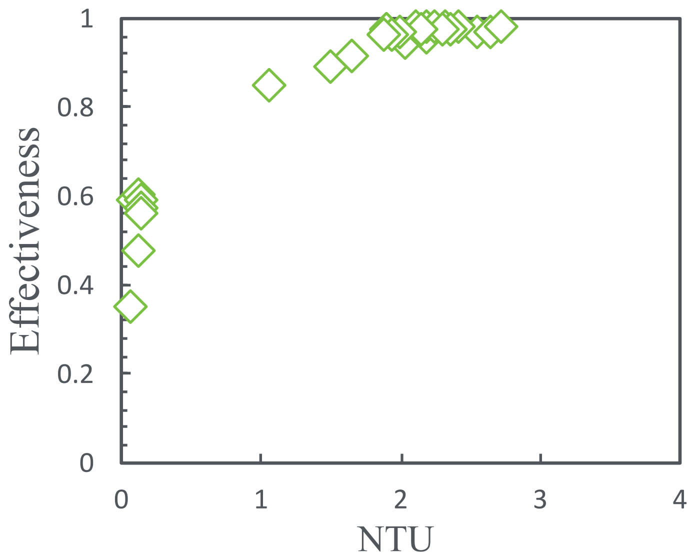
- Humidifier section to control air humidity
- Heat exchanger section to adjust air temperature (cooling and heating)
- Two concentration meters (after absorber and desorber)
- Air flow metering section and 3 liquid flow meters
- 12 temperature and humidity measurements before and after absorber

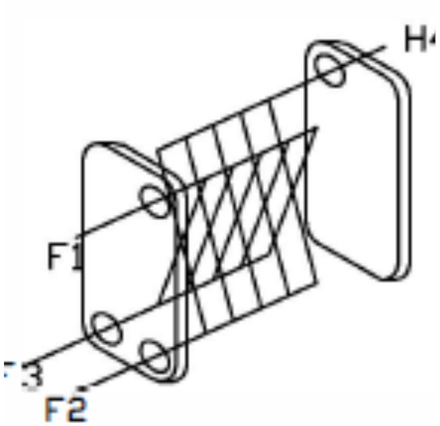


Progress and Accomplishments: Overcome Transport Limitations of Ionic Liquids









Progress and Accomplishments: Energy Factor

This low cost technology can achieve EF > 1

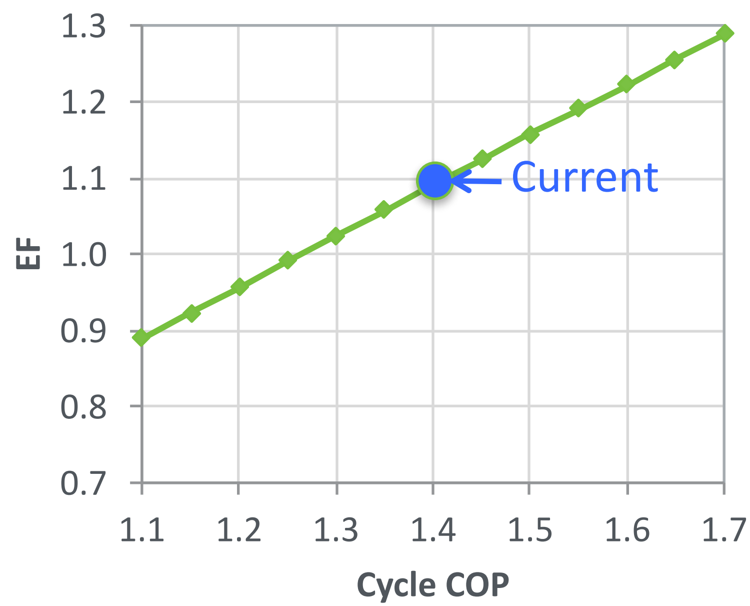
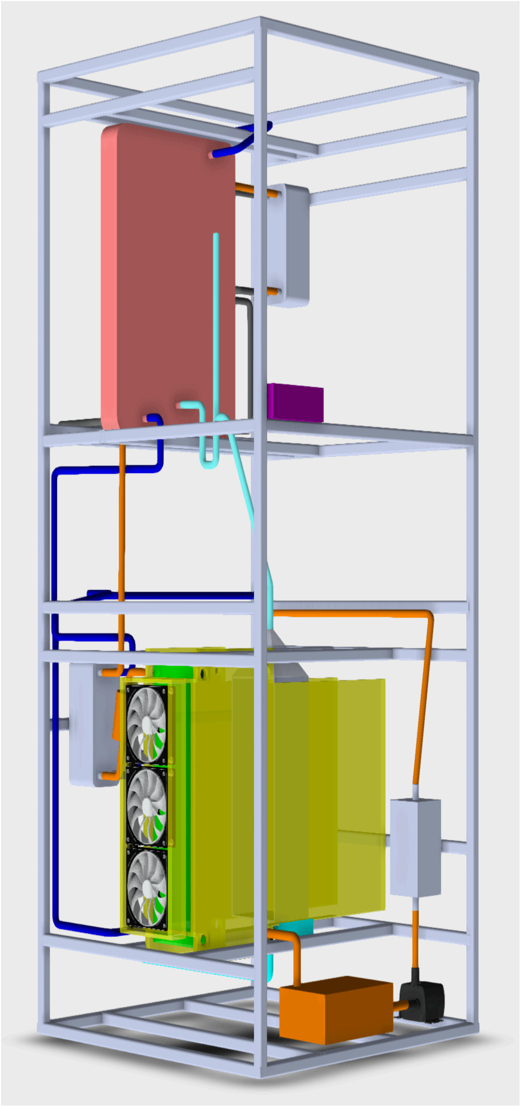
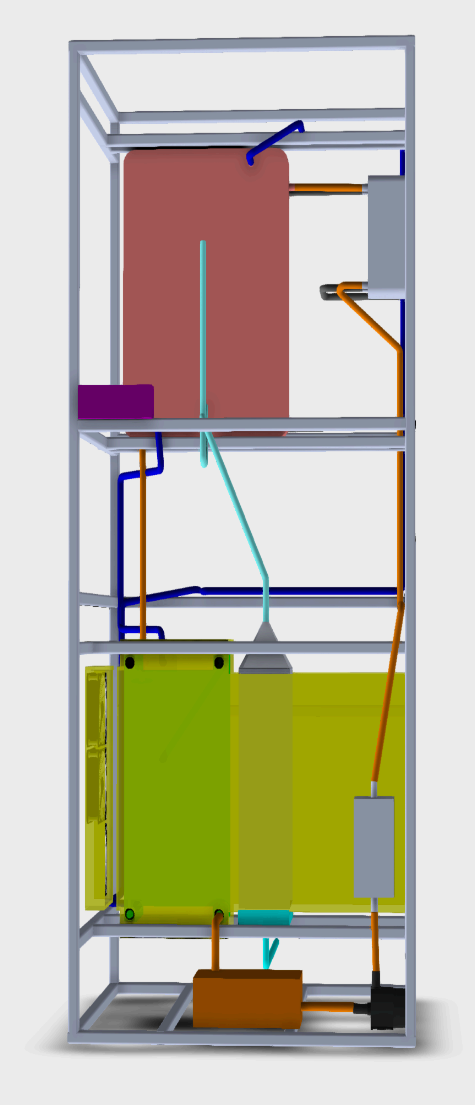


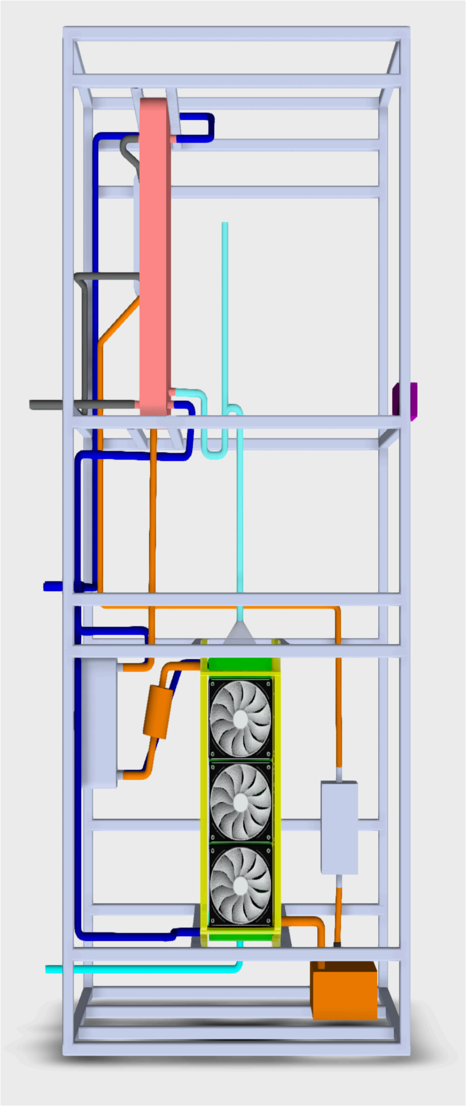
Figure assumes:

- 82% burner efficiency (fuel to desorber)
- 98% total combustion efficiency
- Electrical COP of 30
- Tank loss penalty factor of 94%

Progress and Accomplishments: Prototype Design







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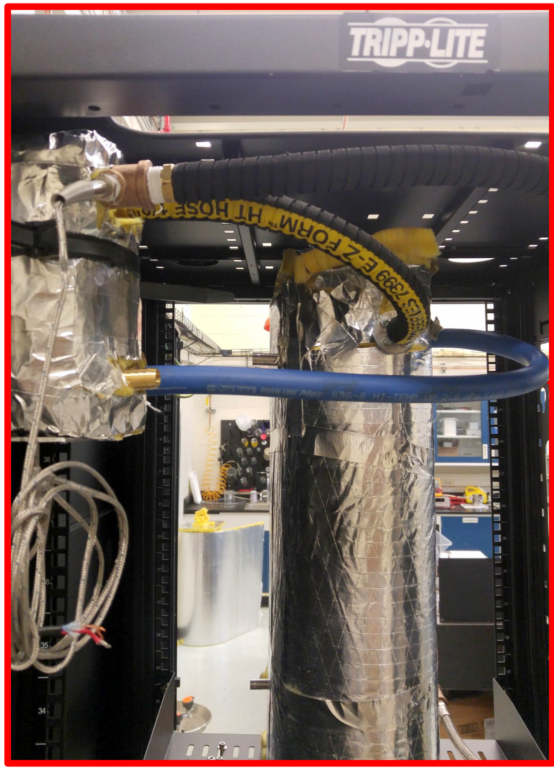
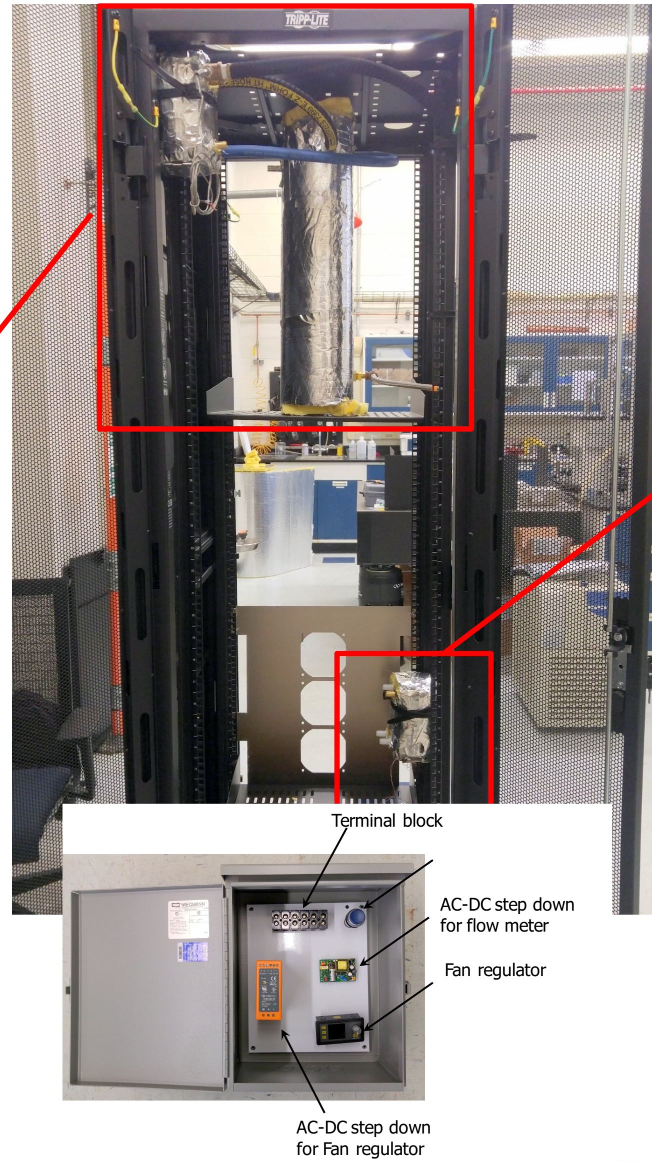
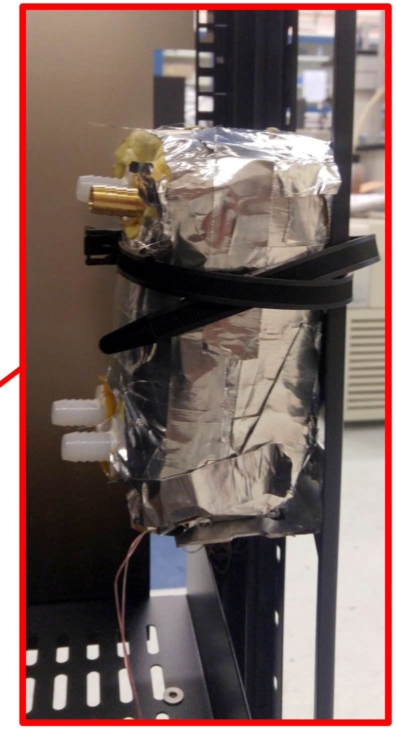
Progress and Accomplishments: Prototype Assembly



Desorber and Solution-oil heat exchanger



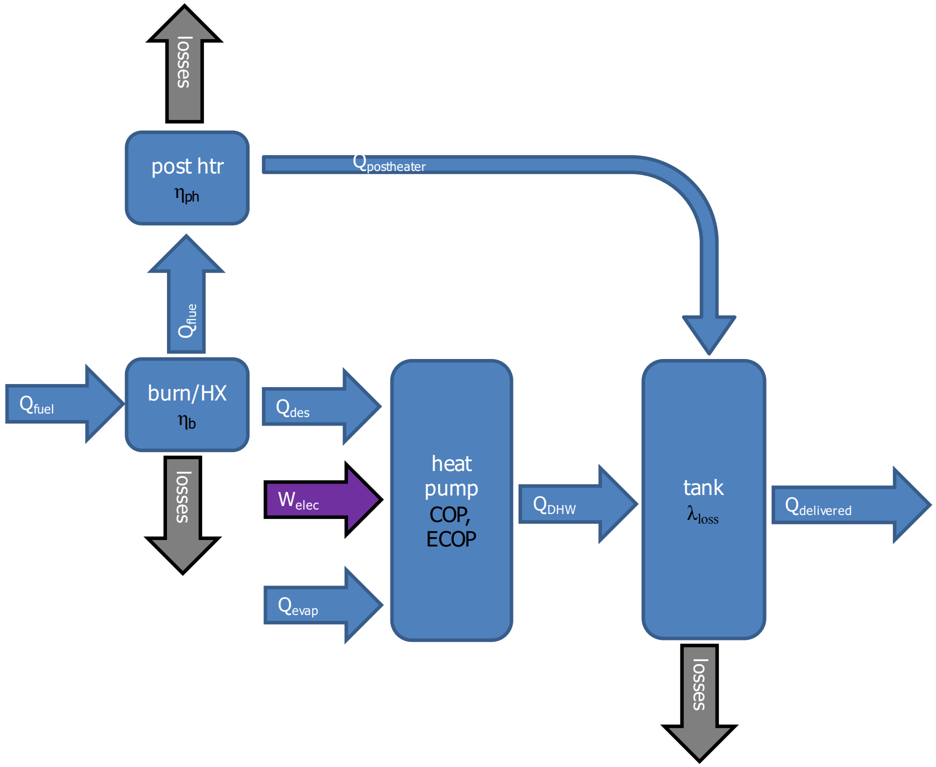


Water-solution heat exchanger

Progress and Accomplishments: System Configurations and Energy Savings

ORNL has been working on system configurations, energy efficiency analysis and test system preparation

Hourly weather data, city water temperature, conditions at installation location (garage, indoor, and attic), stratified storage tank and draw pattern are parameters used in the analysis



Commercial applications have been identified and are being analyzed

Applications with substantial latent load and water heating needs are suitable

- Swimming pools: dehumidification to control space humidity and add the energy back into the pool water
- Ice rinks: dehumidification for fog control and space heating
- Hospitals, hotels, and restaurants

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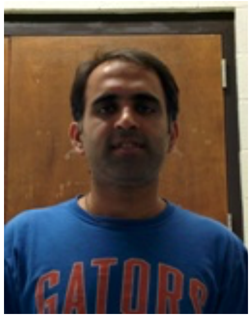
Project Integration and Collaboration

Project Integration: we communicate with other experts in the field and manufacturers on a continual basis

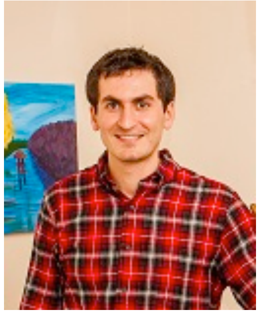
Partners, Subcontractors, and Collaborators:

University of Florida PhD students:


Devesh Chugh


Abdy Fazeli


Reid Schaffer


Mehdi Mortazavi


Rich Rode


Sajjad Bigham


Qanit Takmeel

Communications:

Chugh et al., Applied Energy, submitted, 2017

Glusenkamp et al., Renewable Energy, 2016

ASHRAE Winter Conference, Vegas, 2017

IMPRES, Italy, 2016

ACEEE Hot Water Forum, Portland OR, 2016

ACEEE Hot Water Forum, Nashville TN, 2015

ASME ICNMM, San Francisco CA, 2015

ORNL

Kyle Gluesenkamp

Next Steps and Future Plans

Prototype: Finish the prototype within a month and ship to ORNL for EF tests in an environmental chamber

Improve Performance: Continue enhancing system COP by improving the absorber design and manufacturing process

Commercialization:

- A startup company is formed (MNT, mntusa.com)
- Working with ORNL on system cost analysis and field testing
- Upon successful demonstration of the system performance the following steps towards commercialization will be taken

a. Near term (1yr after completion): modify design based on lessons learned, address failure issues, and fabricate 2nd generation prototype and test
b. Intermediate (1-3yr after completion): field testing and partnership with other domain experts and manufacturers
c. Long-term (3yr.+ after completion): lunch the first product in 2020

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Publications & Patents

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- M. Mortazavi and S. Moghaddam, "Laplace Transform Solution of Conjugate Heat and Mass Transfer in Falling Film Absorption Process," International Journal of Refrigeration, vol. 66, pp. 93-104, 2016.
- R. Nasr Isfahani, S. Bigham, M. Mortazavi, X. Wei, and S. Moghaddam, "Impact of Micromixing on Performance of a Membrane-Based Absorber," Energy, vol. 90, pp. 997-1004, 2015.
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- S. Moghaddam, M. Mortazavi, S. Bigham, Compact and Efficient Plate and Frame Absorber, UF-15794, 2015
- S. Moghaddam, D. Chugh, R. Nasr Isfahani, S. Bigham, A. Fazeli, D. Yu, M. Mortazavi, and O. Abdelaziz, Open Absorption Cycle for Combined Dehumidification, Water Heating, and Evaporating Cooling, Patent Application UF-14820, 2014.
- S. Moghaddam and D. Chugh, Novel Architecture for Absorption-based Heaters, Patent Application UF-14697, 2013.
- S. Moghaddam, Thin Film-based Compact Absorption Cooling System, WO Patent 2,013,063,210, 2013.
- S. Moghaddam, D. Chugh, S. Bigham, 3D Microstructures for rapid Absorption and Desorption in Mechanically Constrained Liquid Absorbents, UF-14936, 2013

Project Budget

Project Budget: Total Budget i) Federal Share $999,993 ii) Cost Share $111,111

**see details below*

Variances: PI assumed additional effort following resignation of a Post Doc and increase in Supplies needed for fabrication of equipment

Funds were moved from theoretical studies of system energy savings to overcome fabrication challenges and complete the prototype

Additional Funding: Not applicable

*Budget History						
Period	10/01/2014– FY 2016 (past)		FY 2017 (current)		7/31/2017 – FY 2018 (planned)	
Details	DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
UF	$688,844	$91,917	$113,156	$19,194	0	0
ORNL	$128,000	$-	$70,000	$-	0	0
Total	$816,844	$91,917	$183,156	$19,194	0	0