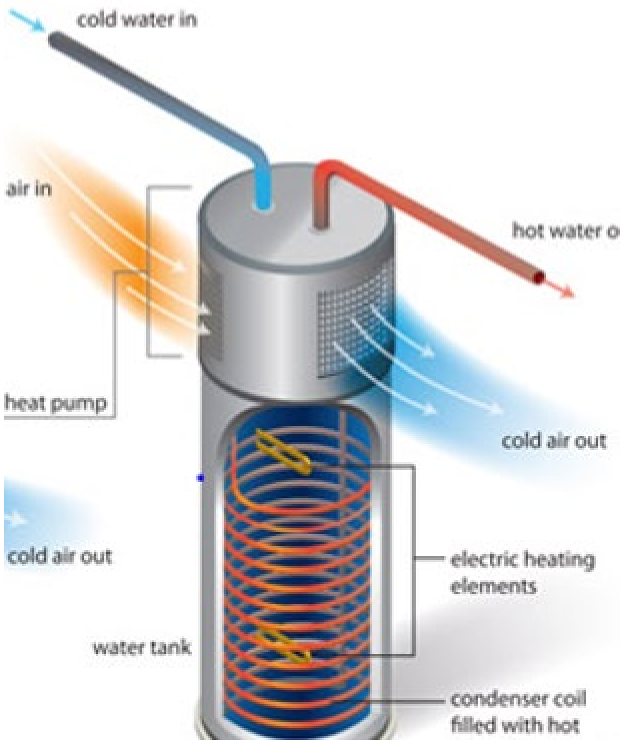
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Flexible HP WH with embedded energy storage



Oak Ridge National Laboratory

Kashif Nawaz (Group Leader- Multifunctional Equipment Integration)

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Project Summary

Timeline:

Start date: December 2020

Planned end date: September 2023

Key Milestones

1. Alpha prototype (design) enables at least 20% higher capacity (June 2021)
2. Lab demonstration of alpha prototype with >20% improvement in capacity (June 2022)
3. Field demonstration of beta prototype for more than 4 hours load shifting (June 2023)

Budget:

	DOE funds	Cost share
FY21	300K	50K
FY22	300K	50K
FY23	300K	150K

Key Partners:

Oak Ridge National Laboratory

A.O. Smith — Innovation has a name.

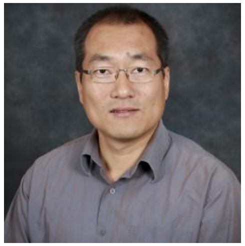
Project Outcome:

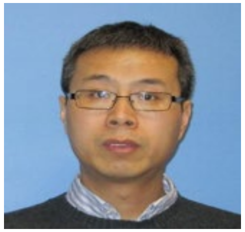
- The project is focused on the development and performance optimization for next-gen HPWH with embedded energy storage solution.
- Demonstration of cost-effective technology to enhance the performance through selection and deployment of energy storage medium.

Development and demonstration of next-gen HPWH for distributed energy storage and grid-interactive efficient buildings

Project Team

- **Oak Ridge National Laboratory**
  - Kashif Nawaz (Sr. R&D staff)
  - Bo Shen (R&D staff)
  - Ahmed Elatar(R&D staff)
  - Jeff Munk (R&D staff)
  - Tony Gehl (R&D staff)
  - Van Baxter (Dist. R&D staff)
  - Joseph Rendall (Post Doc associate)
- **A. O. Smith Corp.**
  - Steve Memory (Research Director)
  - Jiammin Yin (Senior Engineer)
  - Tim Rooney (Mech Engineer)

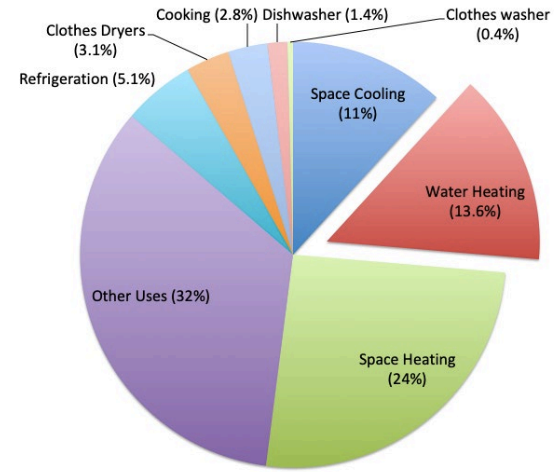





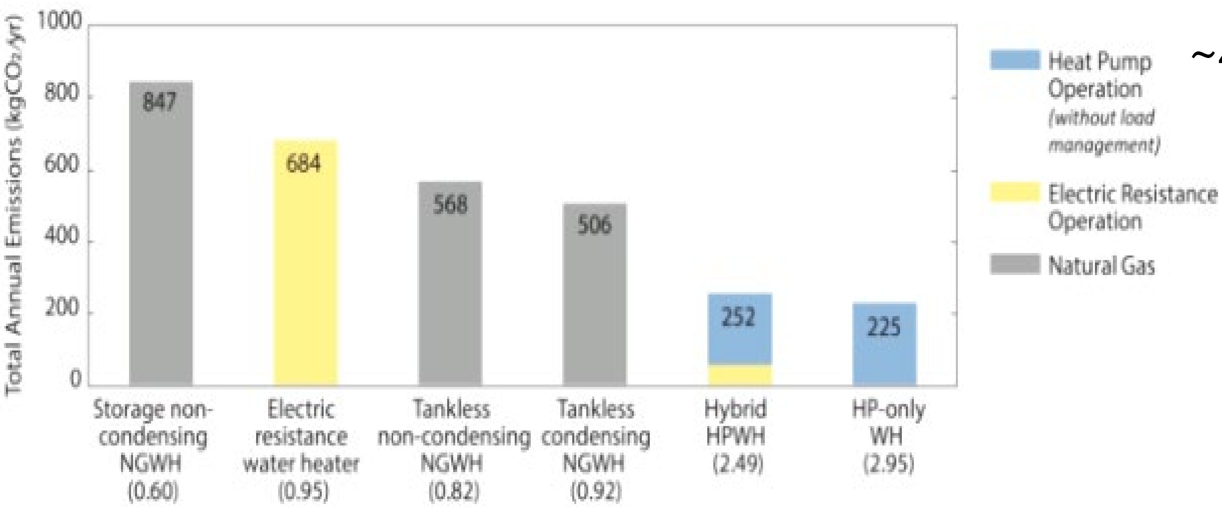


Challenge

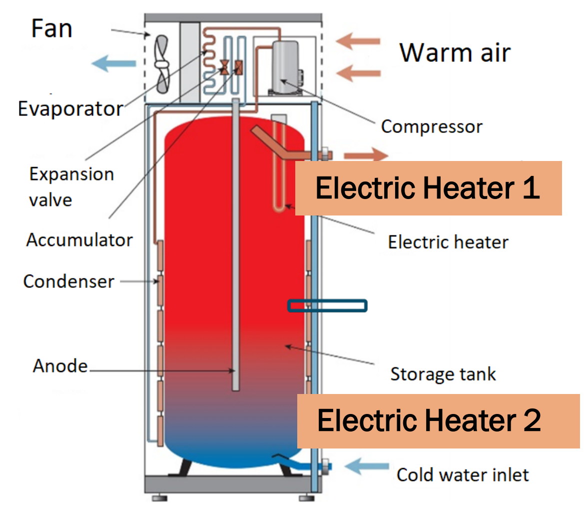
- HPWH are unable to meet the demand through the base-operation (HP) requiring ancillary heat through electric heaters (Hybrid configuration)
- Potential solutions through the deployment of suitable thermal energy storage medium are required for cost-effective load shifting.



~4 Quad/year for water heating



Annual emissions from water heating technologies

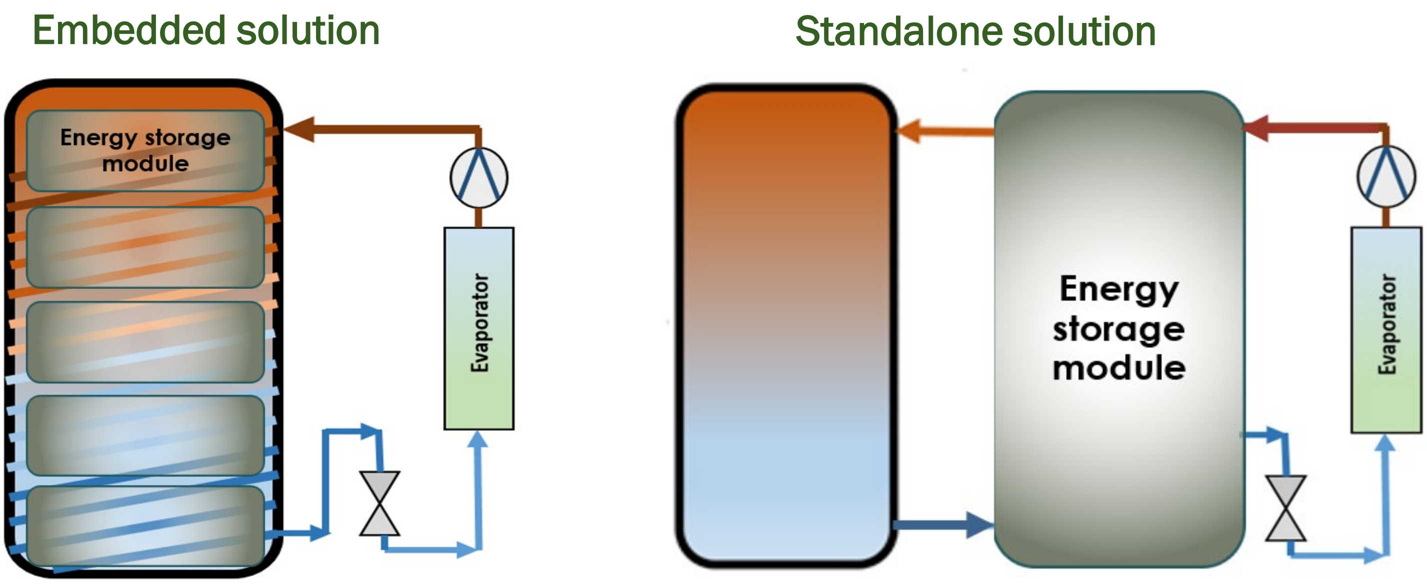


https://www.nrdc.org/experts/pierre-delforge/electric-heat-pumps-can-slash-emissions-california-homes

Challenge

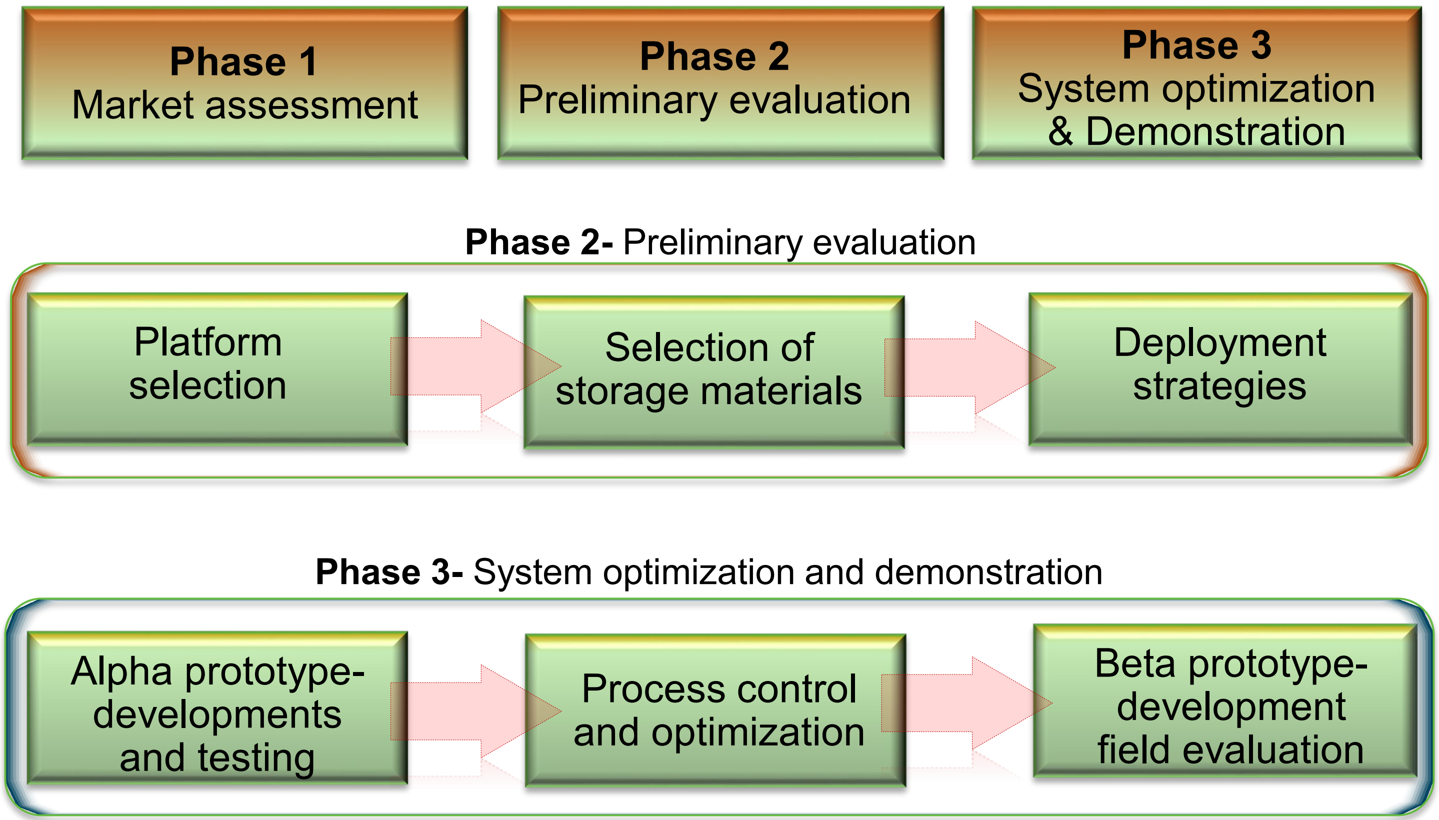
Why embedded solution is critical and more impactful?

- Logistics constraints due to additional space requirements
- Installation of storage device can be challenge
- Maintenance and capital cost
- Acceptance of customers



Demonstrate an **all-HPWH** and achieve a highly flexible operation by **embedded energy storage system**

Solution Approach

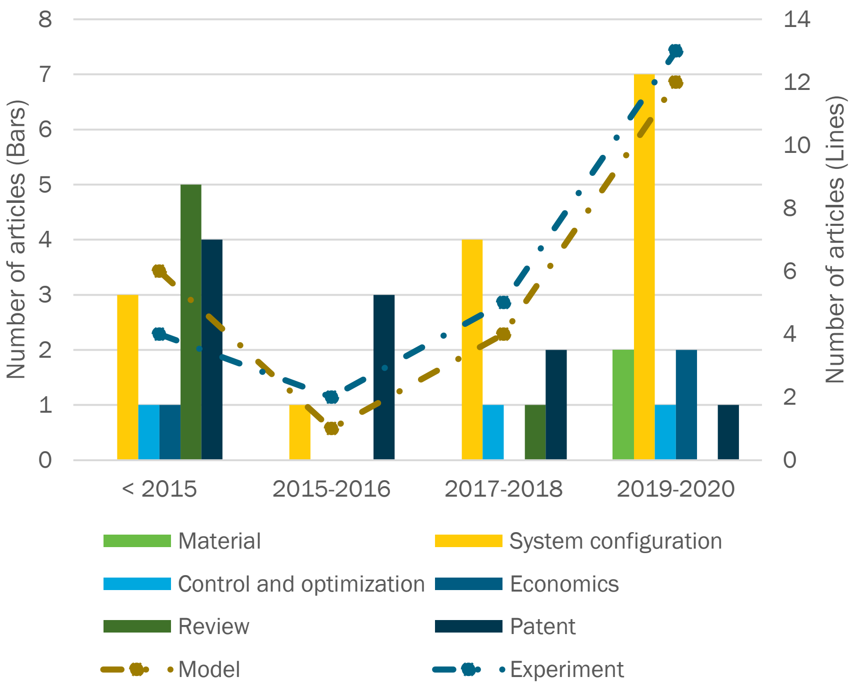


Project Impact

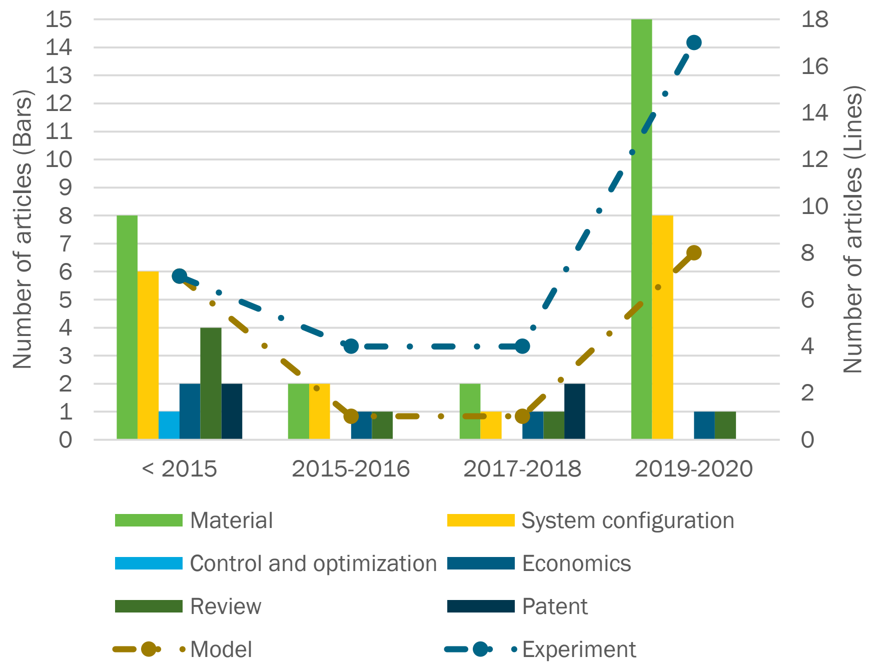
- A highly flexible water heating technology
  - Improved capacity (Higher FHR)- 20% higher capacity with same footprints
  - Reduced carbon emission (~60% compared to electric resistive and 10% compared to hybrid HPWH)
  - At least 30% cost saving compared to state of the art
- Enabling development for Grid-interactive Efficient Buildings
  - At minimum 4-hours of load shifting capability for medium and higher usage patterns
  - Embedded energy storage solution (no engagement of additional vendors)
  - Reduced required maintenance due to compact design
- Implications for additional processes
  - Residential air cooling/heating, refrigeration, Process water heating
- At least <u>250TBtu energy saving</u> in water heating technology.
  - Aligned with BTO goal to develop energy efficient technology to cause 45% energy saving by 2030 compared to 2010 technologies with at least 40% reduction in CO_2 emissions.

Project Progress

Phase Change Material Artifacts



Thermochemical Material Artifacts



Project Progress

Company (Year) - Active/Inactive	Summary of Invention	Applicability to Flex HWPH
Sunamp limited (2020)	Many PCMs with different phase change temperatures were put into a tank with thermal insulation between. A heat transfer coil is added into each section. This patent is pending and absorbs many previous applications and patents.	Invention very similar to what a Flex HPWH could look like on the inside of the tank.
Mitsubishi Electric Corporation (2014)	A HPWH with a 4-way valve was designed and a patent awarded. Methods of use have been patented with this configuration also.	Methods and system have been patented for a sensible tank and PCM heat exchanger connected to the condenser like could be done in a Flex HPWH.
General Electric Company (2013)	A wrapped HPWH is shown and the control methods are suggested.	This active patent might be licensed by water heating companies for wrapped HPWHs.
Promethean Power Systems Inc. (2014)	Many configurations of vertical PCM tubes have been converted. Also an inlet/outlet configuration is suggested. Stagged phase change temperature profiles have been suggested and 3 regions vertically space have been proposed for a method of incorporation.	This US and published world patent covers many internal configurations of encapsulated PCM inside a tank with inlet and outlet distributors. The design does not include a heat pump.
BlueLagoon Technologies Ltd. (2015)	An active patent on an apparatus for heat exchange of PCM materials in a novel heat exchanger for latent storage was awarded. The complex system includes spraying of liquids.	This incorporates complex flow paths and spray heat exchange. There are too many components for a Flex HPWH.
University of Texas System (2019)	A thermochemical cell was created to harvest energy.	Could be a useful technology but was created for solar thermal which is often hotter than DHW temperatures.
General Electric Company (2018)	A heat exchanger with PCM was created to cool electronics that includes fins sunk into the PCM.	This was created to cool electronics but the fin and PCM configuration is protected.
Atomic Energy and Alternative Energies Commission (2017)	A heat exchanger for use with high temperature PCM was developed that looks like a microchannel evaporator with a second layer of PCM on top	This patent was granted in Spain and abandoned in the US. This is for a high temperature reaction and not that useful to a Flex HPWH.

- Rare active intellectual properties on the overall system design.
- Preliminary design concepts with no major implications on overall system dynamics
- Most of IPs are for standalone energy storage unit and integration
- Major focus has been on materials selection and not on the deployment strategies

Project Progress

Inside Tank Deployment

PCM
- Paraffin Waxes
- Fatty Acids
- Salt Hydrates
- Eutectic solder

TCM
- Salt Hydrate-Hydration/Dehydration
- Strontium Bromide
- Aqueous Calcium Chloride
- Metal Sulfate
- Bischofite
- Diels-Alder reactants

Food-grade paraffins

Selection Criteria

Temperature

35 to 65 ºC | 8 to 90 ºC

Storage density

> 100 kJ/kg
> 150 kWh/m3 | > 200 kJ/kg
> 250 kWh/m3

Cost*

0.15 to 15 $/kg | 0.15 to 15 $/kg

Compatibility

nontoxic | stable with metals

Heat transfer characteristics

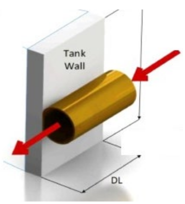
> 0.1 W/kg- ºC
> 100 W/kg | > 0.2 W/kg- ºC
> 200 W/kg

Production at scale

Outside Tank Deployment

PCM
- Paraffin Waxes
- Fatty Acids
- Salt Hydrates
- Eutectic solder

TCM
- Salt Hydrate-Hydration/Dehydration
- Aqueous Calcium Chloride
- Metal Sulfate
- Bischofite



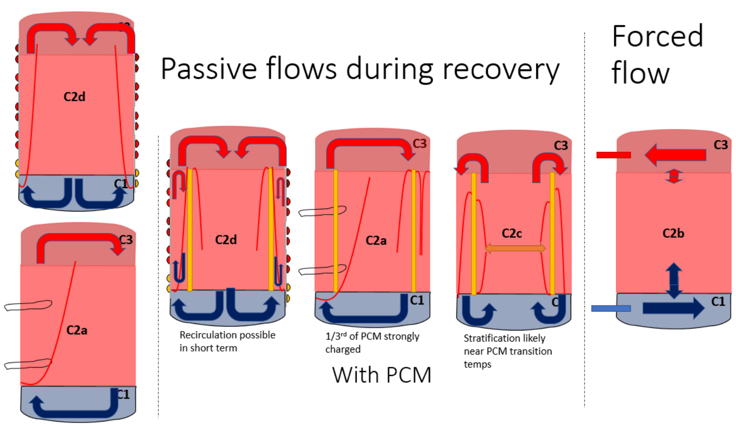
RT8-15 (evaporator)
RT40-65 (condenser)
Sodium acetate trihydrate (condenser)

- Overall performance is a function of deployment strategy
- More flexibility for deployment outside of the tank
- U.S. Food and Drug Administration (FDA) requirements limit the selection of materials for “in-tank” deployments

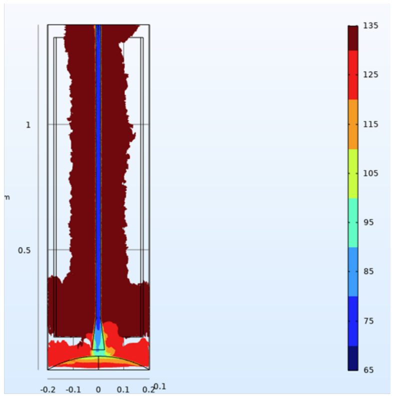
*costs are highly variable depending on the source and quality

Project Progress

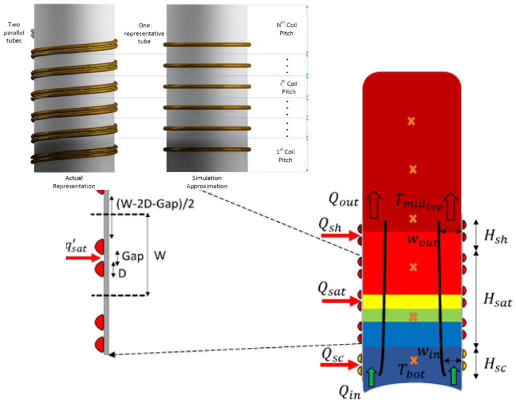
- Tank modeling has been focused on three aspects
  - Flow behavior during recovery process to maintain sufficient stratification (higher UEF)
  - CFD model (3D) for the flow during recovery process to reduce the mixing
  - Discretized model to establish the impact of wrapped around configuration with and without storage material.



Flow behavior with PCM deployed

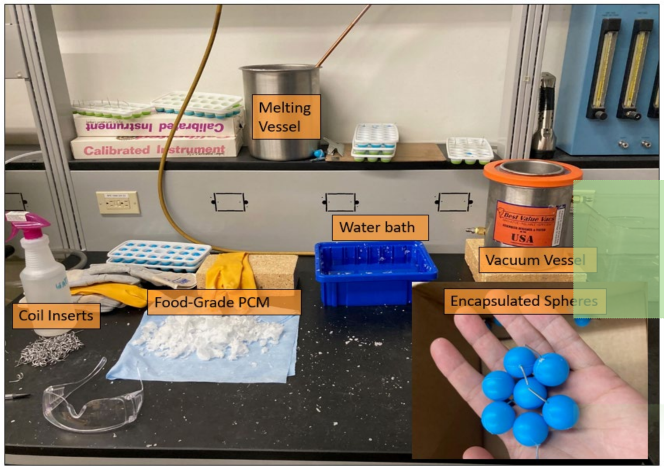


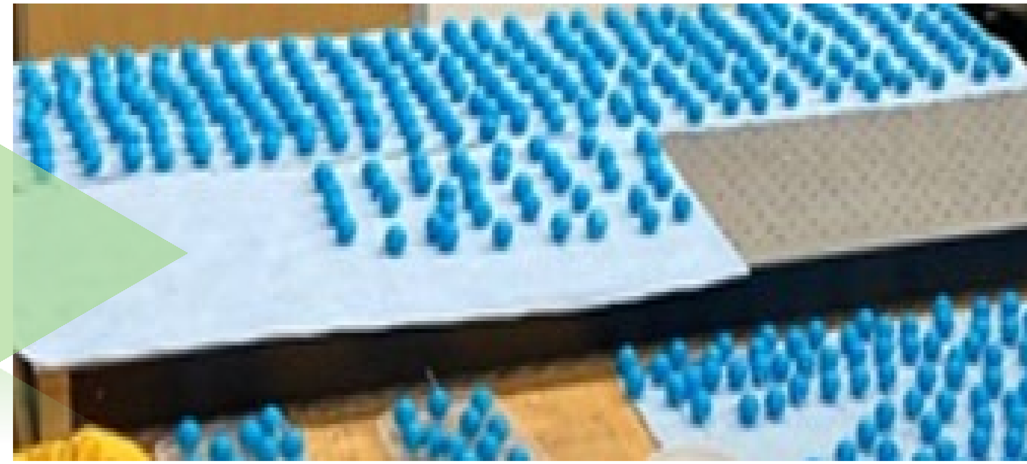
3D model for the temperature profile

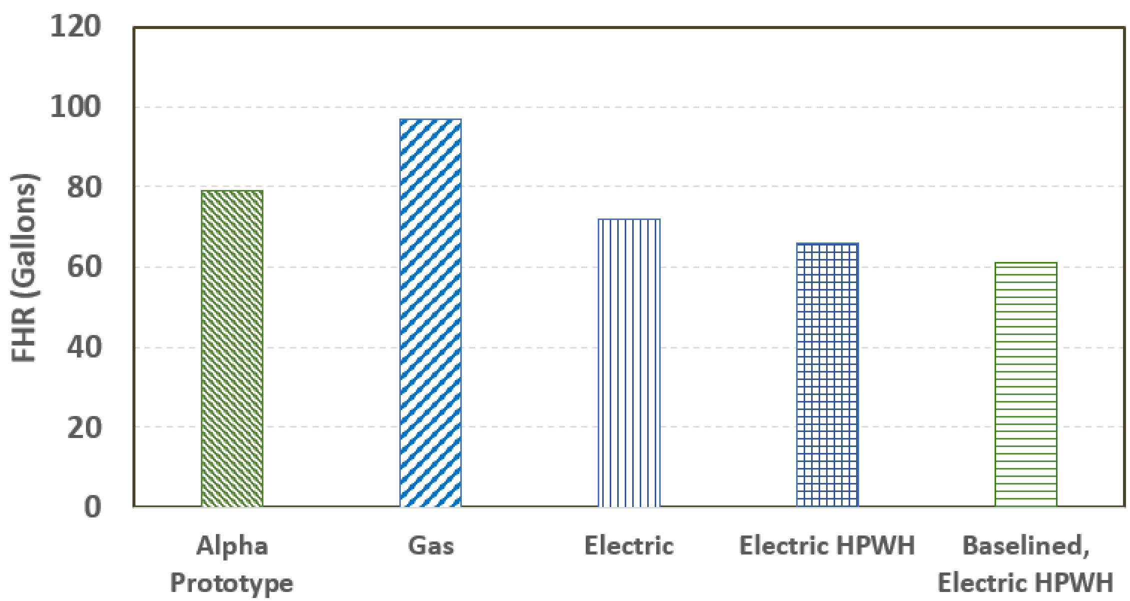


Discretized model for the wrapped around condenser

Project Progress







Stakeholder Engagement

- **Development of the technology**
  - Selection of materials
  - Deployment's strategies
  - Process controls
  - Grid interaction and response
- **Meetings with experts at technical platform**
  - ASHRAE (TC 8.5, TC 1.1)
  - Purdue
- **Presentations/Conference papers**
  - Five journal articles have been published (ATE, IJR)
  - More than twelve conference papers
  - ACEEE Hot Water Forum
  - IJR and ATE papers

AO Smith
Innovation has a name.

Project Progress

Tasks	Task Description
Market assessment	Establishment of major market requirements and identification of appropriate product line (residential vs. commercial)
Identification of appropriate materials	Selection and establishment of novel materials for energy storage applications
Storage tank analysis	Investigation of embedment design and analysis
System modification	Selection and modification of appropriate platform with selected storage technology
Control system development	Determination of major control requirements and process compatibility
Field demonstration	Installation and field evaluation over extended period of time

BTRIC PCM Lab

Unoccupied Research House

Thank you

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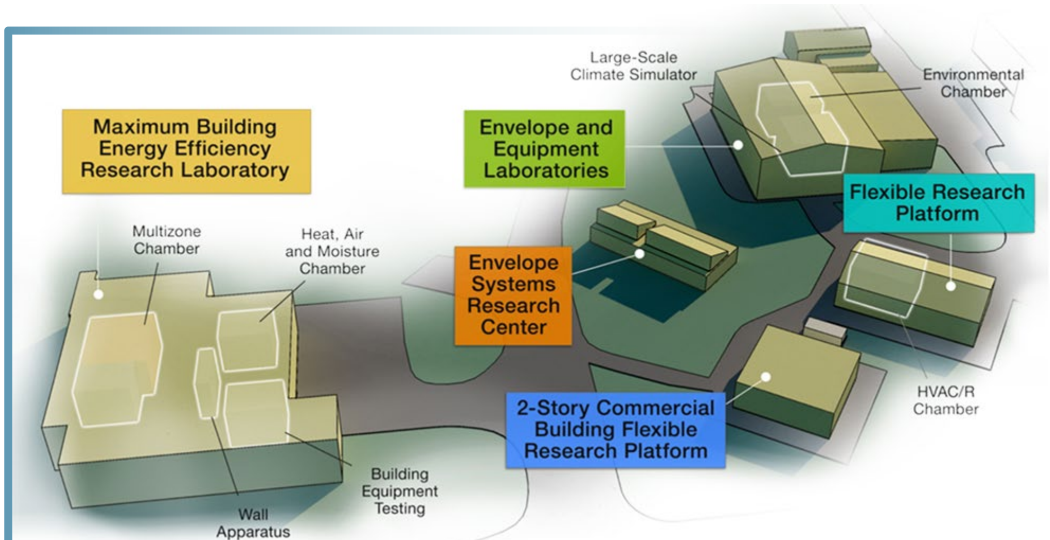

ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results

238 publications in FY20
125 industry partners
27 university partners
10 R&D 100 awards
42 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Budget

Project Budget: $900K, $150K cost-share
Variances: None
Cost to Date: $200K
Additional Funding: None

Budget History					
FY 2020 (past)		FY 2021 (current)		FY 2022 – FY 2023	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
		$300K	$50K	$600K	$50K

Project Plan and Schedule

Project Schedule													
Project Start: 12/1/2020		Completed Work											
Projected End: 9/30/2023		Active Task (in progress work)											
		Milestone/Deliverable (Originally Planned)											
		Milestone/Deliverable (Actual)											
	FY2021				FY2022				FY2022				
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	
Past Work													
Establishment of major market requirements and identification of appropriate product line (residential vs. commercial)													
Selection and establishment of novel materials for energy storage applications													
Investigation of embedment design and analysis													
Selection and modification of appropriate platform with selected storage technology													
The preliminary configuration of flexible HPWH using encapsulated PCM shows at least 20% higher capacity compared to the baseline system (Go/No-Go)													
Current/Future Work													
Model Flex HPWH with 0-D to 3-D models to optimize performance													
Determination of major control requirements and process compatibility													
Construct Beta prototype													
Test Beta prototype													
Installation and field evaluation over extended period of time													
Complete final report													