Game Changing Retrofit Ready Technology: 120-volt HPWHs

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ABSTRACT

The retrofit-ready, plug-in 120-volt heat pump water heater (HPWH) is an emerging technology that is market ready within three years of identification of the need and creation of the specifications. Four manufacturers expect to have products hitting the market in 2022 and 2023. The 120-volt HPWH is a first-of-its-kind technology that can help utilities, cities, and states meet decarbonization goals. The low-power (less than 900-watt) 120-volt design can plug in to existing wall outlets without expensive electrical panel upgrades and/or home rewiring often required for gas replacements. The 120-volt HPWH represents an ideal decarbonization solution for retrofit applications to replace existing fossil fuel-fired tank water heaters and is expected to be well suited to smaller homes with space and power constraints.

This paper provides background on the specification development and an overview of this emerging technology, including opportunities and limitations with each of the market-ready models. The objective of the paper is to raise awareness about the technology and encourage quicker market transformation nationally. The paper also describes a field verification study launched in California for this technology, along with initial findings from participant recruitment (equipment performance validation is not yet available). The goal of the study is to fast-track the market adoption of this game-changing retrofit-ready technology in applicable use cases by verifying its performance and acceptance in the field. Ultimately, the aim is to include these new products as part of utility incentive programs.

Introduction

Building decarbonization, including space and water heating end uses, is critical to the fight against the climate crisis. Water heating is the second largest energy use in U.S. homes (EIA 2015). In larger multifamily buildings, it is the top energy end use – representing 32 percent of total annual energy consumption (EIA 2015). This is an important end use on which to immediately focus market transformation efforts. The heat pump water heater (HPWHs) is a proven technology that is two to four times as efficient as the other common approaches to providing hot water (Khanolkar 2021). Furthermore, load-shifting capable HPWHs can support a growing number of policies for decarbonization by eliminating carbon emissions at the building level while supporting grid conditions. In addition to the efficiency and climate benefits, HPWHs can store hot water for later use, acting as thermal batteries, thus providing load shifting and demand response capabilities that are of increasing importance and value to balancing the grid energy supply.

More than 50 percent of the estimated 118 million existing households nationwide have water heaters that combust fossil fuels on site (EIA 2015). A primary barrier to switching these homes to an efficient HPWH is limited electrical panel capacity and amperage. The 120-volt HPWH is a first-of-its-kind technology that directly addresses this barrier. The low-power,

retrofit-ready design can plug into existing wall outlets without requiring expensive panel upgrades and/or home rewiring that is often needed for traditional 240-volt HPWHs in houses without existing electric water heaters. Once validated in the field, the 120-volt HPWH represents an ideal decarbonization solution for retrofit applications to replace existing gas-fired tank type water heaters and is expected to be well suited to smaller homes with space and power constraints.

Background

In 2019, a group of industry stakeholders identified a gap in the market for a plug-in HPWH that would be compatible with power- and space-constrained installations. This initiated the development of a technical specification for an efficient, load shifting-capable heat pump water heater that could be plugged into an outlet on a shared circuit. The specification was written to address technology and cost barriers that prevent widespread conversion of gas water heaters to heat pump water heaters. The Northwest Energy Efficiency Alliance (NEEA) published this as Appendix A in its Advanced Water Heating Specification version 7.0 (NEEA 2019) for electric water heating. Two years later, the specification has been embraced by four manufacturers that have developed multiple products (i.e., models and tank sizes) to be brought to the market in 2022 and 2023.

National decarbonization opportunity and market landscape

Retrofit ready HPWHs present a major market opportunity. The U.S. Census Bureau estimates that more than half of the nation's housing units are occupied by only one or two people (2021). This small household is a market niche for the smaller, 120-volt product. Additionally, about 65 percent of homes in the U.S. are single-family dwellings and another six percent are mobile homes that would be well-suited to this technology (U.S. Census Bureau 2019). The 120-volt product provides a tremendous opportunity for the retrofit market to decarbonize and support carbon neutrality goals, as about half of the nation's water heating stock is fossil fuel fired water heaters (EIA 2015). In California, this number is far higher, with nearly 90 percent of California's water heater stock (around 13 million water heaters) estimated to be fired by fossil fuels (CEC 2019). Figure 1 below provides a more detailed view of the fuel types for the existing water heating stock in each U.S. region.

While California is a prime region for this technology due to the prevalence of existing fossil fuel fired water heaters, other regions of interest include the warmer climate zones in the West, Pacific Northwest, and Southern U.S. In the Pacific Northwest, approximately 50 percent of water heaters are fired by fossil fuels (NEEA 2017). The Northeast and Midwest are other areas of interest, with 40 and 60 percent gas water heating, respectively (EIA 2015). However, the cold groundwater and ambient air temperatures in these regions may pose a technical barrier to the product's success. Early pilots in these regions will be critical during peak winter seasons to see if hot water demand can be met and customer satisfaction can be maintained even in the coldest months.

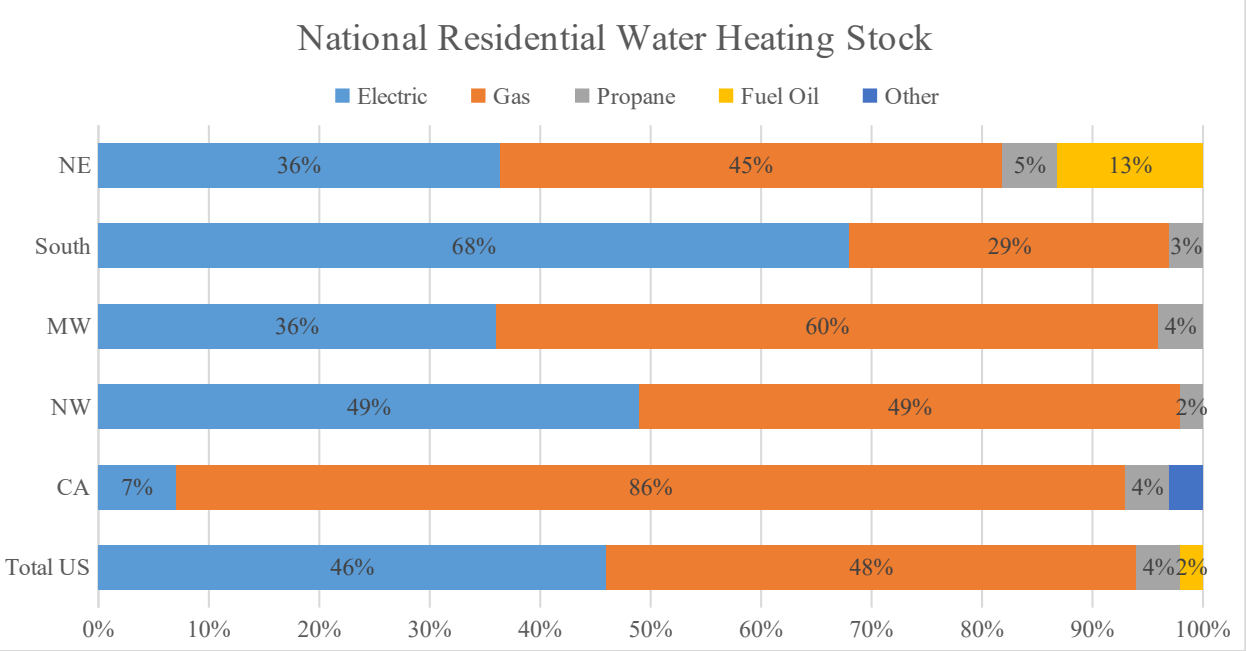

Figure 1. Overview of national residential water heating stock by fuel type. *Source:* NBI based on data from EIA 2015.

An overview of the technology

Heat pump water heater technology has been available on the market since the 1980s. Technology advancement over the years have made HPWHs more conducive for prime-time adoption. This proven technology is an energy-efficient option for many residences but poses installation challenges in some homes with space constraints or inadequate ampacity in the electrical panel, when replacing gas-fired water heaters. The 120-volt HPWH offers a solution for these installations. Table 1 summarizes key characteristics of the emerging 120-volt HPWH technology and the longstanding 240-volt HPWH technology. The information provided in Table 1 is a summary of key metrics and not an exhaustive list. Table 1 does not include specific performance metrics such as the number of showers or number of occupants in the home that can be supported; these details vary by the specific tank size and model.

Table 1. Summary of 120-volt and 240-volt HPWH characteristics

Metric	120-volt HPWH	240-volt HPWH
Ideal application (retrofit vs. new construction)	Retrofit – gas/propane unit replacement	New construction; retrofit - electric resistance unit replacement
Able to operate on a shared circuit?	Yes	No – requires dedicated 40-Amp circuit
Electric panel upgrade(s) required in existing buildings?	No	Sometimes
Estimated first hour rating (50-gallon unit)	45-74 gal	67-94 gal

Electrical Requirements	shared 120-volt / 15-Amp circuit	Dedicated 240V 30-40-Amp circuit
Space-constrained options	Yes	No
Supplemental Heat	Yes, with lower input in some models	Yes
Grid Connectivity	CTA-2045 Compatible, Built-in Wi-Fi compatible	CTA-2045 Compatible, Built-in Wi-Fi compatible

Source: NBI calculations and information from manufacturers. See NEEA's Advanced Water Heating Specification 7.0 (2019) for more information about space constrained applications.

Due to the lower energy input, 120-volt HPWHs do not have as quick of a recovery capability as a comparable 240-volt unit. Higher temperature storage with mixing valves, larger tank sizes, and enhanced tank stratification help to compensate for this slower recovery rate. The emerging 120-volt HPWHs do not have the high-output 4.5 kW electric resistance element found in 240-volt units but, with the higher tank temperature setting, they are expected to run for longer hours and hence consume similar energy as the 240-volt HPWHs. Table 2 compares similarly sized conventional natural gas and electric resistance water heaters with 240-volt and 120-volt HPWHs for heating capacity, tank heating time, and first hour rating.[1] This highlights the lower input capacity and hence the longer heating time of the 120-volt HPWHs. The table also highlights the benefit of the electronic mixing valve (EMV) in increasing the first hour rating. An integrated EMV allows decoupling of the hot water delivery temperature from the storage temperature. Due to an integrated EMV more gallons can be stored at higher temp in the tank without any scalding issues, increasing the first hour rating of the water heater.

Table 2. Comparison of heating capacity and first hour rating for water heater types

Type	Natural Gas	Electric Resistance	HPWH 240-volt	HPWH 120-volt
Size	40 gal	50 gal	50 gal	50/ 50 gal + EMV
Heating Capacity (BTUH)	38,000	15,000	5,000-15,000	5,000
Tank Heating Time (58F-120F)	~30 min	~100 min	250 min	450 min
First Hour Rating	~70 gal	~60 gal	65-95 gal	45/60-75 gal
Typical UEF	0.65	1.44	3.6	3.0 (estimated)

EMV = Electronic mixing valve. UEF = Uniform Energy Factor. *Source:* NBI calculations, DOE (2022) and information from manufacturers.

Market-Ready Models

[1] First hour rating refers to the number of gallons of hot water the heater can supply per hour, starting with a tank full of hot water. The tank capacity, heat source, and heat source size effect the first hour rating.

Most manufacturers have units that meet the space requirements identified in the NEEA Advanced Water Heater Specification 7.0 (that fit within a space of 24" x 26" x 72"). Electrical constraints can be twofold: (1) the existing water heater location may not have access to a dedicated 120V circuit and/or (2) the electrical panel may not be able to accept more circuits at the required ampacity.

While most of the models are 15-amp shared circuit, Rheem is also offering a model that requires a dedicated 15-amp circuit. The dedicated-circuit model is designed for houses built in last 15-20 years, as newer homes typically have the wiring and panel capacity to accommodate these units. All units will have a CTA-2045 certified port (branded as EcoPort), which is an universal port important to ensure grid connectivity and enable participation in future energy management/demand response programs. One manufacturer is developing an offering that utilizes a low global warming potential (GWP) refrigerant, as shown in Table 3.

Table 3. Summary of 120-volt market-ready models

Manufacturer	Gallons	Electrical Features	Grid Connectivity/EcoPort	Refrigerant	Market Availability Status	Type
A.O. Smith	40, 50, 66, 80	Shared circuit, 120-volt / 1 PH, 15A breaker size	Y	TBD	Expected 2022	Unitary
GE	50, 65, 80	Shared circuit, 120/110-volt, 15A breaker size, 60 Hz	Y	134A	Expected 2023	Unitary
Nyle	50, 80	Shared circuit, 120-volt / 1 PH, 15A breaker size	Y	R513A	Available	Split System
Rheem	40, 50	Dedicated circuit, 120-volt / 1 PH, 15A breaker size	Y	134A	Dedicated circuit model: Available	Unitary
	40, 50, 65, 80	Shared circuit, 120-volt / 1 PH, 15A breaker size	Y	134A	Shared circuit model: expected early 2022	Unitary

Field Study

Field assessment of the 120-volt emerging technology will show the potential of this new class of water heaters as a plug-in solution, especially when replacing fossil-fueled water heaters where a 240-volt circuit is not readily available. The field study will further help with

understanding opportunities and gaps to support program design for successful market adoption and transformation. New Buildings Institute (NBI) has initiated a field validation study for the 120-volt HPWH technology in partnership with three California utilities. The plan is to install and implement the study over 12 months while monitoring and measuring data; results are expected by late 2023. Findings from the California study will be leveraged to promote a consistent study design and approach across the county, in partnership with DOE, PNNL, NBI, and other regional partners. To provide a more robust performance evaluation of this new technology, we aim to leverage the research methodology developed and implemented in the initial study by strategically rolling out similar studies in other regions of the country, in partnership with other efforts and programs, such as state emerging technology and energy efficiency programs.

Study Design

Field assessments can provide valuable information about the real-world operation of emerging technologies. While this field assessment is the first of its kind for 120-volt HPWH, multiple field assessments have been completed in the past to evaluate the performance of 240-volt HPWH. One of the first of its kind was presented at the 2012 ACEEE Summer Study, detailing field performance of 240-volt HPWH in California (Amarnath 2012). One year later, NEEA published their findings from the field assessment of 240-volt heat pump water heaters in their colder climate (NEEA 2013). Washington State University's Energy Program conducted a similarly designed study for an emerging split-system HPWH (Washington State University 2014). Sacramento Municipal Utility District (SMUD) assessed 240-volt HPWH in 22 customer homes (SMUD 2016). In all cases, the best practice is to conduct long-term (one year) monitoring of HPWH performance. Long-term onsite monitoring captures seasonal variations in inlet water temperature and ambient air temperature, both of which affect the performance of heat pumps. Data loggers should collect the necessary data points at a one-minute or shorter granularity to capture shorter hot water draws like hand washing. Where possible, surveys are included to assess satisfaction with the HPWH and verify that hot water needs are being met in both the summer and winter seasons.

Research plan: methodology and key parameters

The field validation research approach uses a combination of field testing, surveys, and data modeling and analysis for energy and cost performance. The primary objective is to demonstrate that the 120-volt technology will meet hot water demand in a variety of residential applications, installation locations, and climate zones. Research questions include:

1. Does the system deliver sufficient hot water for typical user needs and expectations?
2. What is the energy and demand performance of the retrofit 120-volt HPWH?
3. What are the product and installation costs?
4. What is the typical customer cost to operate the equipment, in a range of typical homes and utilities?
5. What is the user experience, impacts and interaction with the equipment?
6. What installation variables need to be addressed for commercialization?
7. What is the load shifting capability?

For the initial study in California, households with an existing gas-fired tank-style water heater that meet the screening criteria receive a new 120-volt heat pump water heater and participate in monitoring and data collection for nine to 12 months, covering both peak summer and winter conditions. Throughout the monitoring period, the research team will be tracking hot water runout events, electricity consumption, and water temperatures. At a subset of the sites, load shifting capability of the 120V HPWHs will be tested by simulating a load shifting event between 4 to 9 PM, a proxy for statewide time of use (TOU) rates. Periodic surveys will provide insight into the customer experience and satisfaction level with the 120-volt technology. The research will also gather data from installers related to installation costs, ease of installation, and training needs. Manufacturers continue to provide critical input to the research and technical assistance.

Site Characteristics

The research seeks to maximize the variation in site characteristics to demonstrate the potential of the technology in as many applicable home typologies as possible, while minimizing the risk of occupants running out of hot water. This includes both single-family homes and multifamily buildings in a variety of climate zones. The 120-volt technology is best suited to homes with low-to-medium hot water demand; home occupancy is used as the proxy criteria to identify eligible homes, with the field assessment limited to homes with four or fewer full-time occupants. The field assessment is currently limited to homes with existing gas-fired tank-style water heaters, and the existing water heater tank size is considered to aid in identifying the appropriate 120-volt model for the retrofit. The home vintage is used as a proxy for identifying space-constrained and power-constrained applications; generally, homes older than 1980 often have wiring, panel, and space constraints that make 240-volt heat pump water heater installations challenging. The location of the existing water heater is another key consideration. Water heaters located in a garage or basement are not likely to face ventilation limitations, but the ambient air temperature in these unconditioned spaces can affect the performance of the heat pump water heater. Water heaters located in a conditioned space (typically inside the home in a closet) may be more likely to be limited by ventilation availability but have the advantage of a more stable ambient temperature. While the noise associated with the 120-volt heat pump water heater is not likely to be disruptive to the average homeowner, this is an additional consideration for installations inside the home. Lastly, heat pumps can result in minor changes in the temperature and humidity of the space in which they are installed, which is a more important consideration for interior installations.

In addition to the primary site characteristics described above, other characteristics are important to consider when evaluating the 120-volt technology. Detailed information about the number of hot water fixtures and hot water use habits is needed to better estimate hot water demand. Presence of an available wall outlet within approximately 10 feet of the water heater is required.

Monitoring and Data Collection

One of the key components of the field assessment is the collection of ambient conditions and hot water use data. The primary objective of the monitoring is to demonstrate that the 120-volt HPWH provides adequate hot water. This is achieved by measuring the hot water flow and temperature, leaving the water heater to verify that water is delivered at an acceptable temperature. The other key objective is to collect data that enables analysis of water heater efficiency, and energy use, including insight into the operation under varying ambient air, inlet

water, and hot water draw conditions. Validating load-shifting capability is a secondary objective that will be explored after the water heating performance has been tested and verified.

An energy simulation back-casting exercise will estimate what the usage of the existing gas-fired water heater would have been, had the heat pump water heater not been installed. This helps neutralize any household changes that can affect hot water usage, such as adding a new resident to the home. This also avoids the need to collect water use data through the installation of monitoring equipment prior to installing the heat pump water heater. The study will collect customer meter data for the 12 months preceding the heat pump water heater installation and for the duration of the monitoring period. Customer meter data will be used to cross-check the back-casting analysis and analyze changes in operational cost pre- and post-heat pump water heater installation.

Launch of study

A total of 111 individuals completed a prescreening application to formally indicate their interest in participating in the California field assessment. Of these 111 individuals, a first wave of 56 individuals completed a virtual walkthrough survey to gather more specific details about the home and the existing water heater. A summary of key considerations and findings is below.

The map in Figure 2 below provides an overview of applicant locations within California. There was strong uptake in the Bay Area, representing 20 percent of the applications received, and in climate zone 12 (Sacramento area), representing 25 percent of the applications received. These are all densely populated areas of the state and warrant more attention than climate zones with a lower population, however, the final sites will be selected to represent as many climate zones and home diversity as possible.

Screening Criteria

Some of the key screening criteria to assess favorable sites for the field study included:

- Distance to or ***proximity of the water heater to an available electric outlet***. The specific cord length provided for 120-volt units varies slightly by manufacturer, but generally the distance between the water heater and the nearest outlet should be no more than 10 feet. Of the 56 surveys conducted, only nine applicants (16 percent) were disqualified because the nearest outlet was more than 10 feet away. Four additional applicants that met the outlet distance criteria were disqualified because the outlet location was not feasible to use with the water heater location (for example, water heater located in internal closet with nearest plug multiple feet outside of the closet).
- ***Age of the existing water heater*** was considered, to avoid replacing units less than five years old. Sites with older water heaters were prioritized for this field validation to replicate a more realistic replacement; most people only replace their water heater when it is older or is no longer providing hot water. Enthusiasm for the technology was apparent in the twelve applicants with water heaters less than five years old with one less than one year old.
- Several unique cases were observed where homes had ***more than one water heater, or an ADU*** (auxiliary dwelling unit) with which the water heater was shared.
- Any ***observed code violation*** also disqualified potential participants; two sites were disqualified for this reason. Code violations, even if not directly related to

the water heater, can present permitting roadblocks for a water heater replacement.

- The survey team identified four applicants that had ***panel-related safety issues*** that disqualified them. In three of the four cases, this was due to the panel brand being known for failure and safety concerns. Adding additional load to this panel type poses a potential hazard.
- Homes with a ***recirculation pump*** were not eligible for the study. Recirculation pumps can interfere with the typical HPWH performance, causing the unit to run more and thus increase standby losses. Of all the homes surveyed, only one had a recirculation pump, but this is an important item to consider when looking into installing a heat pump water heater.
- Since this technology is targeting retrofits, the ***dimensions of the install location*** are extremely important. Several sites that were initially considered were later disqualified for space constraint purposes.

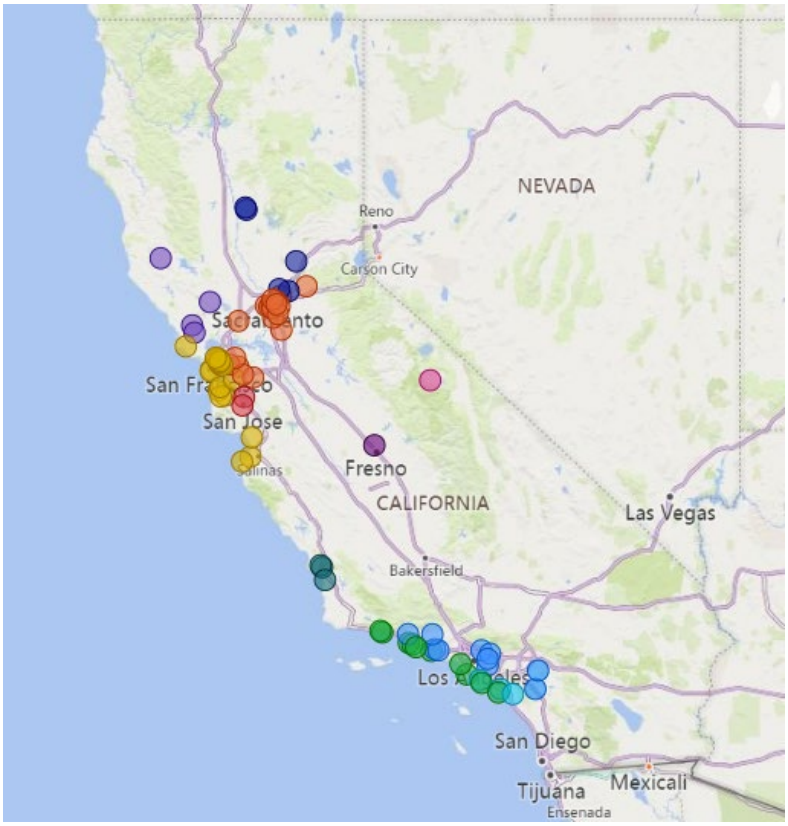

Figure 2. Map of applicants in California. Colors correspond to California climate zones. *Source:* NBI 120-volt field study participant data.

Moving forward

The California study will be a precursor to set the stage for a nationwide technology validation effort. The statewide field study slated to conclude in early 2023 will help verify the research methodology and demonstrate these emerging products in key climate zones throughout California. This will help with initial validation of the technology and support a course

correction of the study methodology if required. It will also help with development of a standard research methodology and supporting material that can be leveraged in other parts of the country to provide consistency. One of the goals of the consistent field study nationwide is development of standardized data collection methods to collect equipment performance and costs and provide program-level information to help inform and accelerate market transformation activities. A larger dataset will provide useful feedback to program administrators and manufacturers about a broad range of installation factors (e.g., equipment, climate, hot water demand, building type). Findings from this study can be used to develop collateral and market outreach materials, such as code compliance fact sheets, trainings for code officials, and installation guidance, all with the goal of increasing product awareness and accelerating market transformation.

References

Amarnath, A., and J. Bush. 2012. "Heat Pump Water Heaters: Field Evaluation of New Residential Products." *ACEEE Summer Study 2012.* https://www.aceee.org/files/proceedings/2012/data/papers/0193-000013.pdf.

CEC (California Energy Commission). 2019. *Residential Appliance Saturation Survey (RASS).* Sacramento, CA: CEC. www.energy.ca.gov/data-reports/surveys/2019-residential-appliance-saturation-study.

DOE (Department of Energy). 2022. "Compliance Certification Database." https://www.regulations.doe.gov/certification-data/CCMS-4-Water_Heaters.html#q=Product_Group_s%3A%22Water%20Heaters%22

EIA (Energy Information Administration). 2015. *Residential Energy Consumption Survey (RECS)*. Washington, DC: EIA. www.eia.gov/consumption/residential/.

Khanolkar, A. 2021. *Heat Pump Water Heater Efficiency Analysis.* Portland, OR: New Buildings Institute.

NEEA (Northwest Energy Efficiency Alliance). 2013. *Heat Pump Water Heater Field Study Report.* Portland, OR: NEEA. https://neea.org/img/uploads/heat-pump-water-heater-field-study-report.pdf .

———. 2017. *Residential Building Stock Assessment (RBSA).* Portland, OR: NEEA. neea.org/data/residential-building-stock-assessment.

———. 2019. *Advanced Water Heating Specification Version 7.0.* neea.org/our-work/advanced-water-heating-specification#:~:text=Versionpercent208.0percent20ofpercent20thepercent20Advanced,(9.0)percent20ofpercent20thepercent20AWHS.

SMUD (Sacramento Municipal Utility District). 2016. *Heat Pump Water Heater Field Testing Report.* Sacramento, CA: SMUD. https://www.smud.org/-/media/Documents/Corporate/About-Us/Reports-and-Documents/2018/HPWH-Field-Testing-Report-1-6-2016.ashx.

U.S. Census Bureau. 2019. "Table B25024: Units in Structure." data.census.gov/cedsci/table?q=B25024percent3Apercent20UNITSpercent20INpercent20STRUCTURE&tid=ACSDT1Y2019.B25024.

———. 2021. "Historical Households Tables: Table HH-4. Households by Size: 1960 to Present." www.census.gov/data/tables/time-series/demo/families/households.html.

Washington State University – WSU Energy Program. 2014. *Advanced Heat Pump Water Heater Research First Midterm Field Study Report.* Olympia, WA: Washington State University.

https://www.energy.wsu.edu/documents/FirstMidtermReportonMonitoringofAdvancedHPWHfromInstallationthruMarch2014-Final.pdf