Retrofit Market Decarbonization with Plug-In HPWHs: California-wide Field Study Results and Market Commercialization Recommendations

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ABSTRACT

Water heating accounts for around 17 to 32% of energy usage in residential and multifamily buildings. Nationally there are more than 123 million existing residential water heaters and every year more than 7.5 million water heaters (WHs) are replaced. It is estimated that 90% of water heating replacements occur on an emergency basis. Without an easy, affordable, and fast heat pump water heater (HPWH) replacement solution, homeowners are more likely to opt for a replacement that is like the incumbent technology. Emerging, plug-in 120-volt HPWHs are market-ready and proving themselves to be important new offerings. The 120-volt HPWH is a first-of-its-kind technology that can help utilities, cities, and states meet decarbonization goals by targeting the retrofit market and emergency replacements. The 120-volt HPWHs are an ideal decarbonization solution for retrofit applications to replace existing fossil fuel-fired tank WHs and are proving to be well suited to smaller homes with space and power constraints. The field study observed an average monthly energy consumption savings of approximately 85% in comparison to the pre-existing water heaters. In addition, about 60% of the sites showed operating cost savings as compared to the pre-existing gas or propane water heater.

This paper provides an overview of lessons learned on the first ever third-party field validation effort of the 120-volt HPWH technology through California-wide installations. In addition to covering the energy and hot water delivery performance findings from the statewide study, it includes contractor and customer feedback, market assessment and recommendations for commercialization. The goal of this paper is to highlight how utility and manufacturer collaboration efforts can help address technology market barriers, raise awareness about the emerging technologies and encourage quicker market transformation nationally.

INTRODUCTION

Currently, the American water heater market is dominated by two types: natural gas burning water heaters and electric resistance water heaters. While heat pump water heaters (HPWHs) are two to four times more efficient than conventional water heaters, they can be three times more expensive to buy and install. As a result, HPWHs captured only 2.3%[1] of the electric water heater market share nationally as of 2021. HPWHs face many barriers but these barriers are mostly to do with market and installation practices, not shortcomings of the technology itself. The most significant barriers are:

- Higher upfront and installation costs
- Installation complexity, due to space, ventilation, and condensation requirements
- The lack of a 240-volt electrical supply required for a standard HPWH

[1] ENERGY STAR®. Unit Shipment and Market Penetration Report Calendar Year 2021 Summary

- General installer and consumer bias towards conventional models

- Lack of technology confidence and understanding of the long-term cost savings and environmental benefits.

The emerging, plug-in 120-volt HPWHs, now entering the market are important new offerings from manufacturers aiming to address some of these key barriers. New Buildings Institute (NBI) worked closely with 120-volt HPWH manufacturers and utilities in California on a statewide 120-volt HPWH field validation program. As part of that program. NBI installed 120-volt HPWHs for 32 customers in most climate zones across California (CA). The units were monitored for water and ambient temperature, flow rate, power consumption, and the customers and contractors were surveyed on their usage and satisfaction with the water heaters. Once the fundamental features and the water heater capability to provide hot water were successfully validated, three of the 32 sites were selected to test the water heater demand response readiness and load shifting features to confirm whether they were able to follow schedules, preheat water, and store water. This effort was part of the Advanced Water Heating Initiative (AWHI), a national market transformation effort to decarbonize water heating in buildings.

BACKGROUND

In 2018, Retrofit Ready Heat Pump Water Heater Summit stakeholders developed a technical specification for an efficient, load shifting-capable heat pump water heater that could be plugged into an outlet on a shared 120-volt, 15-amp circuit. The specification was written to address market gap around technology and cost barriers that prevent widespread conversion from gas tank-type water heaters to heat pump water heaters in existing buildings such as multifamily and manufactured housing, and older homes with water heater closets. To support this new market, Advanced Water Heating Initiative (AWHI) in partnership with California utilities proposed a statewide field validation effort from 2021 to 2023 to validate the emerging technology of 120-volt heat pump water heaters (HPWHs) and expedite the market transformation effort. Five years after the summit, four manufacturers are bringing multiple products (i.e., models and tank sizes) to market.

NATIONAL DECARBONIZATION OPPORTUNITY AND MARKET LANDSCAPE

Retrofit ready HPWHs present a major market opportunity. 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. 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 California. 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 cold climates, indoor installations are viable due to a high prevalence of utility space in conditioned basements.

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

AN OVERVIEW OF THE PILOT STUDY

The goal of this field study was to independently field verify 120-volt HPWHs for user satisfaction, installer acceptance, and energy performance to demonstrate the emerging technology. The findings of the study will help with market commercialization of the technology, including but not limited to policy adoption and program promotion. The research findings will also support targeted efforts to decarbonize the existing buildings market. The main objectives of the study were:

- Demonstrate equipment applicability in various installation locations and climates
- Monitor the performance of the 120-volt HPWH
- Understand costs associated with the 120-volt HPWH
- Gather information from users and installers
- Collect information to support 120-volt HPWH eligibility in utility programs

120-volt Technology

The 120-volt HPWHs share many characteristics with their 240-volt counterparts. The section below highlights some of the key distinct features:

Plug in. The most significant differentiating feature of the 120-volt HPWHs is that they can plug into an existing 15-amp outlet and can share the circuit with other appliances. Unlike a standard 240-volt HPWH, 120-volt HPWHs do not need a dedicated 30-amp circuit. An example of shared circuit application would be when a home cook plugs both a blender and a toaster into a standard wall outlet and uses both appliances at the same time. The 120-volt HPWH can plug into similar wall outlets for easy installation and minimal impact on the existing home electric infrastructure. The full published report here provides more information on market ready products and manufacturers (Khanolkar A. 2023).

Absence of backup heating or reduced element. The reason the 120-volt HPWHs can be installed on a shared circuit is that this new technology does not have an electric resistance back-up element or has a significantly reduced electric resistance element size. A large back up element enables quicker hot water delivery at reduced efficiency. Absence of the element means that the hot water recovery in the case of a depleted tank would be slower than a standard HPWH. A standard 240-volt HPWH typically has three control settings available for customers, "heat pump only" "hybrid mode" and "electric resistance only." The 120-volt HPWH operates in a mode equivalent to the "Heat Pump Only" setting on 240-volt HPWHs. It will be highly dependent on the heat pump compressor with little or no assistance from the electric resistance backup heating. Due to increased reliance on the heat pump compressor, the 120-volt HPWH performance will depend on environmental factors that impact compressor performance—such as incoming water temperature and ambient air temperature.

Integrated thermostatic mixing valve. The thermostatic mixing valve decouples tank temperature from hot water delivery temperature, providing additional hot water capacity available from the tank while minimizing the risk of scalding. To reduce the risk of hot water runout events, manufacturers have incorporated an integrated electronic mixing valve. In addition to the thermal capacity boost, the mixing valve also allows for additional controls and flexibility for scheduling to allow the water heaters to participate in load shifting or demand response programs. With mixing valve, a resident can keep the storage tank hot at 140°F, effectively increasing the storage capacity of the heater. The mixing valve mixes the stored hot water with cold incoming water and limits the delivery temperature to a safe 125°F. This increases the tank's hot water storage capacity without sacrificing comfort or risking scalding (ASSE 2013).

Importance of determining the right tank size. Sizing the tank properly is important in the case of storage water heaters and more so for 120-volt HPWHs as they have no back-up or reduced power back-up element. Installers typically determine a water heater's tank size based on its first specified hour rating. The first hour rating is the amount of hot water that can be provided in one hour, starting with a tank filled with hot water. Water heaters with higher first hour ratings can reheat the storage tank quicker after water draws than those with lower first hour rating. Generally, water heaters fueled by gas combustion reheat faster but less efficiently than heat pump systems. In retrofit applications, a plumber will look for a replacement water heater that has a similar first hour rating to the replaced system to ensure the household can expect comparable amounts of hot water after the retrofit. To achieve similar first hour ratings, a plumber may need to install a larger storage tank on the 120-volt HPWH than the replaced gas or propane water heater.

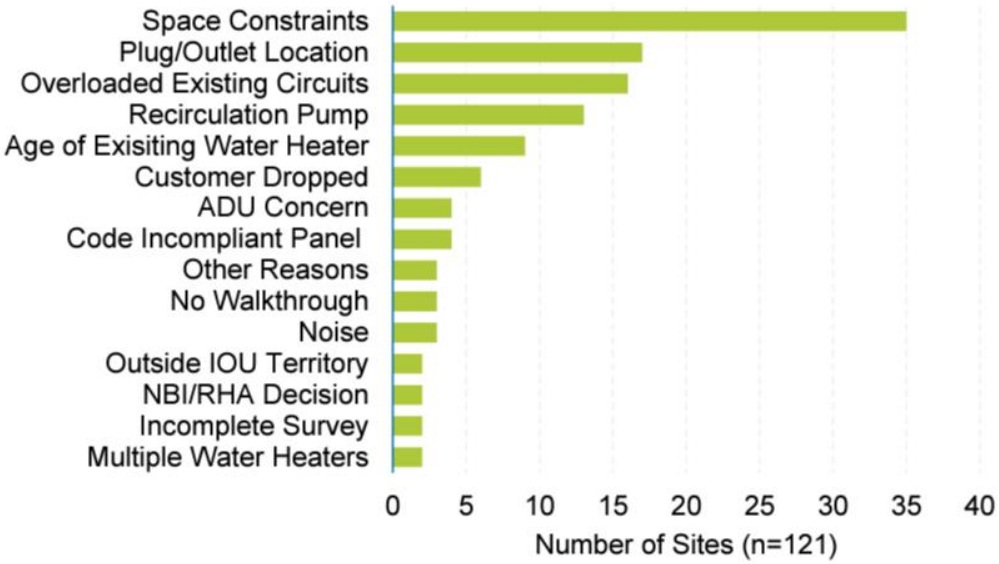
Implementation Results and Findings

This section summarizes the installation, performance, and financial findings from the monitored and surveyed study data from the 120-Volt HPWH field study.

Space constrained sites

The 120-volt specification is written for the space and power constrained retrofit market sector. However, we found that the manufacturer units are not small enough to fit well for all the sites we came across. Especially for indoor-outdoor closet installations with limited space, we had to reject many sites due to space limitations for not only the physical unit but also additional plumbing, ventilation, and condensation requirements. Additionally, many sites had outlets that were either too far from the installation location, or the outlets were already constrained by other plug loads. Figure 3 highlights the key reasons that led to site rejections.

Figure 3. Site rejection reasons



California Plumbing Code Based on the study findings,

We observed that the California Plumbing Code first hour rating requirements cause an increase in HPWH sizing beyond the manufacturer recommendations. In this case, we followed manufacturer recommendations, based on the assessment by code experts that first hour rating (FHR) is typically enforced for new construction. For retrofits, the plumbing code FHR [501.1 (2)] comes into effect, but the sizing requirement is very rarely enforced compared to the energy compliance requirement. While the plumbing code is outdated and needs its next round of updates to incorporate emerging technologies, manufacturers should consider publishing FHR for a range of storage temperatures due to an integrated mixing valve in 120-volt HPWHs.

California building codes also require a platform for gas fired water heaters, but we have found that non-removable concrete platforms make it challenging to fit the HPWH into the existing water heater location.

Regulatory and permitting barriers

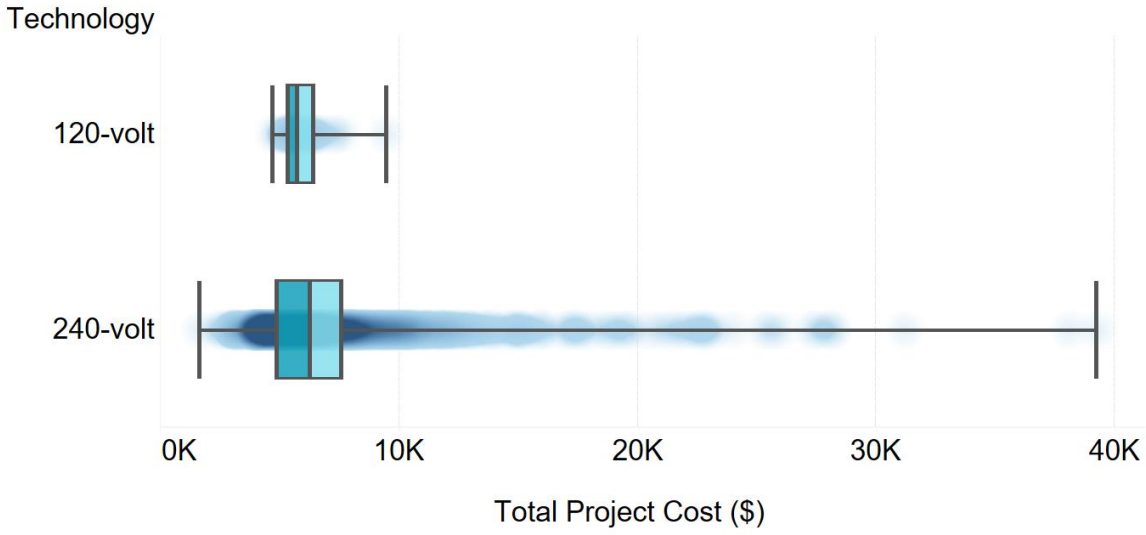
From the study experience, permitting approvals are one of the key barriers for this technology. Due to HPWH's status of emerging technology, permitting departments frequently ask for extra paperwork. For example, full house electrical load calculations with 100% of HPWH load, requiring a dedicated circuit, floor plans, and single line drawings for a water heater replacement. Typically, the permitting process for water heaters is much easier; however, due to the electrical nature of the water heater and lack of awareness around the technology's electrical requirements, we experienced delays. These excessive requirements highlight the need for building official and building department education and awareness. Based on the feedback received from code officials, there are times when water heaters are installed in existing homes without permitting approvals, especially in cases of emergency replacement. So similar to solar auto permits, streamlining permitting process will help with expedited permits.

Home electrical upgrade cost savings and installation findings

The 120-volt HPWH is designed to reduce cost and complexity that customers may incur from installing a standard 240-volt HPWH in a fuel switching retrofit. Replacing a gas water heater with a HPWH with a proximate shared circuit plug point resulted in time efficient and cost-effective replacements. Without availability of this technology, replacement would not have been possible over one visit from the installation team (see electrical site selection criteria in section 4.4 below). Due to differing existing electric equipment in homes, certain buildings may be more or less likely to have electric upgrade cost savings by opting for a 120-volt HPWH. The 120-volt HPWHs saved between $800 and $15,000 per household compared to 240-volt HPWH installation, primarily due to the minimal electrical interventions. Based on the installer feedback, 120-volt HPWHs were also faster to install, making them ideal for emergency replacements.

Figure 4 displays the distribution of total project costs for this study versus that of 240-volt HPWHs using TECH data highlighting the predictable and narrow range of install costs with plug-in HPWHs compared to 240-volt models.

Figure 4. Total project costs: 120-volt vs. 240-volt HPWHs ($)



Survey Findings

To qualitatively assess participant satisfaction, we surveyed participants on five aspects of HPWH performance: satisfaction with hot water output, vibration, noise, temperature near the HPWH, and humidity near the HPWH. Participants were most satisfied with hot water consistency (i.e., not having runout events), and were least satisfied with the HPWH noise. While the overall satisfaction was high, in five cases, participants reported that the HPWH took too long to heat water, or hot water run outs were occurring (5 out of 32 installations).

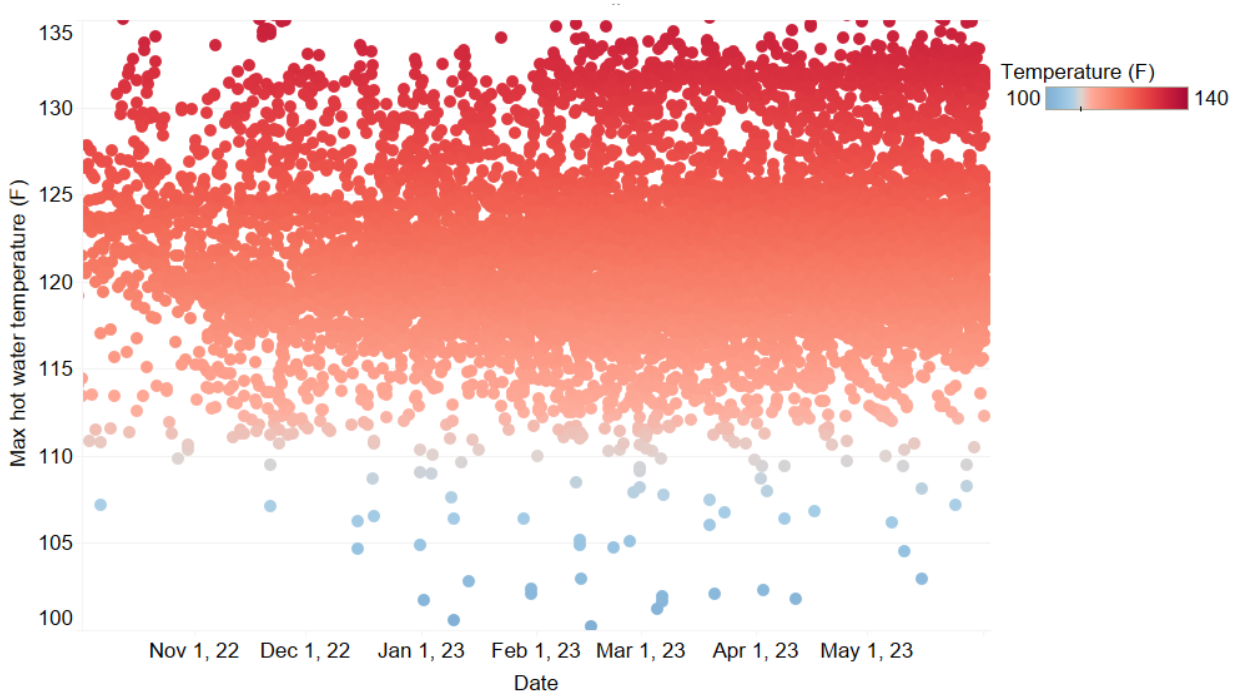
Performance of the 120-volt HPWHs

Hot Water Delivery

We monitored all sites for their hot water delivery temperatures. Currently, there is no industry standard or metric to evaluate hot water comfort. Based on the qualitative data, we assume that hot water demands are met if the water coming out of the water heater does not go below 110°F (Maguire A. 2018). However, Rheem recommends that showers do not exceed 105°F and that 100°F is a comfortable shower temperature[2], so the monitored delivery temperature could fall into this range without users complaining of a hot water runout event. Figure 5 shows the hourly hot water outlet temperature for all the sites. The hot water delivery temperature typically does not fall below the setpoint temperature range of 115- 125°F, and even the high demand sites have a delivery temperature of above 100-105°F

[2] Rheem. What is the Ideal Temperature to Shower in? Showering above 105°F may have negative health consequences, such as eczema.

Figure 5. Maximum hot water draw for hours with at least 5 gallons of water draw



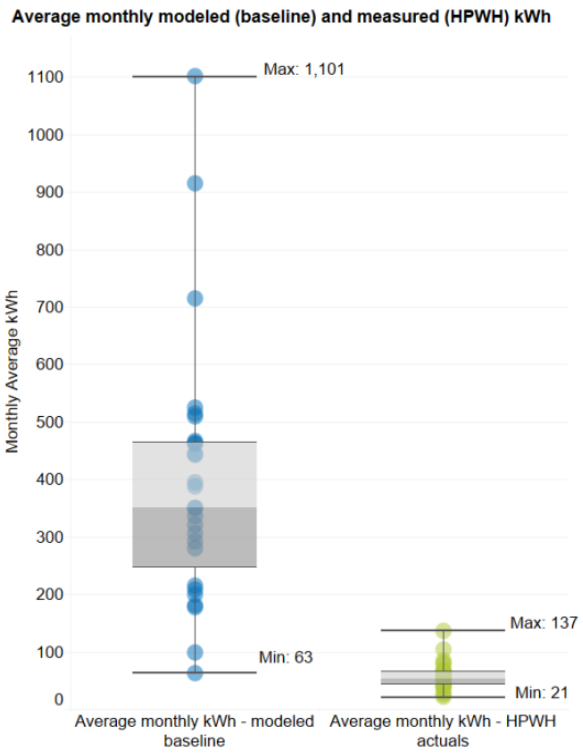
Compressor Power Consumption and Energy Factors

While rated at 15 amps, these plug-in HPWHs only pulled 4-6 amps of current during the monitoring period, except for the model with a small backup electric resistance element, which had the highest pull but still did not exceed 8 amps. Hot water demand peaked between 7:00 AM and 8:00 AM on weekdays, and between 9:00 AM and 10:00 AM on weekends. Overall average energy factor (EF) for the units was 2.98. EF generally increased with high ambient air temperatures; it also loosely increased with higher hot water consumption.

Site Energy Savings Analysis

Using the 25th to 75th percentile of monitored data, we estimate that average energy monthly consumption is between 42 kWh and 66 kWh. An average monthly energy consumption savings of 85% was seen in comparison to the pre-existing gas water heater and 82% for a propane water heater replacement

Figure 6. Average monthly kWh



when normalized to kWh. The Figure 6 on the side shows the average monthly baseline and proposed energy consumption comparison.

Operating cost analysis

While average energy savings are consistent across utility regions, the operating cost savings vary based on the utility rate structures and load profiles of the household. We found a 50% operating cost reduction compared to modeled gas water heaters for PG&E and SMUD customers. For SCE customers, the operating costs during summer months were comparable to fossil fuel fired water heaters, but during winter months, there was a slight increase due to decreased heat pump efficiency from colder air and water temperatures. This increase was also due to the lower gas prices in Southern California Gas territory, resulting in a monthly energy bill increase of $9, based on historical gas rates.

Conclusions and Tech-to-Market Recommendations

For retrofit applications with electrical constraints, and small-medium demands (1-4 people household) the 120-volt HPWH is a compelling technology that can be game changing for meeting decarbonization and electrification goals for residential as well as small commercial market. Below are some key findings and recommendations for supporting wider adoption of this technology.

Market sector assessment, and electrical criteria

Based on the installation financials and ease of install criteria, the low hanging fruit for the 120-volt HPWHs are sites that have an existing shared circuit with sufficient additional available power (i.e., no more than 6 A of load is expected to be connected to the circuit in addition to the water heater). Out of the 153 site walkthrough surveys performed, 32 installations would be able to make use of an existing 120-volt outlet close to the water heater location. Based on the walkthrough survey findings, in California we estimate that approximately 22-30% of the retrofit single-family homes with gas/propane water heaters can be directly supported by this emerging technology. We recommend that only limited electrical remediation sites are targeted by this technology, for example:

- Installation of an additional 15-amp rated outlet on existing accessible circuit.
- Repair or replacement of existing outlet compliant with current National Electrical Code NEC and CA building code. Any time sites require the addition of a dedicated circuit, panel upgrade, or amperage upgrade, 240-volt HPWHs are generally better suited products. This is due to the higher first hour rating and relatively smaller difference in upgrade costs between the products.

Utility/Incentive program considerations

Based on the study findings, we recommend the following when designing an incentive program for 120-volt HPWHs:

Table 1. Incentive program design recommendations

Technology/Market Opportunities	Recommendations
120-volt technology eligibility	Inclusion within existing programs/workpapers: absorbing 120-volt HPWHs into rebate programs that include other hybrid WHs would accelerate adoption.
Accurate assessment	Improved pre-installation assessment: obtaining a more accurate gauge of hot water use can help ensure proper sizing and technology choice.
Commercial building application	Adoption within small commercial buildings: some small commercial buildings have low enough hot water demand that 120-volt HPWHs more than suffice.
Equitable and affordable adoption	Prioritizing low-income outreach: 120-volt HPWHs offer significant installation savings compared to 240V HPWHs, making them ideal for LMI electrification projects.

Policy and market recommendations

Below are the findings that are directly applicable to the market and require specifically targeted action by policy makers:

Table 2. Policy & market barriers and recommendations

Policy and market barriers	Recommendations
California Plumbing Code FHR requirements can lead to WH oversizing	Update code: modifying the Plumbing Code to have separate requirements for new technologies would allow for more accurate WH sizing.
Excessive paperwork and permitting lead to delays	Permitting officer training: it's critical to ensure that permitting officers are aware and accepting of 120-volt HPWHs to prevent delays.
Lack of knowledge around 120-volt HPWH installation	Education and workforce development: because this technology is so new, training installers is paramount to ensure best possible performance and lack of installation issues.

National Effort and Moving Forward

The 120-volt HPWHs are important to decarbonize the retrofit residential and small commercial market sectors. These products should be incentivized by utilities and other programs, such as the Inflation Reduction Act (IRA) tax credits, to support market scaling. In addition, the market requires contractors and permitting department awareness building efforts.

The market needs more innovative solutions like this emerging technology to support the gaps where a 120-volt HPWH is not feasible. While we estimate 22 to 30% of California homes could be directly supported by these plug-in water heaters, the remaining sites still need unique solutions for replacements. Thus, there is an immediate need for smaller footprint/small form factor products and products with improved compressor capability for cold climates. While

European and Asian markets have distinctive products to meet space constraint needs, more of these size-sensible products should be manufactured within the United States. The overall success of this study highlights one critical aspect of water heating—each household has a unique draw pattern. While one could predict the hot water usage of the household based on the number of bedrooms/bathrooms and number of occupants, it is important to understand their satisfaction with the existing unit and to size the new 120-volt units correctly.

References

ASSE International. (2013). Guidelines for Temperature Control Devices in Domestic Hot Water Systems. https://www.asse-plumbing.org/media/21934/guidelines-for-temp-controldevices.pdf

Bay Area Air Quality Management District. (2023, March 15). Air District strengthens building appliance rules to reduce harmful NOx emissions, protect air quality and public health. https://www.baaqmd.gov/news-and-events/page-resources/2023-news/031523-ba-rules

California Energy Commission. (2018, August). Natural Gas Methane Emissions from California Homes. https://www.energy.ca.gov/sites/default/files/2021-06/CEC-500-2018021.pdf

Edison International. (2023). Carbon Neutrality by 2045. https://www.edison.com/ourperspective/pathway-2045

EIA. (2018, November 7). Space heating and water heating account for nearly two thirds of U.S. home energy use. https://www.eia.gov/todayinenergy/detail.php?id=37433https://www.eia.gov/todayinenergy/de tail.php?id=37433

EIA. (2022, May). 2020 RECS Survey Data. https://www.eia.gov/consumption/residential/data/2020/#fueluses

ENERGY STAR®. (2023, April 23). ENERGY STAR® Unit Shipment and Market Penetration Report Calendar Year 2021 Summary. https://www.energystar.gov/sites/default/files/asset/document/2021%20Unit%20Shipment%2 0Data%20Summary%20Report_0.pdfhttps://www.energystar.gov/sites/default/files/asset/doc ument/2021%20Unit%20Shipment%20Data%20Summary%20Report_0.pdf

Energy Systems Integration Group. (2023, January). Heat Pump-Friendly Cost-Based Rate Designs. https://www.esig.energy/wp-content/uploads/2023/01/HeatPump%E2%80%93Friendly-Cost-Based-Rate-Designs.pdf

Focus on Energy. (2022, December). 120V HPWH Research (Phase I). https://focusonenergy.com/120v-hpwh-research-phase-i

Home Depot. (2023, May 3). Hybrid Water Heaters. https://www.homedepot.com/b/Plumbing-Water-Heaters-Hybrid-Water-

Heaters/N5yc1vZckrahttps://www.homedepot.com/b/Plumbing-Water-Heaters-Hybrid-Water-Heaters/N5yc1vZckra

Khanolkar A., Egolf M., Gabriel N. (2023). Plug-In Heat Pump Water Heater Field Study Findings and Market Commercialization Recommendations

NEEA. (2023). Advanced Water Heating Specification. https://neea.org/our-work/advancedwater-heating-specification

NEEA. (2022, March 1). A Specification for Residential, Commercial—Multifamily, and Industrial Water Heaters and Heating Systems Advanced Water Heating Specification Version 8.0. https://neea.org/img/documents/Advanced-Water-HeatingSpecification.pdfhttps://neea.org/img/documents/Advanced-Water-Heating-Specification.pdf

NEEA. (2022, November 21). Heat Pump Water Heaters in Small Spaces Lab Testing: "The Amazing Shrinking Room." https://neea.org/resources/heat-pump-water-heaters-in-smallspaces-lab-testing-the-amazing-shrinking-roomhttps://neea.org/resources/heat-pump-waterheaters-in-small-spaces-lab-testing-the-amazing-shrinking-room

NEEA. (2023, August 30). Plug-In Heat Pump Water Heaters: An Early Look to 120-Volt Products. https://neea.org/resources/plug-in-heat-pump-water-heaters-an-early-look-to-120volt-products

NREL. (2023). ComStock Analysis Tool. https://www.nrel.gov/buildings/comstock.html

PG&E. (2013, June). PG&E Cressey-Gallo 115 kV Power Line Project – Initial Study. https://ia.cpuc.ca.gov/environment/info/aspen/cresseygallo/fmnd/5-12_noise.pdf

Rheem. (2019, October 2). What is the Ideal Temperature to Shower in? https://www.rheemasia.com/blog/what-is-the-ideal-temperature-to-shower-in/

TECH Clean California. (2022, March 7). California Technology and Equipment for Clean Heating (TECH) Initiative - Working Data Set.

U.S. Department of Energy. Pt. 430, Subpt. B, App. E. https://www.govinfo.gov/content/pkg/CFR-2022-title10-vol3/pdf/CFR-2022-title10-vol3part430-subpartB-appE.pdf

Water Research Foundation. (2016, April). Residential End Uses of Water, Version 2: Executive Report. https://www.circleofblue.org/wpcontent/uploads/2016/04/WRF_REU2016.pdf