Identifying and Removing Barriers for 120-volt Heat Pump Water Heaters in U.S. Homes



Image Source: T.J. Pilet

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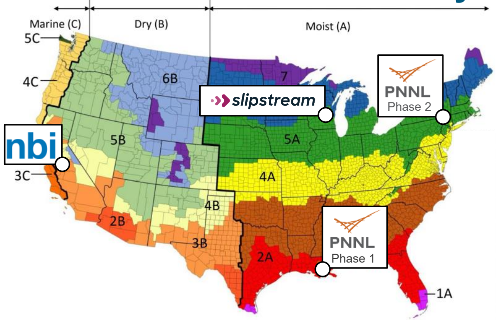
Project Summary

OBJECTIVE, OUTCOME, & IMPACT

Evaluate the energy efficiency and hot water delivery performance of 120-volt heat pump water heaters (HPWHs) and identify challenges and solutions for 120-volt HPWH installations. If successful, 120-volt HPWHs will enable up to ~10% of American homes to decarbonize their water heating without the need for panel upgrades.

120-volt HPWH Field Validation Study Locations



TEAM & PARTNERS

PNNL

Josh Butzbaugh, Tyler Pilet, Tabitha Artuso, Samuel Rosenberg, Abinesh Selvacanabady, and Cheryn Metzger

Partners

Advanced Water Heater Initiative
Rheem, A.O. Smith, All Hours Plumbing, NBI, and Slipstream

STATS

Performance Period: FY22–FY25

DOE Budget: $2.1M, Cost Share: $0k

Milestones:

FY22 Q2 – IRB for 120V HPWH in Hot Climate (New Orleans)

FY23 Q3 – Preliminary results of 120V HPWH performance

FY24 Q4 – Final Mid-Study Report of 120V HPWH in Hot Climate

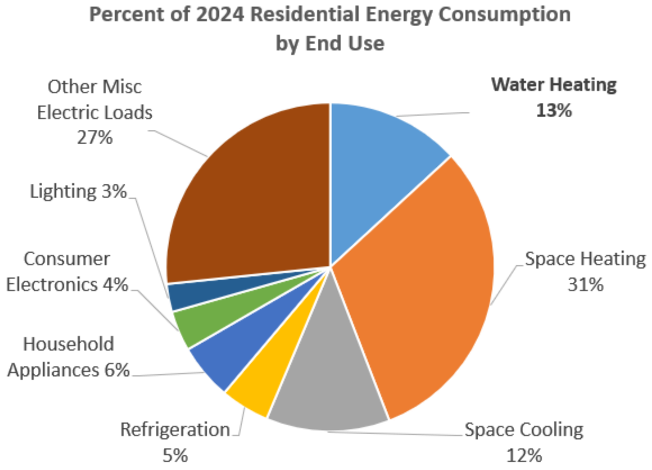
FY25 Q4 – Draft Mid-Study Report of 120V HPWH in Cold Climate

Image Source: BASC, T.J. Pilet

Problem

Water heating is the third largest energy end use in the U.S. residential sector and many homes have limited panel capacity when considering electrification

- As the U.S. decarbonizes the building stock**, 65 million homes** currently using fossil fuel water heating will need to convert to electric water heating systems.
- Fuel switching from gas water heating to **240-volt HPWHs has many complications**, namely:
  - **Limited panel capacity** and/or limited electrical service
  - **Wiring and receptacle** requirements
- Replacing a gas water heater with a 240-volt HPWH can require multiple trades on site, resulting in additional time and cost compared to a like-for-like replacement.



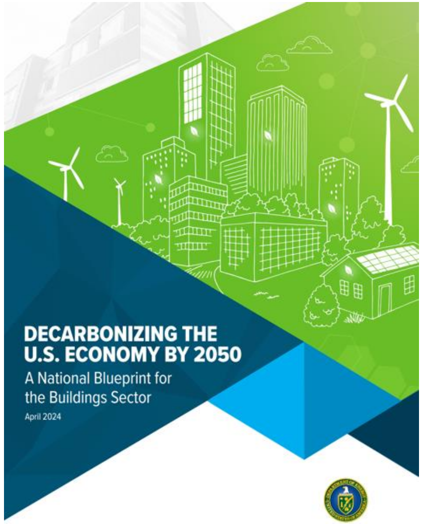
Source: U.S. EIA. March 2023. 2024 Annual Energy Outlook. Table 4: Residential Sector Key Indicators and Consumption, Reference Case.

Alignment with the Decarbonization Blueprint

*"**Approximately 10-15 million single-family homes** with fossil fuel water heaters are appropriate candidates for 120-volt HPWHs"*

This project addresses the Blueprint objective to accelerate on-site emissions reductions, specifically:

- **Heat pumps for residential** and small-to-medium commercial applications **reach 25% of water heating sales by 2035 and >90% sales by 2050**
- By 2035, **120-volt appliances are widely available and increase the ease of deploying electric equipment**
- By 2035, 25%, and by 2050, >90% of residential electricity customers are offered incentives for flexible use of their water heating equipment
- By 2050, all primary electric resistance space and water heating is replaced by heat pumps



Source: Decarbonizing the U.S. Economy by 2050: A National Blueprint for the Buildings Sector

Field Study Impact

This PNNL project fills a gap in field validation research for 120-volt HPWHs in the southeastern and northeastern U.S.

- Understand whether 120-volt HPWHs can efficiently meet residential loads in both regions **based on home size, water heater location, and temperature/humidity conditions**
- Determine **lessons learned for siting, sizing, and installing** 120-volt HPWHs at demonstration sites.

The anticipated impact of this study is to:

- **Develop best practices** for 120-volt HPWH siting, sizing, and installation
- **Help DOE develop electrification guidance** for residential water heating
- **Provide feedback to manufacturers**, and **provide guidance** to the supply chain, homeowners and property owners

120-volt HPWH Field Validation Study Locations

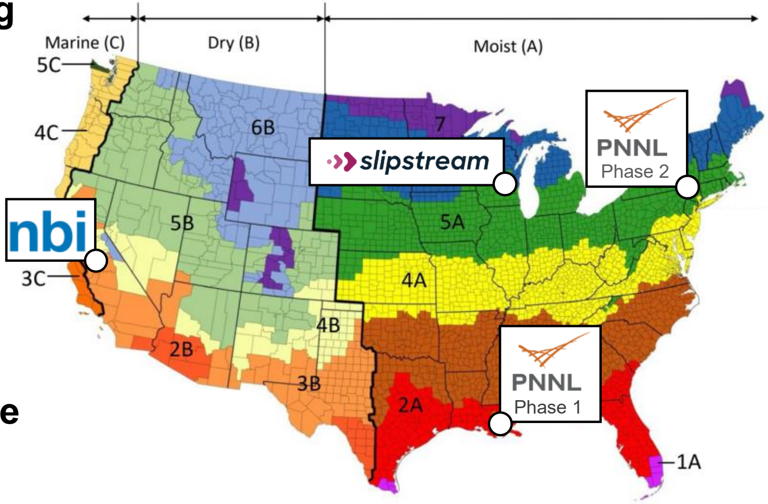


Image Source: BASC, T.J. Pilet

Approach

New Orleans provides a wide array of installation retrofits in a gas-prevalent market

- New Orleans was selected due to:
  - Its **significant percentage of fossil fuel water heating**, both storage and tankless
  - **Variety of water heater locations and installations** (e.g., outdoors, sheds, attics)
  - Cautious trades who are unfamiliar with HPWHs and gas-to-electric water heater conversion

- HPWH installations in New Orleans provide:
  - A **diverse range of home sizes and water heater locations**
  - **Opportunities for unique ducting** configurations
  - Interesting HPWH relocation scenarios (e.g., replacing tankless units)
  - Opportunities for **electrification in a gas-prevalent market**

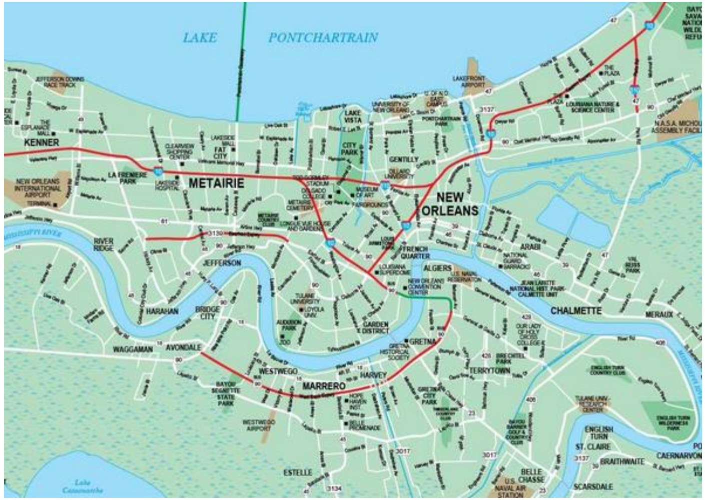


Image Source: Adobe Stock Images

Approach – Recruitment and Install Process

PNNL is working closely with manufacturers and plumbers to install/monitor the latest products

- For the first ten installations in New Orleans, **Manufacturer A was selected as the partner**, the first manufacturer to bring a plug-in 120-volt HPWH product to market.
- **The second round of installations in New Orleans were Manufacturer B's 120-volt HPWH.**
- Recruited a licensed plumber, held planning meetings with each manufacturer, and a representative from Manufacturer A attended the first two installations to help train the installer.
- Participant recruitment required filling out a **pre-installation questionnaire** and providing at least one picture of the water heater location.
- Monitored data to assess energy efficiency and hot water delivery performance
  - **Energy consumption**
  - **Surrounding air temperature**
  - **Inlet and outlet water temperatures**
  - **Hot water flow**

Image Source: T. Artuso

Summary of Progress

22 120-volt HPWHs have been installed to-date, *preliminary analysis delivered, detailed analysis underway*

- **Received approval from the PNNL Institutional Review Board** for recruitment materials (e.g., Informed Consent) (Q2 FY22 milestone)
- Secured a manufacturer partner to supply 120-volt HPWHs as well as an installation partner
- **Recruited 22 participants** (with manufacturer and installer approval of installation plans)
- **Developed a monitoring plan**, assembled/configured equipment
- **Installed 120-volt HPWHs in 22 participant homes**, along with monitoring equipment
- **Preliminary analysis** of 120-volt HPWH energy efficiency and hot water delivery performance (Q3 FY23 milestone)
- Delivered a **memo on installation lessons learned** for 120V HPWHs (Q2 FY24 milestone)
- Delivered a **draft paper on performance resul**ts of 120V HPWHs in a hot-humid climate zone (Q3 FY24 milestone)
- Delivered a **final paper on performance results** of 120V HPWHs in a hot-humid climate zone (Q4 FY24 milestone)

Progress

Improved HPWH site selection guidance based on lessons learned from unexpected physical space limitations

Physical Space Considerations – Water Heater Location

- **A typical 40-gallon, 40 kBtu/h gas storage water heater has a first-hour rating comparable to the typical 65-gallon 120V HPWH.**
- However, a **40-gallon gas storage water heater is 60" tall x 20" in diameter,** whereas the typical **65-gallon 120-volt HPWH is 72" tall x 26" in diameter.**
- Due to physical size, **space-constrained installations require careful planning.**

Image Source: T.J. Pilet

Progress

*Developing guidance to **install units without electric resistance backup only in conditioned space** to overcome air temperature performance obstacles*

Air Temperature Considerations – Water Heater Location

- Even in a hot-humid climate zone (IECC CZ-2), air temperatures fall below the lower limit of the compressor operating range (~37 ºF) for multi-day periods each year.
- For attic installations, air temperatures went above the operating range (~120 ºF).
- Outdoor water heater enclosures, detached sheds, detached garages, and unconditioned attics have an increased risk of compressor cut-out.

Image Source: T.J. Pilet

Progress

Improved guidance in HPWH Installation Tool (https://basc.pnnl.gov/hpwh_installation_tool) based on lessons learned from initial electrical assessments and installs

Installation Electrical Considerations

- **For this study, all installations were completed without changes to the home's electrical infrastructure.**
- However, **electrical assessments were necessary**, which were conducted through pre-installation site visits (~30-60 minutes each).
- A circuit finder tool helped identify other end uses sharing a circuit before HPWH install.
- Approximately **25%** of visited homes either:
  - **Did not have a receptacle** nearby
  - Had **a non-functional receptacle** nearby
  - Had a **functional receptacle but not enough available amperage**
  - Had **outdated, unsafe, or undersized wiring**
- Installers will need to learn how to conduct electrical assessments

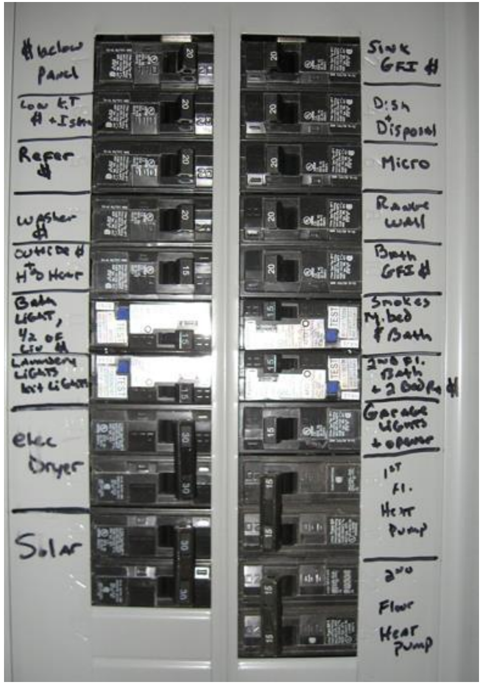


Image Source: U.S. DOE, Building America Solution Center

Progress

Based on the experience of the install team during this field study, PNNL will work with distributors in FY25 to help ensure the right materials are available for installs

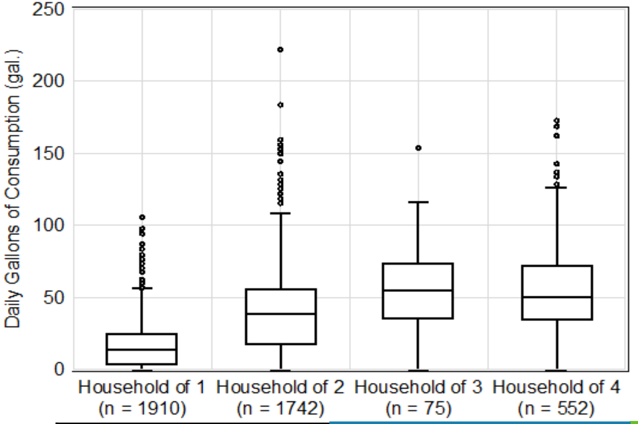
- **The list of special-order materials grew as this project progressed:**
  - Made-to-order 30" x 74" x 30" metal water heater enclosures
  - 8-inch insulated flex duct
  - 8-inch duct terminations
  - Proprietary duct kits
  - Vent/duct grills
  - Custom-size louvered doors
  - Replacement thermistors
- **Availability of materials is critical to installers for emergency replacements**. However, many of these materials were not in stock and required order.
- In general, **installations required 4-8 hours of labor** (not including time spent on site visits, electrical assessments, and return trips).

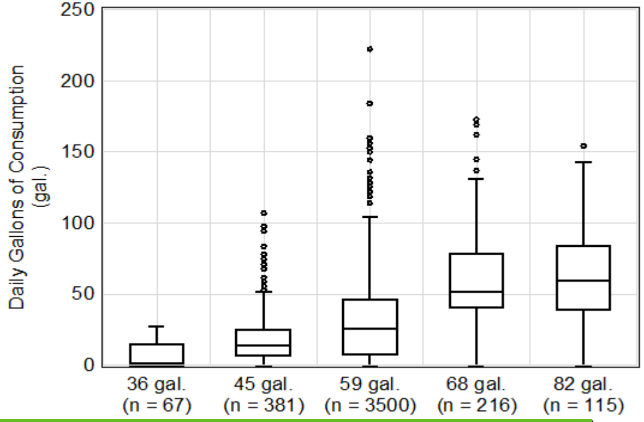
Image Source: T.J. Pilet

Progress – Analysis of Hot Water Usage

Occupant hot water usage validates energy and hot water performance

Plots show gallons-per-day (GPD) of hot water consumption calculated based on household occupancy (left) and measured volume of 120V HPWH (right)





Average GPDs for energy use comparison

Occupancy	Average GPD	Upper Whisker GPD	Upper Whisker GPD Percentile
1	16	56	97th
2	39	109	99th
3	56	116	99th
4	54	127	97th

Proximate peak sizing GPDs

Progress – Energy Use Analysis

Data suggests occupancy and installation location affect energy usage, but further analysis is needed as sample size is increased.

- Approximate annual energy consumption **ranged from 252 to 941 kWh**. Results were limited to participants who've been in the study for approximately an entire year
- **Average annual energy use was 503 kWh** for an average occupancy of 1.8 people
- Strong correlations between occupancy, hot water use, and energy use
- **Certain participants had a high number of days with little (< 1 gallon) hot water consumption**

Site ID	Household Occupancy	Water Heater Location	Average hot water GPD (Gal)	Annual energy usage (kWh)	Days with < 1 gal. of usage (Days)
Site 01	1	Closet	17.3	317	37
Site 02	1	Utility Room	13.4	326	80
Site 03	2	Outdoor Enclosure	48.1	941	6
Site 04	1	Detached Shed	11.1	252	153
Site 05	3	Closet	45.6	624	32
Site 06	2	Closet	44.0	865	43
Site 07A	2	Attached Shed	25.2	448	69
Site 08	1	Attached Shed	20.2	321	17
Site 10	2	Outdoor Enclosure	30.8	434	18

Progress – Identification of Hot Water Runouts

120-volt HPWHs provided adequate hot water for 98% of study days

- Of **4,216 days of participant hot water use, hot water outlet temperatures fell to 95 °F in ~2% of days (i.e., ran out of hot water).**
- **7 participants accounted for most of the run outs (~93%) out of 16 sites**. Their hot water outlet temperatures fell to 95 °F in 6% of days.
  - **5 of the 7 had their 120V HPWHs located in unconditioned spaces.**
  - Of the 2 with 120V HPWHs in conditioned spaces, 1 previously had a gas tankless water heater.
  - In their pre-install survey, **6 of the 7 participants reported never running out of hot water with their gas water heater.**
- High water usage in a short timeframe was the primary cause of run outs, cold air secondary

Occupancy	Average usage during runout event (Gal)	Average use during hour prior to event (Gal)	Average use during second hour prior to event (Gal)	Summed Usage (Gal)
1 (n = 14, 1%)	26	28	14	68
2 (n = 33, 2%)	32	33	8	73
3 (n = 3, 4%)	27	22	17	66
4 (n = 16, 3%)	29	25	20	74

Table omits five hot water runout outliers for which occupants used hot water until it ran out, and then continued to run hot water afterward to prevent pipes from freezing.

Future Work

In FY25, PNNL will continue data collection in New Orleans and focus on expansion into the Northeastern U.S.

Continue progress in New Orleans

- Gather additional data for winter 2024-2025 to strengthen energy and hot water delivery analysis for publication
- Understand the impact of back-up electric resistance for Manufacturer B's 120V HPWH, particularly during winter, by occupancy and water heater location
- Prepare a video for 120V HPWH installation guidance
- **Update of the DOE Installation Tool using lessons learned: https://basc.pnnl.gov/hpwh_installation_tool**

Move focus to Northeast U.S. to understand performance in Climate Zones 5 and 6

- Apply lessons learned (e.g., installation best practices and lessons learned from siting) from New Orleans to cold climate study.
- Received approval for recruitment materials from IRB, and secured installer partner
- Started recruitment in Eastern Massachusetts and Eastern New York, and ordering monitoring equipment for assembly
- Targeting Q1-Q2 FY25 for initial installations

Thank you

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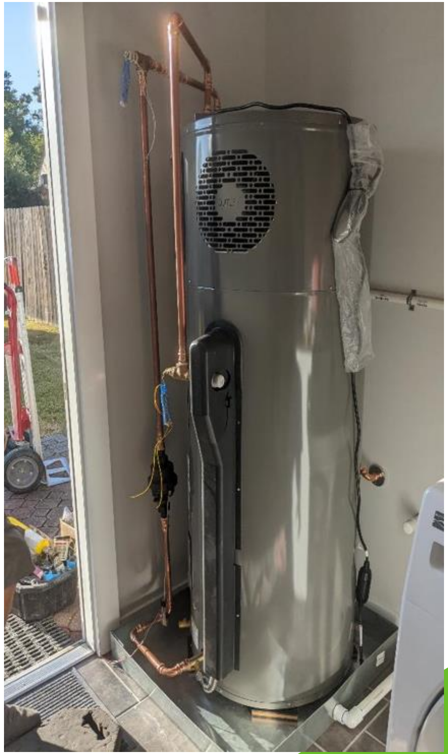

Image Source: T.J. Pilet

Reference Slides

Project Execution

	FY2023				FY2024				FY2025			
Planned budget	$651,500				$594,500				$600,000			
Spent budget	$581,500				$584,500				-			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
FY23 Q3 Milestone: Preliminary Analysis of 120V HPWH Performance Data												
FY24 Q2 Milestone: Memo of Installation Lessons Learned												
FY24 Q3 Milestone: Draft Mid-Study Report of 120V HPWH Performance Results												
FY24 Q4 Milestone: Final Mid-Study Report of 120V HPWH Performance Results												
Current/Future Work												
FY25 Q2 Milestone: Installation Lessons Learned and Best Practises in Cold Climate												
FY25 Q4 Milestone: Draft Mid-Study Report of 120v HPWH Performance in cold climates												

Team

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