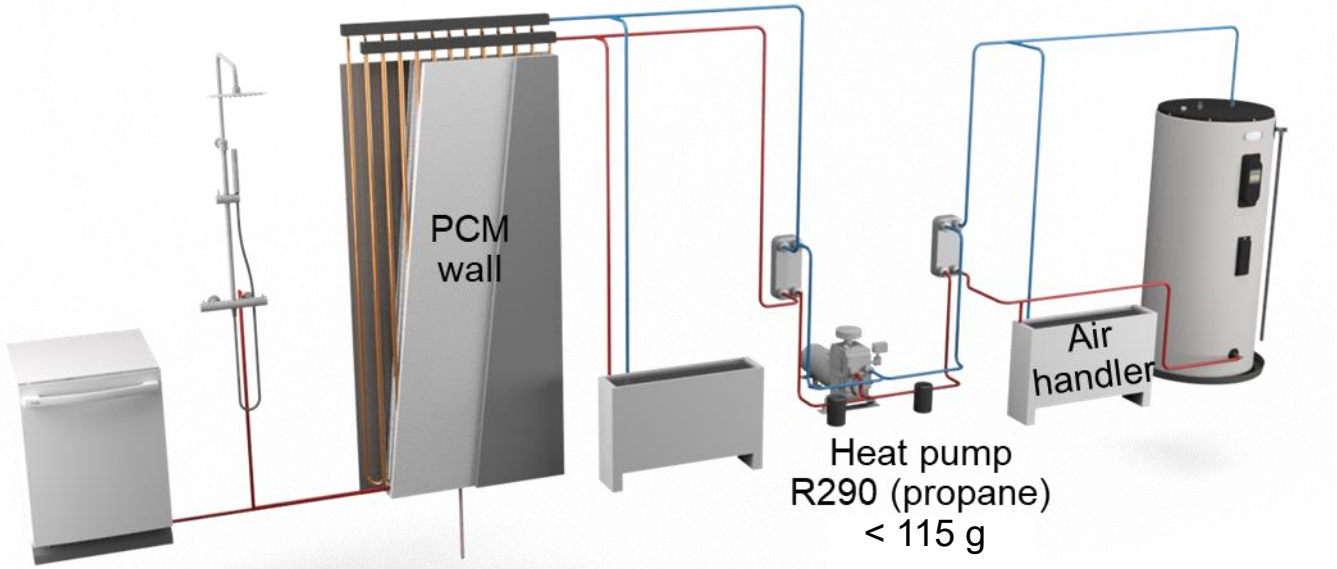
2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review: GEB by ME Grid-interactive Efficient Buildings by Modular Design of Plug-and-play Equipment

GEB by ME: Grid-interactive Efficient Buildings by Modular Design of Plug-and-play Equipment



Oak Ridge National Laboratory
Kyle Gluesenkamp, Distinguished R&D Scientist
gluesenkampk@ornl.gov
BTO WBS 03.02.02.54

Pacific Northwest National Laboratory
Michael Poplawski, Chief Engineer
michael.poplawski@pnnl.gov
BTO WBS 03.02.02.69

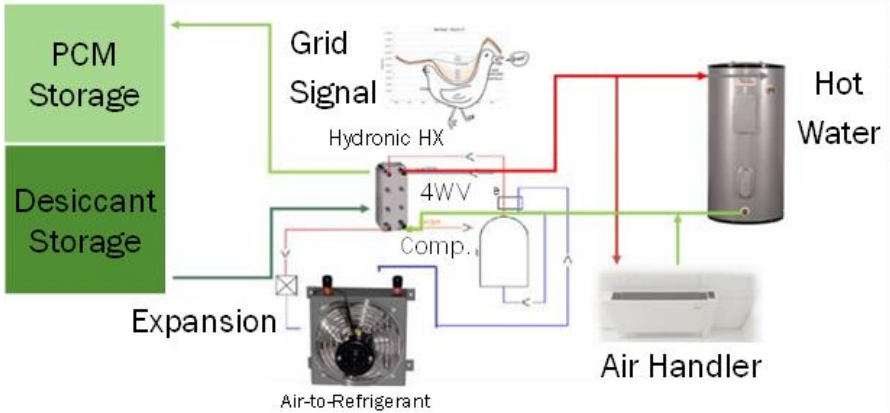
Project Summary

Objective

- Develop a novel concept of modular plug-and-play equipment ecosystem that is low-cost and easy to retrofit to realize electrified grid-interactive efficient buildings

Outcome & Impact

- Develop preliminary prototypes and simulations for plug-and-play, grid-integrated equipment to guide next-gen R&D.
- Achieve 50% reduction in CO2 emissions and 60% reduction in peak demand through an integrated system approach.
- Catalyze the market introduction of a low-cost, easy-to-retrofit modular equipment ecosystem for buildings.
- Providing accessible electrification solutions for hard-to-decarbonize communities.



TEAM & PARTNERS

- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory
- University of Maryland
- Melink ZERO
- NexTEMP Solutions (formerly GEOAire)

STATS

Performance Period: FY23 - FY26

DOE Budget: $2,250k, Cost Share: $397k (15% TPC)

Milestone 1: Market and technology assessment (FY24 and FY25)
Milestone 2: Modular modeling platform development (FY24, FY25)
Milestone 3: Modular heat pump water heater development (FY24, FY25)
Milestone 4: Modular, reversible hydronic heat pump development (FY25, FY26)
Milestone 5: Whole house design optimization simulation (FY25, FY26)
Milestone 6: Complete system field demonstration (FY26)

Problem

- Upgrading HVAC and WH equipment is a **major expense ($3.2 k – 12.5k[1])**
- Electrifying may require an **electrical panel upgrade ($3k[2])**
- **Incremental upgrades** are not possible

- Existing market dynamics and factors have resulted in limited investment in R&D for **affordable efficient technologies for underserved communities** (~970,000 household living in public housing units[3])

- **Split incentives**: Renters are not incentivized to invest in HVAC improvements because the systems are integrated into the walls, floor, and attic, and can't be taken to their next home (44 million rental household[4,5])
- Federal Inflation Reduction ACT offers rebates for micro/portable electric heat pumps; however, these **technologies are not widely available**, tend to be expensive, and require a dedicated 120/240 V circuit

- Current HVAC and WH systems **do not communicate** with each other or the grid
- Increasing penetration of renewable but **intermittent generation of renewable** generation technologies poses a new challenges for grid management.

[1] American Society of Home Inspectors
[2] https://www.thisoldhouse.com/electrical/reviews/cost-to-upgrade-electrical-panel
[3] https://www.hud.gov/topics/rental_assistance/phprog
[4] https://www.canarymedia.com/articles/heat-pumps/renters-you-too-can-get-a-heat-pump-a-micro-one-at-least
[5] https://www.vox.com/climate/2023/4/7/22954507/inflation-reduction-act-renters-home-rebates

Impact

Project Impact

- Develop an efficient **low-GWP modular** smart building equipment system with grid integration capabilities
- Inform **early-stage R&D**, accounting for energy and cost performance, and considerations across integration, use and installation
- Provide a 50% reduction in CO2 emissions and 60% reduction in peak demand
- Allow for easy and low-cost installation, **plug ang play/grab** and go modularity of components, easier retrofits, a singular compressor/condenser unit, and a low GWP refrigerant

Societal Impact

- An **accessible electrification solution** for crucial decarbonization of communities that are often overlooked and challenging to decarbonize (such as renters, and disadvantaged communities)
- The current R&D can **educate and influence** decision-making by utility and industrial companies and local, state, and federal policymakers, leading to accelerated decarbonization and electrification of all communities supporting federal energy justice incentives.

Alignment – electrification options for renters

Affordability and Equity

- Speed up access to **affordable, energy-efficient low-GWP modular heat pump technology** for electrification without needing panel upgrades
- DIY options empower low-income households, renters, and multi-family residents to invest in energy-efficient products they can own, helping **overcome the split incentive and affordability barriers**

Resilience

- **Improved resilience** by adding load flexibility to electrification, especially in low-income housing with affordable thermal energy storage module

Increase Energy-Efficiency

- Accelerates the availability of highly efficient low-GWP modular products, delivering **over 40% performance improvement** compared to existing low-cost, inefficient space conditioning and water heating systems

On-site emissions reduction

- A low-capital upgrade option that reduces on-site emissions by replacing inefficient gas-fired water heaters and furnaces, as well as high-GWP HVAC equipment, achieving a **50% reduction in CO2 emissions**

Transform the Grid Edge

- Integrating residential HVAC and water heating equipment with the grid facilitates greater renewable energy adoption and low-emission grid utilization
- Attain a **60% reduction in peak demand** to reduce upfront grid infrastructure costs and promote the transition to electrification

Approach – Current Market Landscape

Existing Products

- Packaged Terminal Heat Pump Unit (PTHP)
- Portable Heat Pump (PHP)
- Saddle Window Unit
- Heat Pump Water Heater (120 or 240 volt)
- 120 volt mini-split

Shortcomings of Existing Products

- **Voltage Ratings:** Some products are rated for 120 V; the majority operate at 208/240 V
- **Circuit Limitations:** 120 V products are not suitable for plug-in shared circuits
- **Installation:** Professional installation typically required
- **Operation Mode Limitations:** Designed for either space conditioning or water heating not both. Not modular.
- **Global Warming Potential (GWP):** Some products use low-GWP refrigerant (R32), while majority still use high-GWP refrigerant (R410A)

Fujitsu Terminal Heat Pump

EPHOCA (PTHP) interior Mounted

GRADIENT Saddle Heat Pump

Bosch 120 Volt Mini-Split

STASH TES Mini-Split

Approach – Novel Modular HVAC Ecosystem

New Modular Product Ecosystem

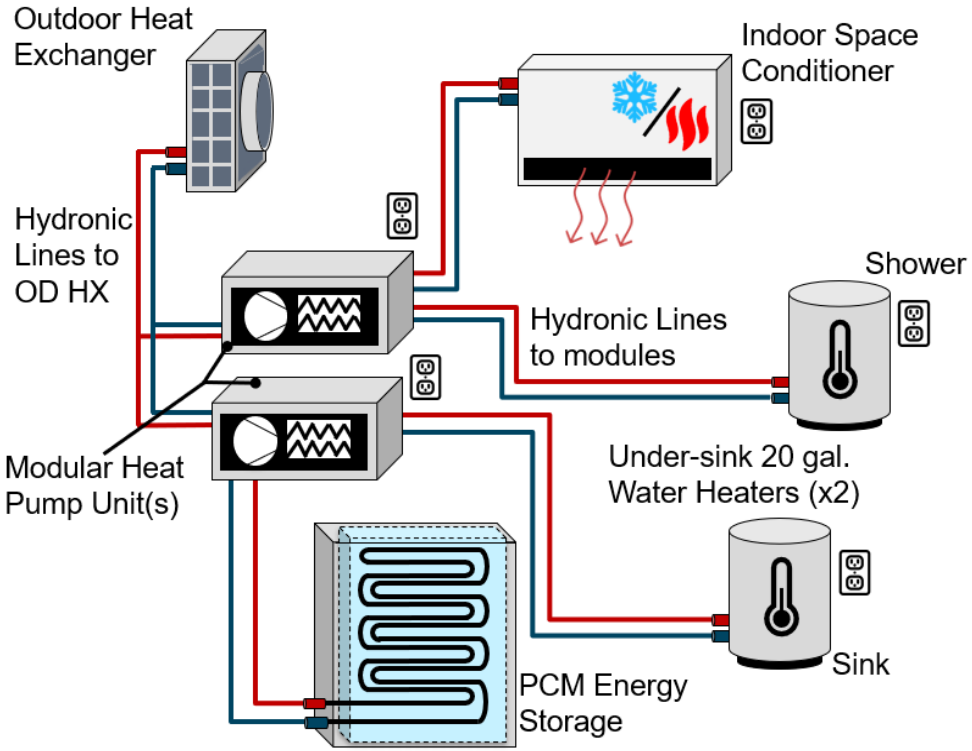
- Modular heat pump units create thermal energy interconnection
- Consumers can upgrade their HVAC system selectively without professional installation
- Applicable to single-family and multi-family homes, and apartments

Minimum Viable Product Set

- 1x Modular Heat Pump Unit
- 1x Outdoor Heat Exchanger
- 1x Indoor Unit (water heater or space conditioner)

Plug-and-play & Grab-and-go

- 120 V power source like other consumer products
- Hydronic connections between units allow for DIY assembly/disassembly



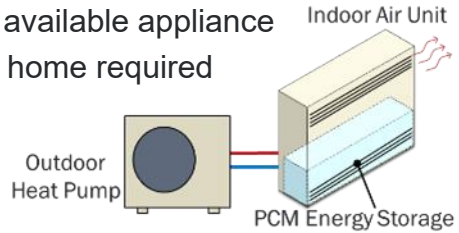
Approach – All-encompassing HVAC technology

Packaged Window Heat Pump

- Cooling and heating window unit
- Space conditioning only
- No storage or GEB capability

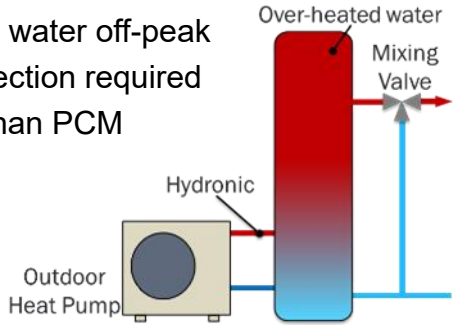
Thermal Storage Mini-Split Heat Pump

- Thermal energy storage during off-peak
- Space conditioning is only available appliance
- Refrigerant connections at home required



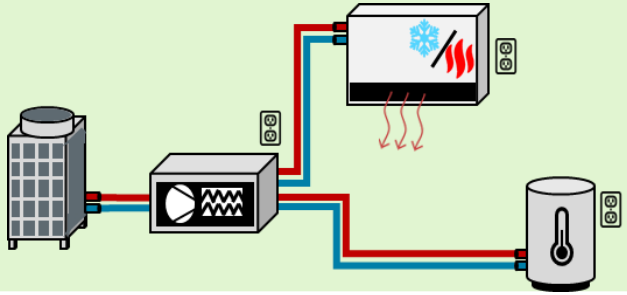
Water Heater Storage System

- CO_2 heat pump over-heats water off-peak
- High-voltage (240 V) connection required
- Water less energy dense than PCM



GEB by ME Ecosystem

- Multiple appliances
- Easy DIY 120 V and hydronic quick-connects
- Energy storage and grid-connected load shifting



Approach – Novel Cost Solution & Equipment Development

Lower Cost through Simple Installation

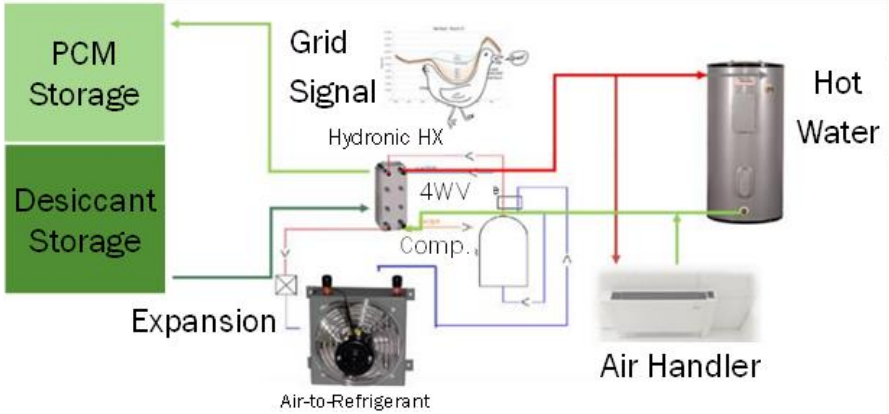
- DIY installation through quick-connect hydronics, plug and play/grab and go device ecosystem
- 120 V plug-in power for each module

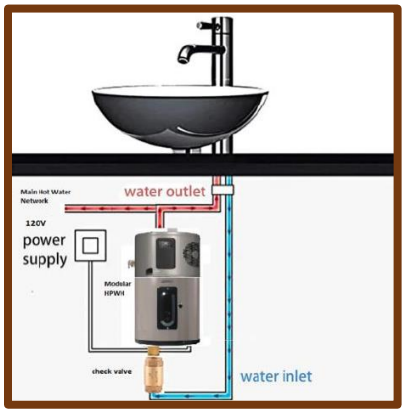
Device Ecosystem

- Modular HVAC components communicate and work together
- Reversible heat pump integration with thermal energy appliances facilitates response to different appliance demands and grid signals

Modular 20-gal Heat Pump Water Heater

- Compact, modular 20-gal HPWH to provide instant hot water at use location, connected to main hot water network
- Focus on FHR (smaller tank) and low cost (market competitive)





Approach – Market Engagement and Stakeholders

Market Impact

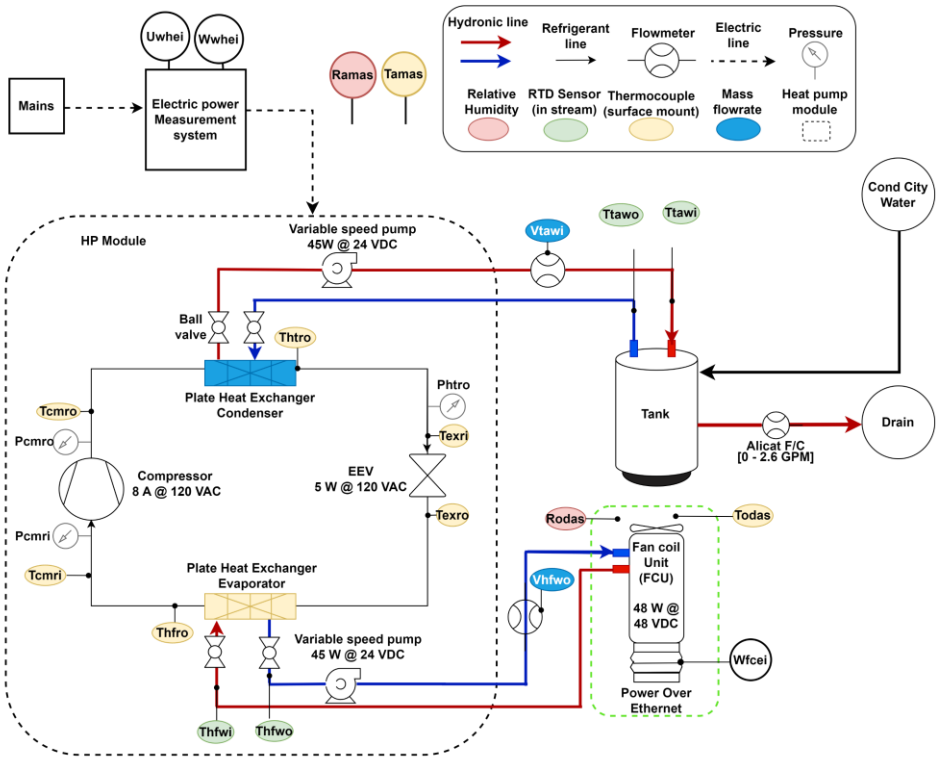
- Allow for **low-cost installation and easy retrofit** with plug-and-play modularity of components
- Result in a payback period shorter than 5 years due to the higher whole-house energy efficiency and easier installation

Market Engagement

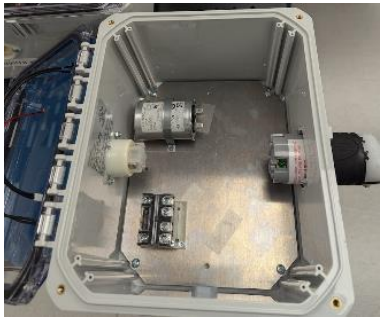
- Will seek multiple stakeholder viewpoints on stakeholder needs and preferences, cost targets and affordability
  - ✓ *E*.g., building owners/occupants, supply chain, retrofit workforce network, utilities, low-income programs and organizations
- Will publish a market assessment of the modular equipment system

Progress – Experimental

- **First Breadboard Prototype for Water Heating**
- **Overview**
  ORNL has designed and is building the first breadboard prototype for modular water heating.
- **Design Documentation**
  - Detailed P&ID Diagram
  - Detailed Electrical Diagram
- **Components**
  - Fan coil unit designed to be powered over Ethernet (PoE) – 48V, < 1 amp
- **Current Status**
  - Breadboard prototype is in progress

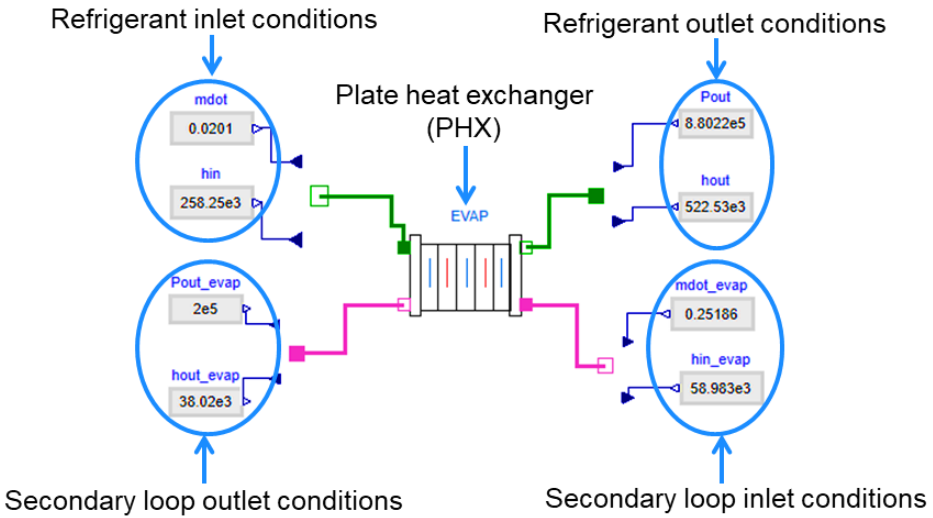


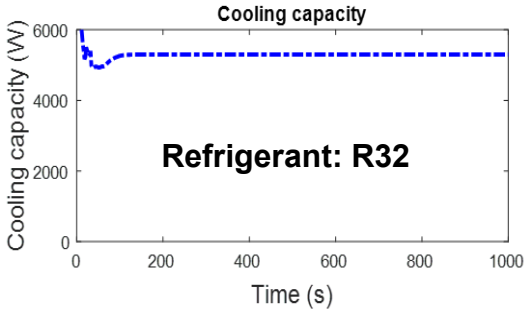
Progress – Experimental Setup

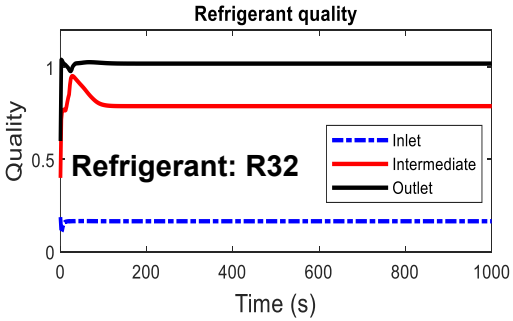


Progress – Modeling

- **Modeling Platform Development**
  - Developing detailed components and system level modular model in Modelica
  - Provide final optimized configuration for field prototype
- **Detailed components model for**
  - Compressor, and EEV
  - Indoor/Outdoor Heat Exchanger
  - Thermal Storage Tank (Sensible/Latent)
  - Secondary Loop
  - Thermal Storage Tank (Sensible/Latent)
- **Current Status**
  - Developing component model and simplified cycle model for verification
- **Future Work**
  - Model validation with experimental data



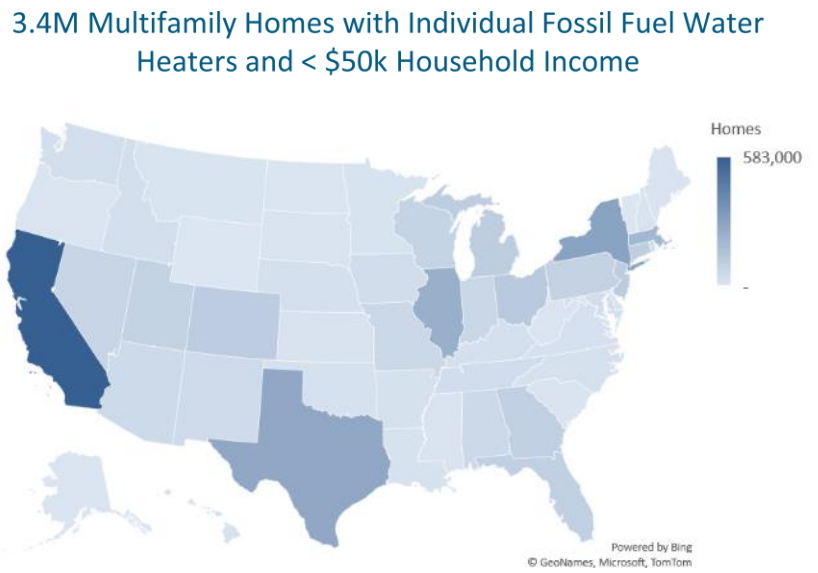




Progress – Assessment of Potential Market #1

- Target: Multifamily homes with individual (1 per residence) fossil-fuel water heaters installed in the home and less than $50,000 household net income.
- Impact: Energy use reduction resulting from HPWH efficiency improvement

Rank	State	# of Homes	% of MF Homes
1	California	583,000	14%
2	New York	292,000	8%
3	Texas	269,000	10%
4	Illinois	236,000	14%
5	Massachusetts	202,000	18%
6	Ohio	120,000	12%
7	Colorado	111,000	19%
8	New Jersey	110,000	9%
9	Michigan	107,000	15%
10	Connecticut	103,000	23%

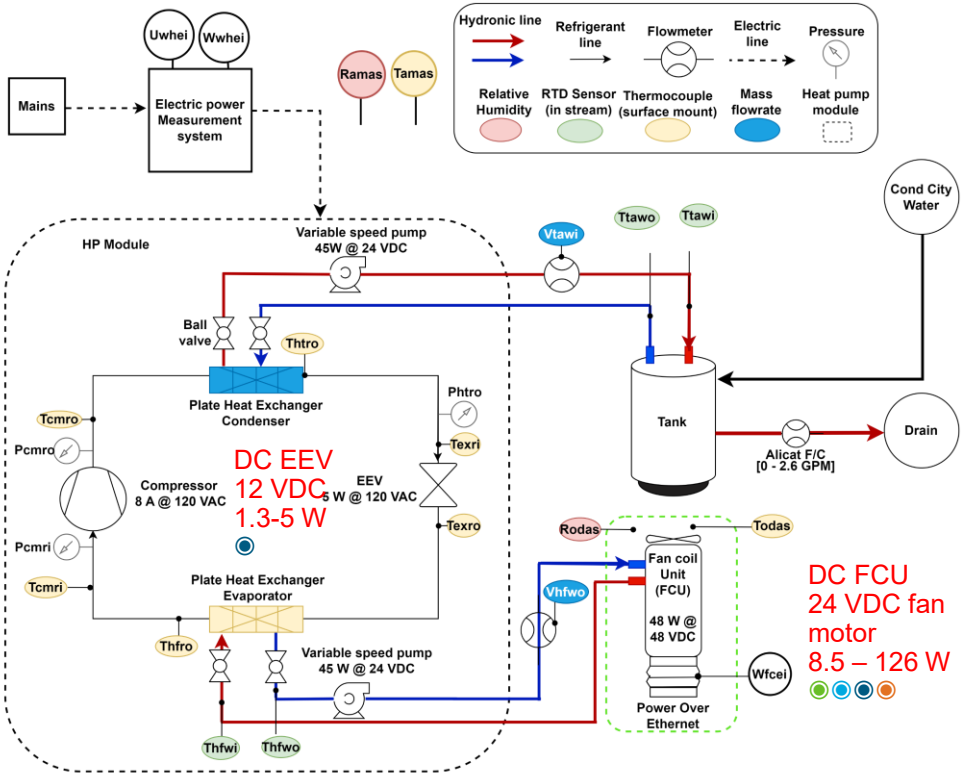


Progress – Assessment of Potential Market #2

- Target: Commercial buildings with point-of-use electric tankless water heaters that are converted to modular HPWHs.
- Impact: Peak demand (kW) reduction, estimate by building type. For context, typical commercial electric demand charges can range from $6 to $14 per kW per 2017 NREL research.

	Building Type	No. of Buildings	Average Sq. Ft.	Average kW Demand Reduction per Building
1	Office	81,000	24,000	3.7
2	Assembly	79,000	11,000	8.4
3	Vehicle repair/storage	79,000	9,900	1.7
4	Non-refrigerated Warehouse	78,000	36,100	1.8
5	Strip Mall	55,000	38,500	4.5
6	Retail	52,000	7,200	1.8
7	Education	48,000	12,500	10.0
8	Restaurant	36,000	5,000	2.5

Progress – Assessment of Compatibility with Commercial DC Distribution Technologies



DC Circulation Pump
12/24 VDC
7 - 45 W

DC Compressor
24/48 VDC
530 – 1037 W

DC EEV
12 VDC
1.3-5 W

DC Circulation Pump
12/24 VDC
7 - 45 W

DC FCU
24 VDC fan motor
8.5 – 126 W

- Emerge Alliance
  Class 2 NEC power
  24 VDC
  100 VA (W)
  $
- Power over Ethernet
  Class 2 NEC power + data
  48-56 VDC
  90 W per port
  $$
- USB 3.0
  Class 2 NEC power + data
  5-48 VDC
  240 W
  $$
- Fault Managed Power
  Class 4 NEC power + data
  up to 450 V (AC or DC)
  2 kW
  $$$

Future Work & End Vision

Future Work

- Modular heat pump water heater development, prototyping, and validation for hardware
  - ✓ Sizing and selecting compressor, heat exchangers, compressorized system components, storage tank
  - ✓ Goal of UEF > 3.3 and FHR > 30 gal per one modular 20-gal HPWH unit
- Modular modeling and simulation platform development (UMD)
- Modular reversible hydronic heat pump development integrated with water heater and energy storage
- Expand and evaluate reversible hydronic heat pump system with water heater, energy storage, and outdoor system addition
- Supervisory agent-based, grid-responsive modular controls development
- Updated/additional market and technology assessments (PNNL)

End vision: A new affordable modular plug-and-play HVAC product ecosystem

- Demonstrate proof-of-concept hardware, potentially using commercially available DC electrical distribution technologies
- Demonstrate modular controls that enable simple plug-and-play system operation
- Provide modular modeling and simulation platform for a) supporting design and analysis, and b) predicting performance of real-world systems
- Provide assessment of multiple potential target markets, and develop product-to-market commercialization strategy with Original Equipment Manufacturer (OEMs)

Thank you

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Kyle Gluesenkamp
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Project Execution

	FY2024				FY2025				FY2026			
Planned budget	$675k				$675k				$0			
Spent budget	$543k (incl. late FY23)				plan: $762k (incl. sub)				plan: $720k (incl. sub)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Milestone: Market and Technology Assessment	◆											
Milestone: Detailed design of Modular HPWH Platform			◆									
Future Work												
Milestone: Modular Modeling Platform Development					◆							
Milestone: Assemble and Instrument the Modular HPWH Prototype					◆							
Milestone: Laboratory Performance Evaluation verified the performance goals, reaching a UEF >3.3 and FHR >3 gallons				◆	◆							
Milestone: Market and Technology Landscape					◆							
Milestone: Establishment of co-simulation platform					◆	◆						
Milestone: Whole HPWH Unit Model Development and Verification						◆	◆					
Milestone: Assemble and Instrument Modular Reversible Hydronic Prototype in Environmental Chamber and achieve 60% peak load shifting and 50% CO_2 reduction for a single bedroom								◆				
Milestone: Simulate Whole House Energy Management								◆	◆			
Milestone: Modular System Control Optimization									◆	◆		
Milestone: Design and Fabricate a modular hydronic heat pump for field demonstration									◆	◆	◆	
Milestone: Start Field Demonstration of modular HPWH												◆
Submit the project final report												◆

◆ Target

◆ Actual

Subcontract to University of Maryland was in place FY24 Q4

Team

Project Lead, System Design, Experimental, and Controls (Oak Ridge National Laboratory)

Kyle Gluesenkamp
Distinguished
R&D Staff

Bo Shen
Senior
R&D Staff

Xiaobing Liu
Senior
R&D Staff

Navin Kumar
Technical
Staff

Borui Cui
Associate
R&D Staff

Sajjan Pokhrel
Postdoctoral
Researcher

Joshua Stiborek
Postdoctoral
Researcher

Market and Technology Assessment (Pacific Northwest National Laboratory)

Michael Poplawski
Chief Engineer
Team Lead

Josh Butzbaugh
Energy Analyst

Anay Waghale
Electrical Engineer 3

Modeling, Controls, and Optimization (University of Maryland, CEEE)

Reinhard Radermacher
Director CEEE
Minta Martin Professor

Vikrant C Aute
Co - Director CEEE
Research Professor

James Tancabel
Postdoctoral
Researcher

Haopeng Liu
Postdoctoral
Researcher