DOCKETED

Docket Number:	22-DECARB-01
Project Title:	Heat Pump and Decarbonization Goals
TN #:	242601
Document Title:	Presentation - Opportunities for PNNL-CEC Collaboration Heat Pumps and Heat Pump Water Heaters
Description:	Presentation from Joshua Butzbaugh (PNNL)
Filer:	Gabriel Taylor
Organization:	Pacific Northwest National Laboratory
Submitter Role:	Public Agency
Submission Date:	4/6/2022 3:17:18 PM
Docketed Date:	4/6/2022

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Opportunities for PNNL-CEC Collaboration: Heat Pumps and Heat Pump Water Heaters

April 5, 2022

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Agenda

- **Background**
  - Capabilities at PNNL
  - E3 Initiative
- **Recent HP and HPWH Research (2019-2021)**
- **Current HP and HPWH Research (2022 and beyond)**
- **Questions/Answers**

Background – PNNL Capabilities

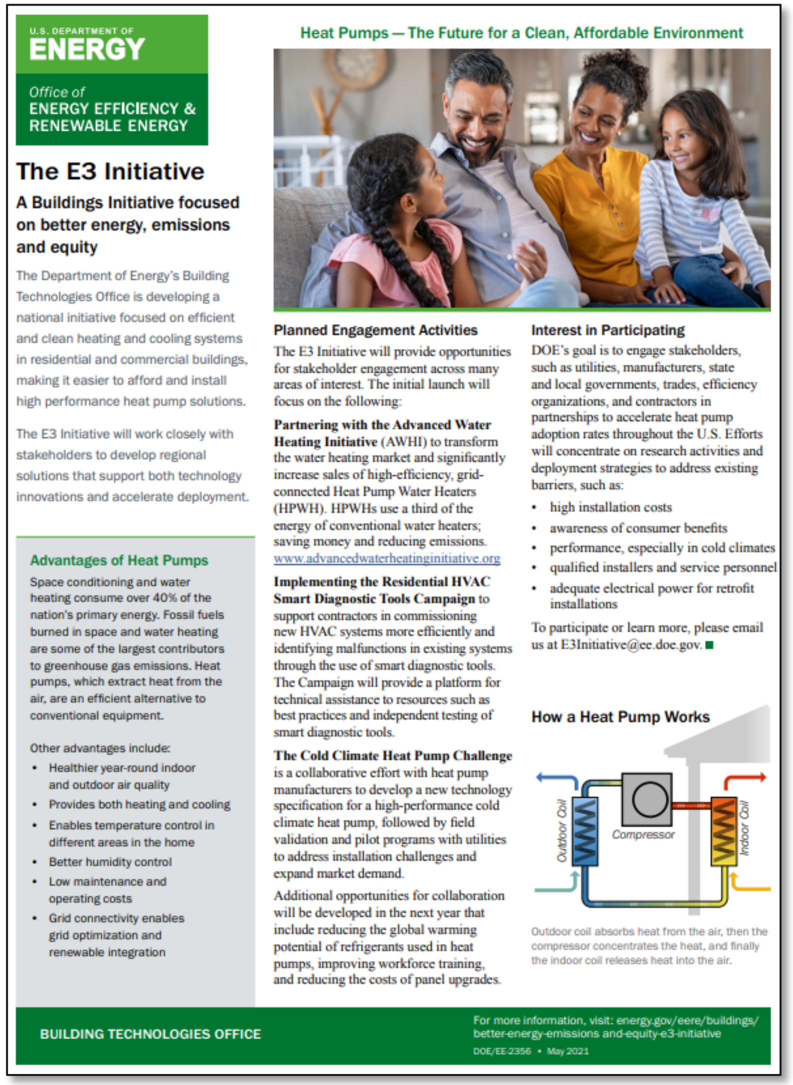
- PNNL has extensive research and analysis capabilities for residential and commercial buildings
  - Lab testing
  - Field validation
  - Technology assessment
  - Specification development
  - Energy use analysis
  - National impact assessment
  - Greenhouse gas emissions
  - Campaigns/challenges
- PNNL research facilities include:
  - Lab Homes
    - Side by side identical homes with simulated occupancy
    - Represent typical existing homes (1,500 sq ft, 3 bedroom, 2 baths)
  - Environmental test chambers
    - Testing air-to-air HVAC systems between 2 – 10 tons
    - Outdoor chamber designed for 0°F - 125°F air conditions
  - IoT common operating environment

PNNL Lab Homes

PNNL Environmental Chambers

Background – E3 Initiative

- Increasing renewable energy generation and electrifying end uses is a viable way to decarbonize buildings
- In May 2021, Secretary Granholm announced the Initiative for Better Energy, Emissions, and Equity (E3)
  - **Cold Climate Heat Pump Technology Challenge**: aims to reduce the carbon footprint of cold climate heating solutions in U.S. by improving energy efficiency and affordability
    - Collaboration with manufacturers to develop a specification for high-performance cold climate heat pumps
    - Field validation and pilot programs with utility providers to address installation challenges and expand market demand
  - Announced partnership with the **Advanced Water Heating Initiative** to increase market adoption of heat pump water heaters (HPWH)
  - Called for development of **low to no global warming potential (GWP) refrigerants** through industry collaboration
  - Spotlighted workforce training: **Smart Tools for Efficient HVAC Performance Campaign,** formerly known as the Residential HVAC Smart Diagnostic Tools Campaign



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Heat Pumps — The Future for a Clean, Affordable Environment

The E3 Initiative

A Buildings Initiative focused on better energy, emissions and equity

The Department of Energy's Building Technologies Office is developing a national initiative focused on efficient and clean heating and cooling systems in residential and commercial buildings, making it easier to afford and install high performance heat pump solutions.

The E3 Initiative will work closely with stakeholders to develop regional solutions that support both technology innovations and accelerate deployment.

Advantages of Heat Pumps

Space conditioning and water heating consume over 40% of the nation's primary energy. Fossil fuels burned in space and water heating are some of the largest contributors to greenhouse gas emissions. Heat pumps, which extract heat from the air, are an efficient alternative to conventional equipment.

Other advantages include:

- Healthier year-round indoor and outdoor air quality
- Provides both heating and cooling
- Enables temperature control in different areas in the home
- Better humidity control
- Low maintenance and operating costs
- Grid connectivity enables grid optimization and renewable integration

Planned Engagement Activities

The E3 Initiative will provide opportunities for stakeholder engagement across many areas of interest. The initial launch will focus on the following:

Partnering with the Advanced Water Heating Initiative (AWHI) to transform the water heating market and significantly increase sales of high-efficiency, grid-connected Heat Pump Water Heaters (HPWH). HPWHs use a third of the energy of conventional water heaters; saving money and reducing emissions. www.advancedwaterheatinginitiative.org

Implementing the Residential HVAC Smart Diagnostic Tools Campaign to support contractors in commissioning new HVAC systems more efficiently and identifying malfunctions in existing systems through the use of smart diagnostic tools. The Campaign will provide a platform for technical assistance to resources such as best practices and independent testing of smart diagnostic tools.

The Cold Climate Heat Pump Challenge is a collaborative effort with heat pump manufacturers to develop a new technology specification for a high-performance cold climate heat pump, followed by field validation and pilot programs with utilities to address installation challenges and expand market demand.

Additional opportunities for collaboration will be developed in the next year that include reducing the global warming potential of refrigerants used in heat pumps, improving workforce training, and reducing the costs of panel upgrades.

Interest in Participating

DOE's goal is to engage stakeholders, such as utilities, manufacturers, state and local governments, trades, efficiency organizations, and contractors in partnerships to accelerate heat pump adoption rates throughout the U.S. Efforts will concentrate on research activities and deployment strategies to address existing barriers, such as:

- high installation costs
- awareness of consumer benefits
- performance, especially in cold climates
- qualified installers and service personnel
- adequate electrical power for retrofit installations

To participate or learn more, please email us at E3Initiative@ee.doe.gov.

How a Heat Pump Works

Outdoor Coil

Compressor

Indoor Coil

Outdoor coil absorbs heat from the air, then the compressor concentrates the heat, and finally the indoor coil releases heat into the air.

BUILDING TECHNOLOGIES OFFICE

For more information, visit: energy.gov/eere/buildings/better-energy-emissions and-equity-e3-initiative

DOE/EE-2356 • May 2021

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Recent Research:
Heat Pump Water Heaters

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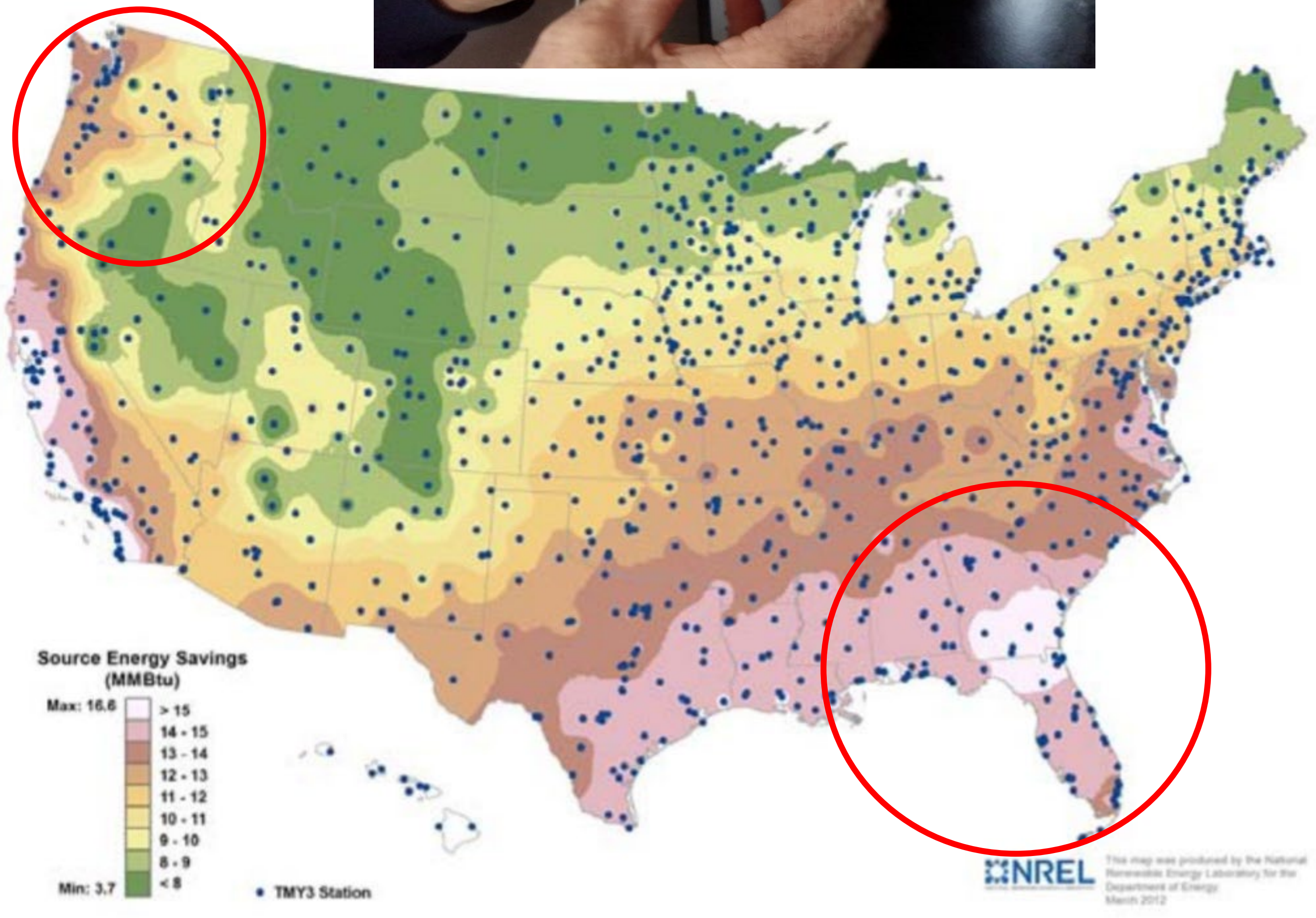
Grid-connected HPWH Field Study

Northwest and Southeast Studies

2017-2020: BPA, PGE, NEEA, and PNNL

- Over 200 water heaters with CTA-2045 devices in initial study
- Tested non-targeted, targeted, and smart load shifting strategies
- Results showed average of about 600 Wh shifted with shed events up to 5 hours



NREL Highlight: NREL Develops Heat Pump Water Heater Simulation Model, 2012. Based on research performed by Jeff Maguire.

2020-2022: PNNL and FSEC

- Load shifting lab tests of all major HPWH manufacturers across multiple tank sizes/use profiles (includes a prototype)
- Load shifting field tests in over 45 sites

This map shows the source energy savings potential of heat pump water heaters (3.37 site-to-source ratio), including effects from climate and space conditioning interactions. The white and pink areas represent the most savings.

Max Tech HPWH Field Study

Refrigerant Selection

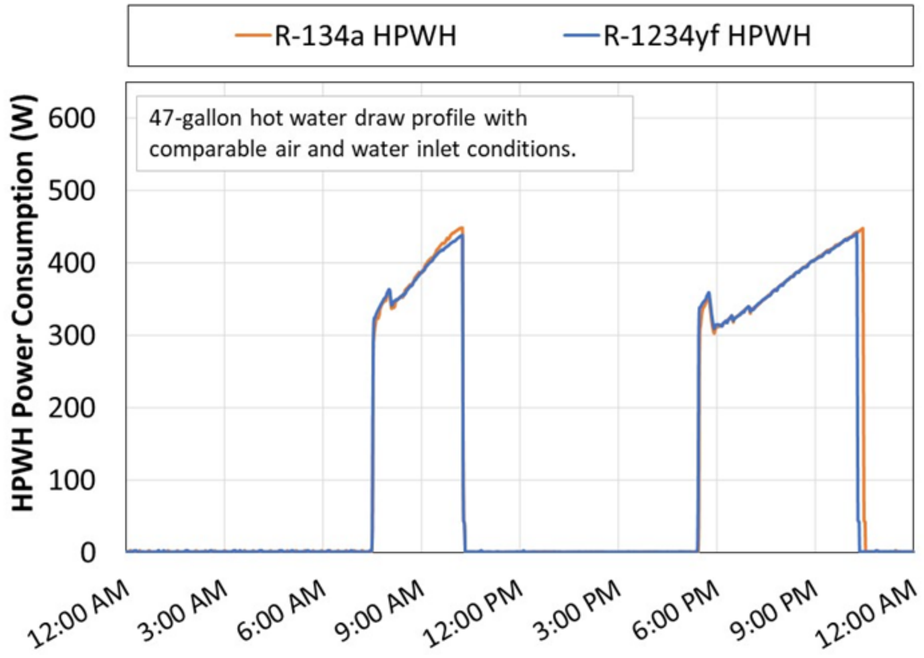
- Existing HPWHs: R-134a (GWP of ~1,300)
- Max Tech: **R-1234yf (GWP of ~1)**

System Efficiency

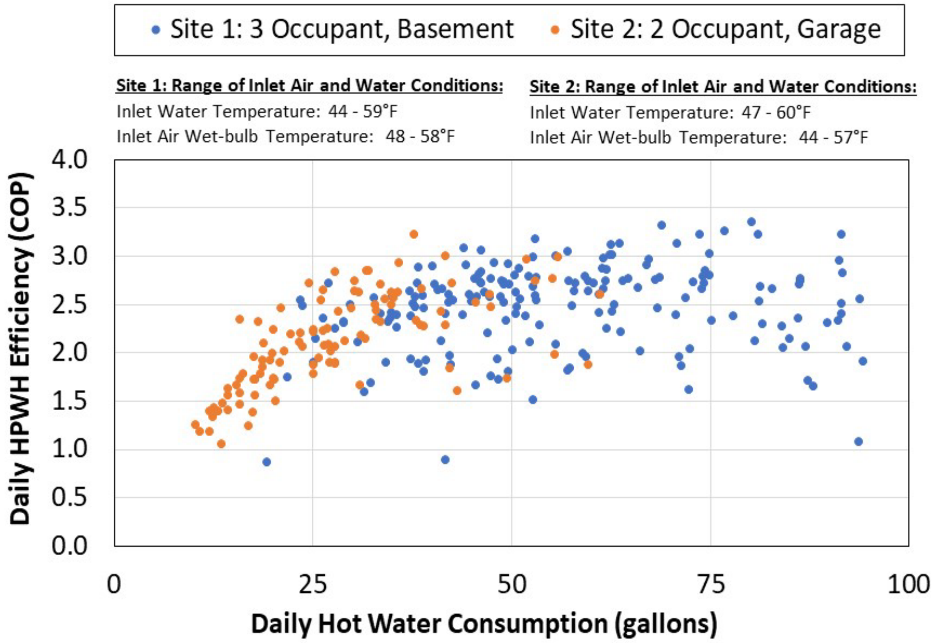
- Existing HPWHs: COPs from ~2.0 to ~3.5 in the field
- Refrigerant change-out **(maintain COP)**

Max Tech HPWH Project Roles

- Low GWP refrigerant selection and charge optimization w/ manufacturer – ORNL ET
- **Lab home testing – ORNL/PNNL RBI**
- **Occupied field site evaluation - PNNL RBI**
  - **Institutional Review Board (IRB) approval**
  - **Field Site Recruitment**
  - **Subcontract with electrician/safety protocols**
  - **Data collection, analysis, reporting**



Side-by-side R-134a and R-1234yf HPWH evaluated under a variety of identical conditions

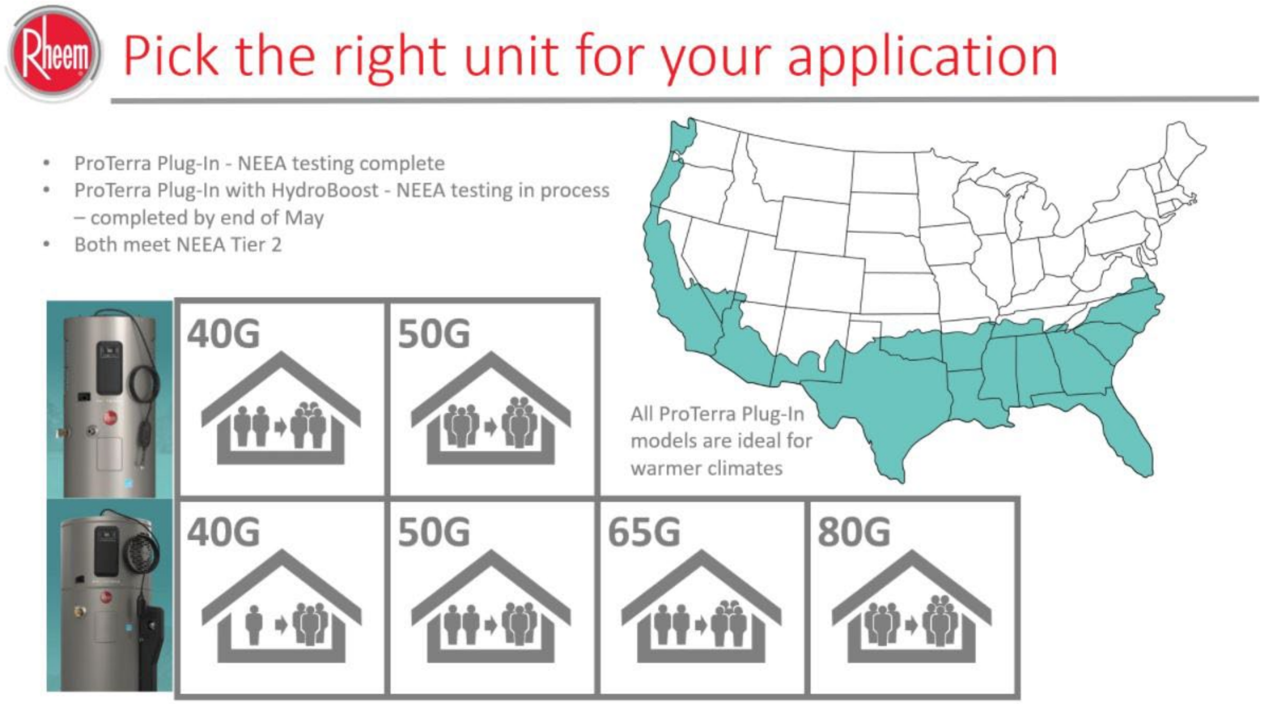


Operational and Homeowner View:

- 16 months of issue-free operation
- Positive homeowner survey results

A Path To Decarbonizing Residential DHW Loads
Background

- Converting fossil fuel water heaters to HPWHs is expensive when a home doesn't have enough electrical capacity to accommodate a 240-volt HPWH
- Plug-in 120-volt HPWHs can operate on a 15-amp circuit to accommodate homes without the electrical service and panel capacity for 240v HPWHs
- **The 120v HPWH doesn't have an auxiliary heat source, and thus has performance limitations in colder climate locations**, especially where water heaters are installed in semi-conditioned or unconditioned spaces



A Path To Decarbonizing Residential DHW Loads

Hot Water Delivery Capability

Assessed the one-hour hot water delivery capability of 240v and 120v HPWHs compared to the typical gas storage and electric-resistance water heaters (gallons of output)

	Rochester, MN Basement		San Diego, CA Garage		Seattle, WA Garage	
Water HeaterType	1-hr Delivery Capability	% Difference with Gas Storage	1-hr Delivery Capability	% Difference with Gas Storage	1-hr Delivery Capability	% Difference with 5.5 kW ERWH
240v HPWH, 50-gal	54	-22%	59	-31%	56	-14%
240v HPWH, 65-gal	63	-8%	69	-20%	66	1%
240v HPWH, 80-gal	73	6%	78	-9%	75	15%
120v HPWH, 50-gal, 500 W HP	43	-38%	43	-50%	42	-35%
120v HPWH, 50-gal, 500 W HP, Mixing Valve	49	-30%	51	-41%	49	-25%
120v HPWH, 65-gal, 500 W HP	53	-23%	53	-38%	53	-19%
120v HPWH, 65-gal, 500 W HP, Mixing Valve	61	-12%	64	-26%	62	-5%
120v HPWH, 80-gal, 500 W HP	64	-8%	64	-26%	63	-3%
120v HPWH, 80-gal, 500 W HP, Mixing Valve	73	6%	77	-11%	74	14%
Gas Storage, 40 gal, 38 kBtu/h	69	0%	86	0%	78	20%
ERWH, 50 gal, 4.5 kW	56	-19%	63	-26%	60	-8%
ERWH, 50 gal, 5.5 kW	61	-12%	70	-19%	65	0%

Rochester Basement
- Inlet water temp: 38 °F
- Wet bulb air temp: 50 °F

San Diego Garage
- Inlet water temp: 60 °F
- Wet bulb air temp: 34 °F

Seattle Garage
- Inlet water temp: 50 °F
- Wet bulb air temp: 38 °F

$$GD_{1hr} = (Vol * Tank_u) + (Q_{in} * Eff) / (dT * Cp * y)$$
$$GD_{1hr\text{-}120\text{-}mv} = (Vol * Tank_u * (T_{mix}-T_{inlet})/(T_{del}-T_{inlet})) + (Q_{in} * Eff) / (dT * Cp * y)$$
$$GD_{1hr\text{-}240} = (Vol * Tank_u) + ((Q_{in\text{-}hp} * Eff_{hp} * F_{hp}) + (Q_{in\text{-}er} * Eff_{er} * F_{er})) / (dT * Cp * y)$$

A Path To Decarbonizing Residential DHW Loads

HPWH System Design – Decision Points

San Diego, CA – 4 Bedrooms – 500 W Compressor – Garage and Closet Installations

System Configuration	HP Location	Integrated Mixing Valve	Tank Size (Gal)	HPWH Hours	ER Hours	Runout Events	Annual GHG Savings (MTCO2e)	Annual Utility Bill Savings ($)
120V	Closet	Y	80	3558	0	0	0.874	$ 91
240V	Closet	Y	80	3554	2	0	0.873	$ 90
120V	Garage	Y	80	3603	0	0	0.865	$ 83
240V	Garage	Y	80	3596	3	0	0.863	$ 81
120V	Closet	N	80	3481	0	1	0.890	$ 104
240V	Closet	N	80	3475	4	1	0.887	$ 102
120V	Garage	N	80	3521	0	1	0.882	$ 97
240V	Garage	N	80	3514	4	1	0.878	$ 94
120V	Closet	Y	65	3554	0	1	0.875	$ 91
240V	Garage	N	65	3501	12	1	0.872	$ 89
240V	Closet	Y	65	3547	4	1	0.871	$ 89
120V	Garage	Y	65	3599	0	1	0.865	$ 83
240V	Garage	Y	65	3591	4	1	0.862	$ 81
240V	Closet	N	65	3464	11	2	0.882	$ 97
120V	Closet	N	65	3473	0	4	0.891	$ 106
120V	Garage	N	65	3511	0	4	0.883	$ 98

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Recent Research:
Heat Pumps

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Grid-Connected Multi-Split HPs Field Study

Objective

- Examine the load shifting potential of CTA-2045 Residential Heat Pumps in the field as a complementary grid resource.

Collaborators

- Utilities: Bonneville Power Administration, Portland General Electric, Cordova Electric Cooperative
- CTA-2045 Implementer: E-radio

Field Sites located around Portland, OR and Cordova, AK

Approximately 10 field sites with 20 controllable indoor units

Residential Field Site Characteristics		% of Recruited Field Sites
Indoor Unit Type	Ductless	92%
	Ducted	8%
Number of Indoor Units with Heat Pump	1	23%
	2	38.5%
	3	38.5%

CTA-2045 Adapter to Indoor Unit

Multi-Split Heat Pump

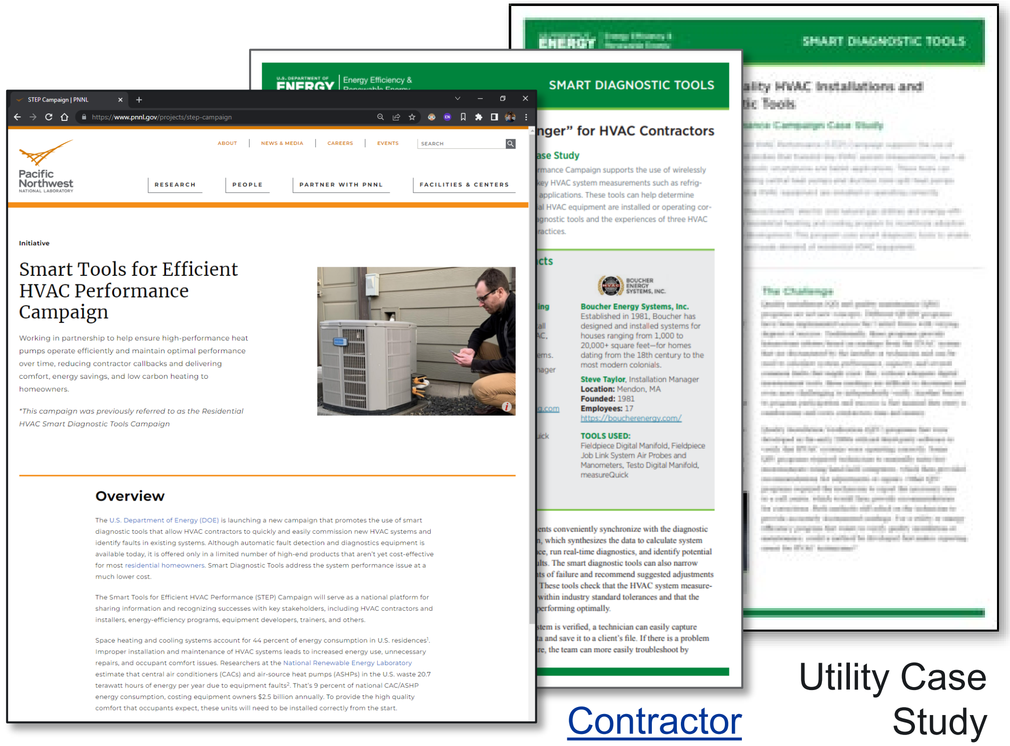
Smart Tools for Efficient HVAC Performance (STEP) Campaign

STEP
SMART TOOLS FOR EFFICIENT HVAC PERFORMANCE
CAMPAIGN

- Organizing committee

BUILDING PERFORMANCE ASSOCIATION · ACCA · U.S. DEPARTMENT OF ENERGY · neea · CEE Working Together, Advancing Efficiency · NATE · Pacific Northwest National Laboratory

- Resources to support overcoming barriers to adoption (STEP fact sheet, contractor case study, utility case study, smart diagnostic tool training material)
- Outreach to Campaign early adopters and pilot partners
- Campaign webpage: https://www.pnnl.gov/projects/step-campaign



Webpage

Contractor Case Study

Utility Case Study

Early Adopter Supporters and Participants

Arkansas HVACR Association "Coming Together to Serve Arkansas" · New York State of Opportunity · Tru Tech Tools Quality Tools. Essential Support. · Boucher Energy Systems, Inc. · Holliday Heating + Cooling · Jeff Remick Ack-Air Duct LLC · slipstream · mass save Savings through energy efficiency · ICF · testo · bluon · mQ · cee

AFDD Projects

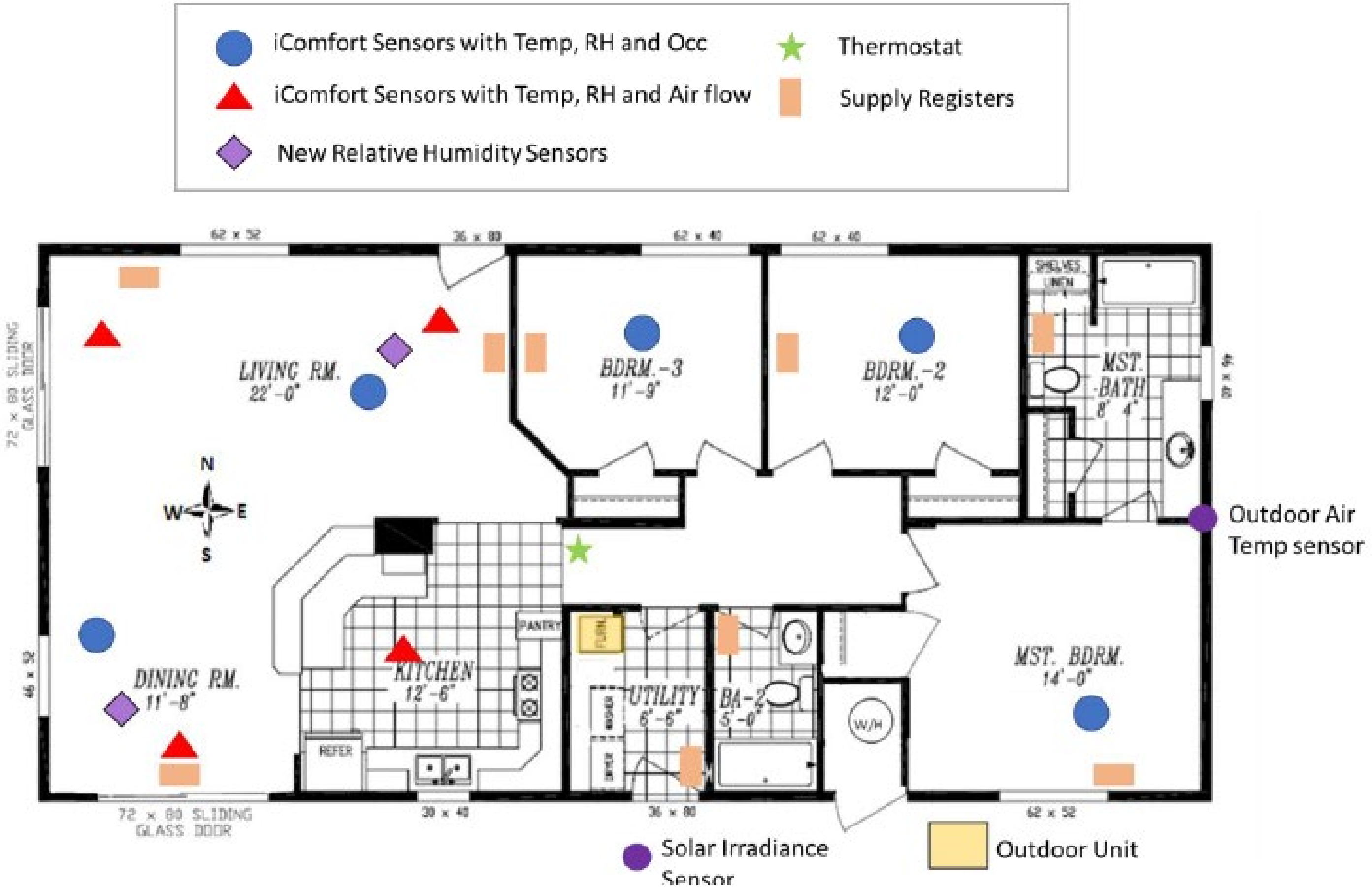
IoT Based Comfort Control and Fault Diagnostics System for Energy Efficient Homes

- Scope for PNNL: Test new iComfort FDD system in the PNNL Lab Homes
- Partners: Texas A&M University, Clemson, Drexel University

Development and Validation of Home Comfort System

- Partners: University of Oklahoma
- Scope for PNNL: Collecting data in the PNNL Lab Homes, help develop and test algorithms

AFDD Residential Market Analysis
https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-30077.pdf



Cold Climate Packaged Heat Pumps

- Large potential for reverse cycle heating in heat pump technologies, with corresponding energy savings and reductions in carbon emissions
  - Large market for room/zonal space conditioning equipment, historically focused on cooling
  - PTACs use electric resistance heat; current PTHPs use electric resistance heat below outdoor temperatures of ~40ºF; few RACs provide heating

- PNNL performed a technology assessment and energy/carbon analysis to understand the viability of a Technology-to-Market Competition for ccPHPs
- Technology assessment identified the removal of defrost meltwater during heating as the primary technological barrier
  - Retrofitting drainage in the replacement market is invasive and costly (shown on right)
  - Accommodating drainage is straightforward in the new construction market, but calls for market, builder, and codes coordination
- Other market barriers include: first cost, limited production, lack of third-party validation, and limited buyer awareness

Cold Climate Packaged Heat Pumps

- Hotel/motel/lodging is currently the primary building type for PTAC/PTHPs with ~80% of stock
  - Heating loads were modeled for lodging applications by building vintage and climate zone
  - Conclusion: Significant opportunity in replacements/retrofits in older buildings in cold climates

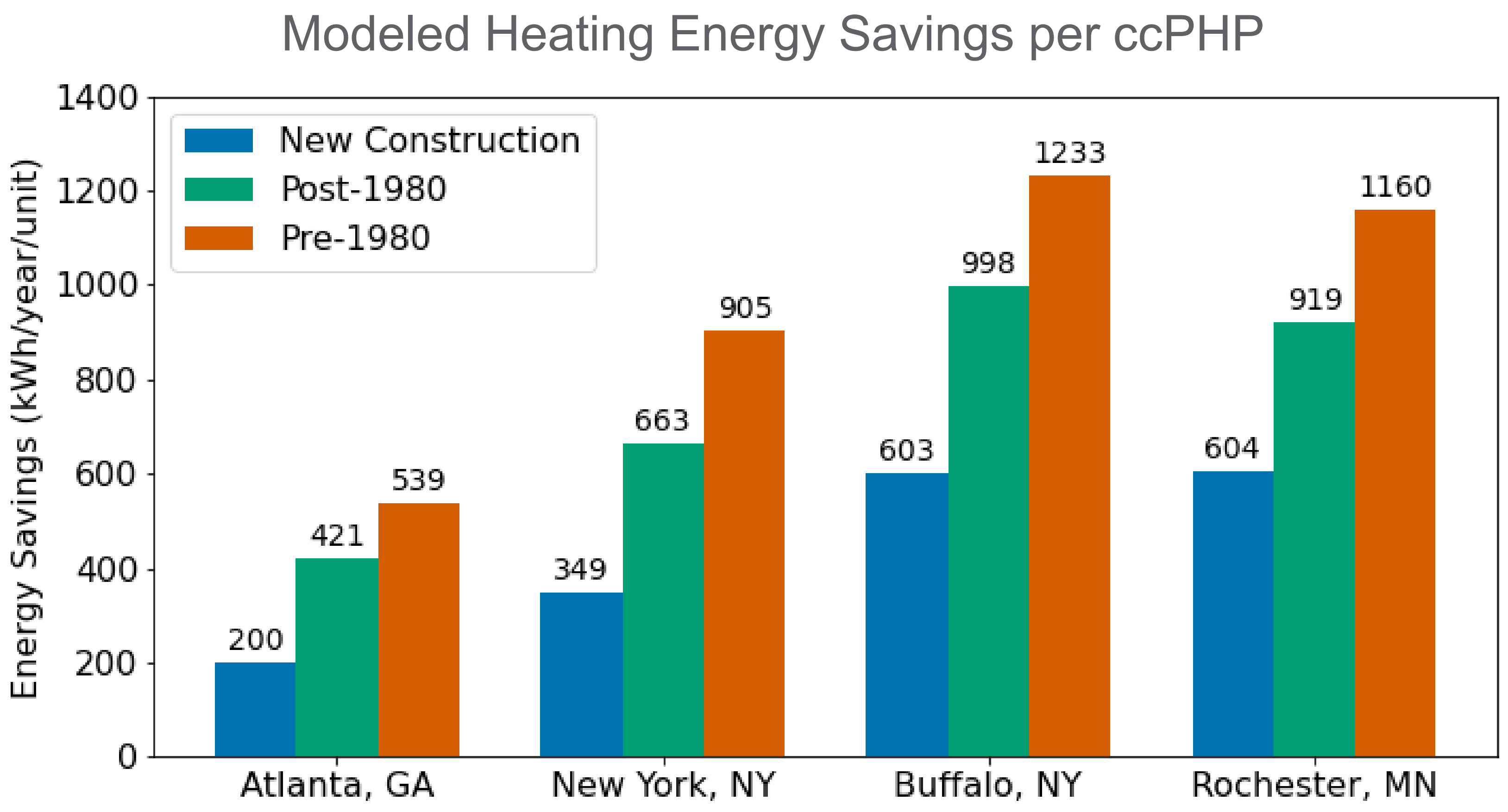


Figure. Modeled annual heating energy savings (kWh/year) for a ccPHP with a compressor shutoff temperature of 5°F for each location and building vintage.

Climate Zone	City
3	Atlanta, GA
4	New York, NY
5	Buffalo, NY
6	Rochester, MN

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Current Work

Summary of Current Work

HP Strategies in Disadvantaged Communities (Partner: Launch Point Community Center in Houston, TX)

- Research questions regarding how to reach disadvantaged communities for HVAC workforce and fuel switching messages to consumers

Decision Guidance for Contractors for HPs and HPWHs

- Includes decision trees for siting, sizing, electrical, ducting, and drainage.
- Opportunity to answer remaining research questions
- Focus on technical guidance

120v HPWH Field Validation

- Working closely with the Advanced Water Heating Initiative led by New Buildings Institute
- Using the same field validation protocol where possible

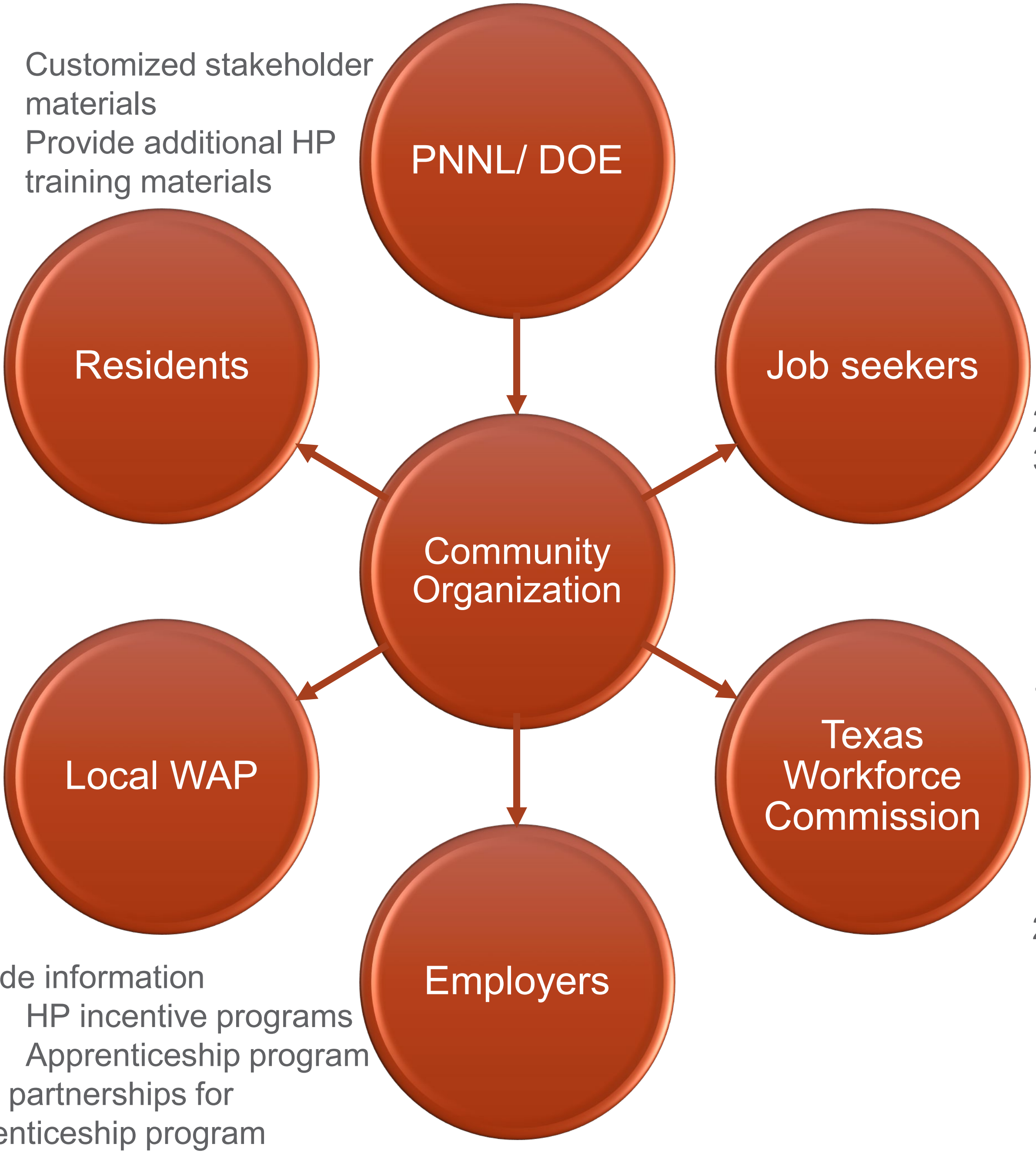
Multipurpose HP/HPWH at PNNL Lab Homes

- Evaluate performance of as-shipped and unique operating modes (heat recovery, simultaneous space and water heating, etc.)
- Consider the feasibility of system for broader residential applications
- Provide guidance for next steps and future deployment of system

HP and HPWH Database

- Collecting existing HP and HPWH field data
- Collecting new HP and HPWH field data
- Aggregate data visualization and downloads

Heat Pump Strategies for Disadvantaged Communities



PNNL/ DOE

1. Customized stakeholder materials
2. Provide additional HP training materials

Residents

1. Provide information
   - Financial assistance available
   - Buying guidance
   - Low / no cost maintenance

Job seekers

1. Provide information
   - Career opportunities
   - Certification requirements
   - Apprenticeship program
2. Conduct applicant screenings
3. Offer HVAC/HP nationally recognized training

Local WAP

1. Goal to have training required for WAP preferred HVAC contractors

Texas Workforce Commission

1. Enroll trainees in apprenticeship program
   - Pay 50 – 75% of apprentice salary
   - Scholarship for training tuition
2. Enroll employers in apprenticeship program

Employers

1. Provide information
   - HP incentive programs
   - Apprenticeship program
2. Seek partnerships for apprenticeship program

Key mechanisms for dissemination of materials

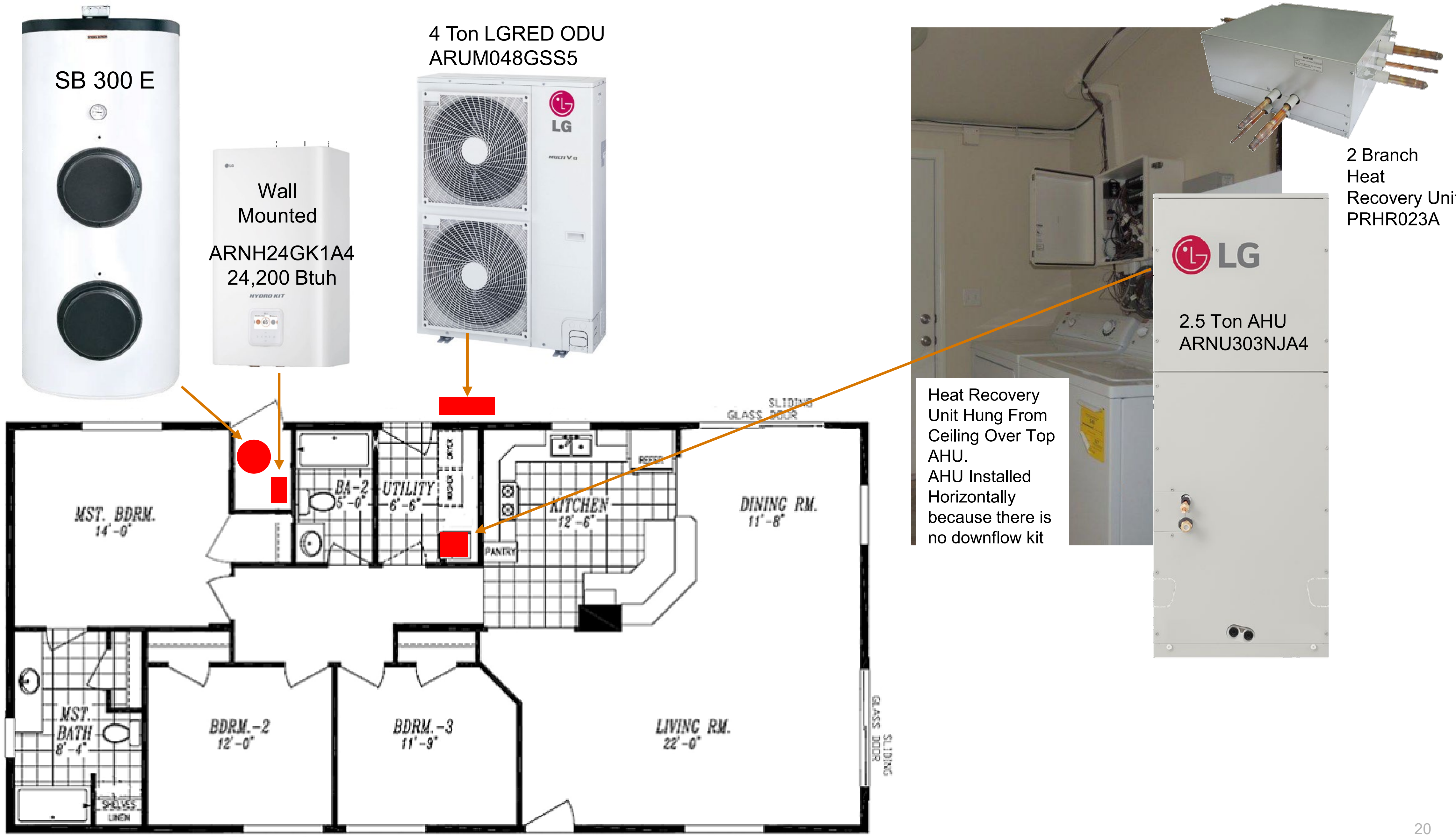
1. HVAC training courses
2. Regular community events (e.g., food drives, COVID testing, etc.)
3. Dedicated community event for awareness of HP tech / workforce

Key expected outcomes

1. Local residents trained as local WAP preferred HVAC contractors
2. Low income residents earn higher wages
3. Local residents aware of affordable options for HP tech
4. Replicable model to scaling HP workforce/ deployment nationally

Multipurpose Heat Pump Testing

Lab Home Set up for Testing



Heat Pump and HPWH Database

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Heat Pump Field Database

Log In | Register

Enter keyword Search

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Data Sharing for Industry Leaders

Aggregate heat pump and heat pump water heater data repository and data visualization tool.

Get Involved

Centralized Database for Heat Pump and Heat Pump Water Heater Field Data

Residential and commercial heat pump technologies are field tested by programs across the United States. The Heat Pump Field Database is a centralized data repository that provides easy data upload and download for the nation's leading heat pump and heat pump water heater researchers.

Users can use the buttons below to get started on any of the actions described.

Upload Your Complete Datasets
Publish data to a publicly accessible database that is accessible via the cloud.

Custom Downloads
Create queries using project metadata to filter for only the datasets that are relevant to your research.

Real-Time Visualizations
Connect to your active sites using an Application Program Interface (API). Generate plots to help troubleshoot data streams or to visualize your results in real-time.

Custom Visualizations
Create custom queries using project metadata to answer specific research questions.

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Thank you

Interested in collaborating?

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