QUICK START GRANT **FINAL REPORT**

Statewide 120-Volt Heat Pump Water Heater Field Study

New Buildings Institute

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TECH CLEAN CALIFORNIA

Executive Summary

Heat pump water heaters present a clear pathway to support building decarbonization and energy efficiency. Despite this, heat pump water heaters face many barriers such as high upfront and installation costs, space requirements and installation complexity, inadequate electrical infrastructure, and a general bias towards conventional models limiting adoption rather than shortcomings of the technology itself. The emerging plug-in 120-volt (V) heat pump water heaters entering the market are an important new offering from manufacturers aiming to address some of these key barriers.

New Buildings Institute (NBI) worked closely with 120V heat pump water heater manufacturers and utilities in California on a statewide field validation program. Through this program, NBI has installed and monitored 120V heat pump water heaters for 32 customers in most climate zones across California. This program is part of NBI's Advanced Water Heating Initiative, a national market transformation effort to decarbonize building water heating.

The Quick Start Grant project examined energy performance, installation, equipment, operating costs, and customer satisfaction for 120V heat pump water heaters. This work resulted in valuable lessons for manufacturers, utilities, policymakers, and installers working to advance electrification efforts. For the electrical and space constraint applications, this field validation determined that the 120V heat pump water heater is a compelling technology that can be a robust solution for meeting decarbonization or electrification goals for the retrofit market sector for residential and small commercial applications. The study produced a set of recommendations for policymakers and utilities designing an incentive program covered in the **Key Learnings** section.

Project Description

Project Team

The research team included New Buildings Institute (NBI), Richard Heath & Associates (RHA), and kW Engineering. NBI is a 501(c)(3) nonprofit organization whose mission is to push for better buildings that achieve zero energy, zero carbon, and beyond to protect people and the planet. The project also included a Technical Advisory Committee consisting of experts from Hot Water Research, PG&E, SCE, SMUD, VEIC, PNNL, DOE, CEC, Rheem, GE, and Nyle Water Heating Systems.

Market Barrier

Water heating and space heating combined account for two-thirds of residential energy usage in the United States and should be the cornerstones of any plan to decarbonize the built environment. Water heating accounts for around 17 to 32 percent of energy usage in residential and multifamily buildings.[1] Nationally, there are more than 123 million, and more than 7.5 million are replaced annually.[2] It is estimated that 90 percent of water heating replacements occur on an emergency basis.[3] Without an easy, affordable, and fast heat pump water heater replacement solution, homeowners are more likely to opt for a replacement similar to the incumbent technology.

Currently, the American water heater market is dominated by two types: fossil fuel (natural gas) burning water heaters and electric resistance water heaters. While heat pump water heaters are two to four times more efficient than standard electric resistance and fossil fuel-fired water heaters, they can be three times more expensive to buy and install. Heat pump water heaters captured 2.3 percent of the electric water heater market share nationally in 2021.[4]

Heat pump water heaters 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

TIMELINE:
January 2022 – June 2023

HOUSING TYPE:
Single Family

EQUITY SEGMENT:
Low-Income Customers

TECHNOLOGY:
Heat Pump Water Heaters

LOCATION:
Statewide

1 U.S. Energy Information Administration 2018
2 Building stock from 2020 RECS
3 2020 RECS Survey Data
4 2021 Energy Star Unit Shipment Report

- The lack of a 240V electrical supply required for a standard heat pump water heater
- General installer and consumer bias towards conventional models
- Lack of technology confidence and understanding of the long-term cost savings and environmental benefits

Proposed Solution

In 2019, 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 120V, 15A circuit. The specification addressed technology and cost barriers that prevent widespread conversion of gas water heaters to heat pump water heaters.[5]

The market was facing a supply and demand issue as utilities did not see market-ready products to provide incentives, and the manufacturers did not see enough demand in the market to invest in the production of this emerging technology. The Advanced Water Heating Initiative identified a gap in the market. In partnership with California utilities and supported by this Quick Start Grant, NBI proposed to administer a statewide field validation effort from the middle of 2021 to the middle of 2023 to validate the emerging technology of 120V heat pump water heaters and expedite the market transformation effort.

The Quick Start Grant supported some aspects of this significantly larger field validation effort, including offsetting project installation costs for the 120V heat pump water heater equipment and monitoring and verification equipment needed to validate the performance of heat pump water heaters in 32 sites representing a variety of site characteristics.

Theory of Change and Scalability

The 120V heat pump water heater is an innovative product with the potential to reduce total installed project costs in electrifying existing gas water heaters. This cost is a primary barrier to achieving scale in heat pump water heaters. Replacements or upgrades to the electrical panel and conduit to accommodate a 240V heat pump water heater can incur over $20,000 in costs to the homeowner, depending on the extent of work needed. The 120V product can minimize or eliminate these infrastructure costs. Moreover, the energy performance and cost data collected will be used in work paper development that investor-owned utilities will use to further increase investment in heat pump water heater programs.

5 The Northwest Energy Efficiency Alliance (NEEA) has published this as Appendix A in their Advanced Water Heating specification (AWHS V8.0) for electric water heating (NEEA 2019), and it is also part of the Energy Star (R) residential water heating specification version 3.3. Three years later, the specification has been embraced by Rheem, GE, and Nyle Water Heating Systems, bringing multiple products (i.e., models and tank sizes) to market between 2022 and 2023.

California's existing housing stock provides a large market for the 120V technology, with about nine million households containing one to three occupants.[6] A similar number of homes in California are classified as single family detached/attached or mobile (manufactured) homes.

While the "amp diet" of the 120V emerging technology product has the potential to address technical and cost barriers, the lack of market awareness will continue to be a market barrier that prevents scale. Field deployment projects allow for documentation of real-world lessons learned. Learnings from this pilot can facilitate the development of case studies and actionable guidance materials for the building industry. NBI intends to finalize this market connection following the field validation portion of the study.

Program Changes and Evolution

This project aimed to test and validate 120V heat pump water heaters from three different manufacturers. There were few changes that occurred during the implementation of the Quick Start Grant project, including:

- **40 percent of the Quick Start Grant project funding was intended for installations in low-income households.** For this, the project relied on self-reporting of customers. There were a few instances where customers reported that they were low-income or disabled, but not enough data was provided to understand the full impacts of the program for low-income customers. The project team could not verify the total number of low-income households participating in the program.

Project Goals and Achievements

Summary of Project Goals and Achievements

KPI/Goal	Metric	Data Source	Project Results
32 installations of 120V product across a variety of site characteristics (housing type, location of water heater, climate zone, type of demand, etc.)	Number of installations	Surveys and participant data collection protocols (metering, verification, and billing analysis)	32
40% of sites are in low-income households	Number of income-qualified households	Self-reporting in participant survey	N/A

The 120V heat pump water heaters are critical to decarbonizing the retrofit residential and small commercial market sector, and these products should be incentivized by the utilities

6 United States Census Bureau. (2019). American Community Survey 1-Year Estimates. Retrieved from https://www.census.gov/programs-surveys/acs.

and via the Inflation Reduction Act (IRA) tax credits to provide market scaling. In addition, the market requires contractors and permitting department awareness-building efforts.

The overall success of the 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 to size the new units correctly.

This section provides a high-level summary of project results. For additional information, please refer to the full study report listed in the **Key Publications** section.

Installations of 120V Heat Pump Water Heaters Across Various Site Characteristics

Heat pump water heaters were installed in 32 sites across California, capturing 13 climate zones. Climate zones one and 16 provide cold climate representation, climate zones 10 through 13 provide hot climate representation, and all other climate zones are considered mild. The project had a higher density of sites in climate zone 12 due to Sacramento Municipal Utilities District (SMUD) sites.

The project included households with one to four occupants, from one- to five-bedroom homes. Most homes in the study were three-bedroom homes with two occupants. The water heater was located in the garage for most homes that successfully met the site criteria. Additionally, four sites were selected where the heat pump water heaters could be installed in a smaller space inside the home. Most homes in the study were older, with only four built after the year 2000.

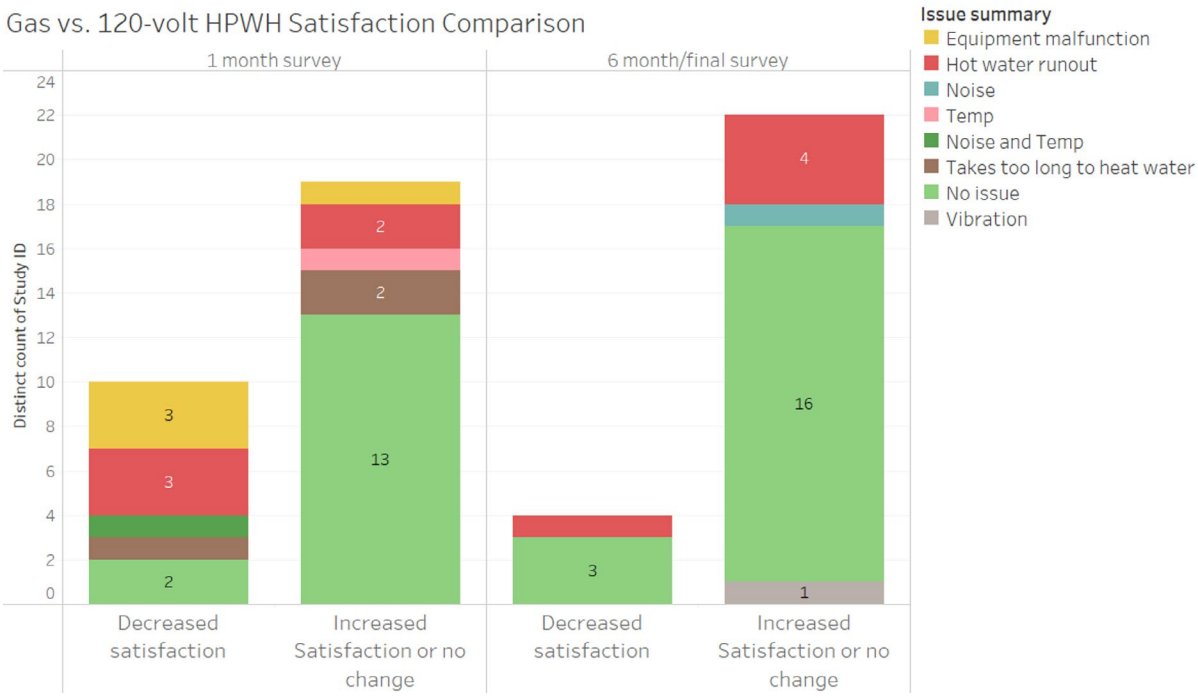
40 Percent of Installations in Low-Income Households

The project explicitly tried to capture income information from the participants during the site selection phase, however most participants were not willing to share this information. The project also did not have a clear definition of “low-income”. The lack of customer income information resulted in the project being unable to confirm the number of installations that occurred in low-income households.

Customer Satisfaction with Hot Water

After the first month of operation,19 of the 32 participants (59 percent) ranked their satisfaction with the 120V heat pump water heater as the same or better than their previous gas or propane water heater. While some respondents reported decreased satisfaction with the heat pump water heater compared to their last water heater, no respondents ranked their satisfaction with it lower than a three on the one-to-five scale. Conversely, five customers rated their satisfaction with their gas water heater as lower than three out of five. Reasons for dissatisfaction with the gas water heater include low efficiency (i.e., high fuel use), concerns about the flue, and unmet hot water demand.

Most of the participants that reported decreased satisfaction with the 120V heat pump water heater during the one-month survey period had experienced a specific issue with the water heater: either a short-term equipment malfunction, a hot water runout, disruptive noise, and/or a change in temperature of the space where the heat pump water heater was installed. At the time of the six-month follow-up survey, only four customers reported decreased satisfaction.



In cases where participants reported that the heat pump water heater took too long to heat water, or hot water runouts were occurring, field study personnel provided customer education including recommendations regarding setpoint and mixing valve temperature adjustment options and best practices for limiting high hot water use in rapid succession.

Notably, three of the five respondents who experienced hot water runout were in the top five-highest overall combined hot water users of all study participants. All five participants who experienced hot water runout used more than 130 gallons of hot water (and, in one case, nearly 200 gallons) on their peak hot water use day. One site received a 50-gallon heat pump water heater due to space constraints but routinely drew more than 60 gallons of hot water per hour.

Performance of the 120V Heat Pump Water Heater

To study energy performance, the project examined numerous factors, including temperature differences between water mains and ambient air across locations, hot water delivery and customer demand profiles, compressor run times and power consumption, performance for load-shifting, load shape profiles, and coefficient of performance results. Hot water delivery temperatures tended to be above 110°F, even at high-demand sites. While a deliberate

attempt was made to select sites that are low to medium occupancy (two- to four-person person households), the project did have some sites with sporadic demand of more than 100 gallons, and as high as 300 gallons during holiday season. The 120V model did not have an electric resistance back-up element to account for the high demand days.

The project team also observed that the compressor runs about five to six hours daily. The run time and period depend on hot water usage and draw patterns; in some cases, the team did see the compressor come on during the 4:00 p.m. to 9:00 p.m. statewide peak, highlighting the need for this technology to be grid interactive. The team was able to capture data related to performance for three different load-shifting customers that utilized different temperature set point schedules. To evaluate the efficiency of the 120V heat pump water heaters, the team used a calculated daily average coefficient of performance which quantifies compressor performance. Coefficient of performance is defined as the amount of heating provided by the heat pump to the hot water tank per unit of electrical power supplied. This metric does not include any storage (tank) or distribution losses. The project found an overall average coefficient of performance of 2.98.

Product, Installation, and Operating Costs

This project tracked the upfront product, installation, and operating costs to give the market an accurate picture of the cost of implementing a 120V heat pump water heater in various home types. The 120V heat pump water heater proved to be a time-efficient and cost-effective replacement for natural gas water heaters due to ease of installation. By comparison, most 240V heat pump water heater installations would not have been possible in one visit by an installation team. Since this technology targets the retrofit market, the project team recommends installing it in households with an existing circuit ready to receive a 120V heat pump water heater or that requires limited electrical remediation. Electric upgrade interventions associated with the 120V heat pump water heater installation ranged from $75 to $200. While 120V product costs were more expensive than 240V counterparts, the cost differential remained significantly less than those accrued by longer installation times and electrical infrastructure upgrades.

While energy savings are consistent across the utilities, the operating cost savings vary based on the household's utility rate structures and load profiles. The field validation found that average monthly operational costs for 120V heat pump water heaters were reduced by more than 50 percent for PG&E and Sacramento Municipal Utilities District (SMUD) customers. Whereas for Southern California Edison (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. The overall operational cost savings from the field validation in California utility service areas, with some of the highest electricity costs in the nation, bodes well for savings in other parts of the United States.

Key Publications

A more thorough and detailed final report from the 120V Heat Pump Water Heater Field Study can be accessed here:

> New Buildings Institute. (2023). *Plug-In Heat Pump Water Heater Field Study Findings & Market Commercialization Recommendations*. https://newbuildings.org/resource/plug-in-heat-pump-water-heater-field-study-findings-market-commercialization-recommendations.

Customers' and Partners' Experiences

> *"I think the heat pump water heater performs much better than the previous gas water heater. We have had no complaints about hot water supply, and the energy usage is way, way down."*

> *"Completely love this product, it's great. Have not run out of hot water once, and it's very quiet. Game changer product."*

Key Learnings

The market needs more innovative solutions like this emerging technology to support the gaps where a 120V heat pump water heater is not feasible. While 22 percent of the study sites could be directly supported by 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 to support the colder half of the country. While European and Asian markets have distinctive products to meet space constraints, more such products should be manufactured within the United States.

This field study aimed to independently verify 120V heat pump water heaters for user satisfaction, installer acceptance, and energy performance to validate the emerging technology. Once validated, the study's findings should help with the 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 building market.

Based on the project's findings, for the electrical and space constraint applications, the 120V heat pump water heater is a compelling technology that can be game-changing for meeting decarbonization or electrification goals for the retrofit market sector for residential and small commercial applications. Below are some key findings and recommendations for supporting wider adoption of this technology. As noted above, more detailed learnings and information can be found in the study's full report in the **Key Publications** section.

Manufacturer Recommendations

While 120V units are getting market ready--four renowned manufacturers have near market-ready units--multiple other manufacturers are closely watching the development related to this technology. Based on the first-ever independent field validation study, we have identified recommendations for manufacturers about product development and commercialization. Please see the following recommendations:

- **Need clear instructions in the manual and specifications on integrated mixing valve.** Since these products look similar to the 240V heat pump water heaters that come without a mixing valve, it is easier for the installers to get mixed up with the installation requirements. It is critical for the manufacturers to distinguish this key product feature in their marketing materials.

- **Need smaller footprint, small form factor units.** The 120V product is targeted for the retrofit market where space is of the essence. Due to the lower first-hour ratings compared to gas units, 120V heat pump water heaters require two sizes up compared to the existing gas tank size. Thus, they are physically larger than the replacement and require adequate air space surrounding the unit. In addition to gas tank-type water heaters, replacements for instantaneous "tankless" gas units will be needed (most likely being wall-mounted units). Likewise, there are form factor issues in replacing electric resistance water heaters with heat pump water heaters ("low boys," for example, or units in tightly confined spaces). In summary, multiple new product types will be required to accommodate different housing types and space requirements.

  Per the lab test results, there is only a three to eight percent energy penalty for heating the water at a higher setpoint. We recommend looking at higher setpoints and smaller footprint tank sizes like 30 and 40 gallons.

- **Packaged units are preferable for the residential market.** Split systems have their role in some applications but also have additional installation challenges compared to a fully packaged water heater, as it is a multi-component installation.

- **Need for heat pump water heater product fixes.** We heard a few complaints from the installers and customers about manufacturing defects and malfunctioning units. Examples include oversensitive sensors, a leaky tank, and a missing control panel. While most of these are not 120V technology-specific, special attention is required to eradicate the manufacturing defects from the heat pump water heater design.

Utility/Incentive Program Recommendations

Based on the study findings, when designing an incentive program for 120V heat pump water heaters, please see the following recommendations:

- **Absorb the products into current heat pump water heater incentive programs.** The 120V technology is very similar to the incumbent 240V heat pump water heaters. While

smaller units have a slightly lower uniform energy factor (UEF) than the current 240V unit, we still recommend that these units be absorbed into existing incentive programs for easier and quicker technology adoption into the market sector.

- **Integrate into weatherization programs.** To promote 120V heat pump water heaters in fuel switching retrofits through weatherization programs, the measure's cost-effectiveness will need to be validated. Alternatively, there may be an opportunity for 120V heat pump water heaters as a health and safety measure, which are not subjected to the same cost-effectiveness criteria. 120V heat pump water heaters may be eligible when replacing atmospheric/power-vented gas or propane water heater in a weatherized home without adequate combustion air. Heat pump water heaters don't require combustion air, so a resident would not need to add mechanical ventilation in this case. If a well-insulated home does not have adequate combustion air, it could create negative pressure in a mechanical closet. This could cause a flue gas draft, creating a health and safety hazard . We have not thoroughly researched the implications of 120V heat pump water heaters on weatherization programs, but this may be an area for future research.

- **Include light commercial buildings in programs.** Commercial buildings using natural gas or propane water heaters under 80 gallons may be candidates for 120V heat pump water heaters. Residential water heaters may be installed in small commercial buildings that have less hot water demand. In commercial buildings, the hot water demand often varies by building type. From experience implementing energy efficiency programs, northwest market characterization surveys, and National Renewable Energy Laboratory (NREL)'s ComStock dataset, we have found that small offices and retail buildings tend to have less hot water demand and may be served by residential units. Energy efficiency programs should intentionally include commercial buildings that use residential water heating equipment in their programs, as these buildings may be ignored in some jurisdictions.

- **Maximize equity aspects of the programs.** Installing 120V heat pump water heaters is less labor intensive than 240V units requiring a minimum of three to five hours of labor with condensate and ventilation requirements. In addition to electrical upgrade-related financial savings, we see operating cost savings for some sites. The sizing of tanks should vary based on factors that include equity-oriented factors like the number of people. We recommend maximizing outreach within low-income communities to ensure they benefit from the comfort, health benefits, and reduced energy burden that the 120V heat pump water heater provides.

Policy and Market Recommendations

For the market and targeted action required by the policymakers, please see the following recommendations:

- **Update California plumbing codes.** The California Plumbing Code first-hour rating requirements cause an increase in heat pump water heater sizing beyond the manufacturer's recommendation. 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. Based on the code official's suggestion, we recommend that the plumbing code needs to be revisited to focus on the low-flow fixture use cases and new emerging water heaters with integrated mixing valves that allow for higher first-hour ratings.

California building codes also require a platform for gas water heaters, but we have found that platforms make it challenging to fit the heat pump water heaters on the site. Since these platforms are not required for heat pump water heaters, the ones that can be easily removed should be removed.

- **Improve permitting department education and trainings.** Due to the emerging nature of the heat pump water heater technology, the jurisdictions are requiring extra paperwork, which delays the installation. It is critical that market-facing materials and training are explicitly developed targeting the education of the permitting officers. In addition, some tools and templates could be made available, and the whole permitting process could be simplified for electrification projects.

- **Increase installer education and awareness.** Workforce development and training is key for any electrification project success.

Market Sector Assessment, Best Applications, and Key Considerations

- **Electrical criteria for low-hanging fruit.** Based on the installation financials and ease of installation criteria, the low-hanging fruit for the 120V heat pump water heaters are sites that have an existing shared circuit with a minimum available capacity per manufacturer rated power draw (e.g., 7A for shared circuit units). Of the 153 site walkthrough surveys, 32 installations used the existing 120V plug point closer to the water heater location with minimal ($50) electrical work. Based on the walkthrough survey findings, in California, approximately 22 percent of the retrofit single family homes with gas 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 NEC and California building code.

  Any time the site requires the addition of a dedicated circuit, panel upgrade, or amperage upgrade, a 240V heat pump water heater is an ideal solution. For the 120V installations, the non-feasible site criteria are:
  - » Requirement of an extensive upgrade to the existing circuit (e.g., circuit breaker replacement, upgrading of the current electrical conductor(s), code violations impacting installation, or the new outlet required is greater than 25 feet from the nearest outlet.
  - » Requirement of installing a new dedicated circuit, or main distribution panel and/or subpanel upgrade or amperage service upgrade.
  - » Observable code violations that may create hazards or result in failed permit final inspection.

- **Site selection recommendations.** Based on the runout events that occurred during the study, we recommend that installers and/or homeowners adhere to the following key considerations. For instance, upsizing the heat pump water heater is especially important for households, with children, teenagers, or guests, anticipating spikes in hot water demand.

KEY CONSIDERATIONS FOR THE RIGHT SITES FOR 120V HEAT PUMP WATER HEATERS:

1. This technology is appropriate for smaller demand sites, one- to three-person households. It is critical that the water heaters are sized correctly.
2. Upsize the tank to ensure adequate first hour hot water. For four-person households with children, install an 80-gallon tank.
3. Use the mixing valve to maximize available hot water by pre-heating to 140°F.
4. Ensure sufficient air volume (minimum 700 cu. ft.) in the room where the heat pump water heater is installed so performance does not degrade due to a drop in intake air temperature.
5. While the manufacturers are working on a solution for noise levels (bringing them below 55 dB(A)), we recommend installing noise dampening pads at the time of installation. Or making sure that the water heaters are placed in garages or basements, away from the living areas.
6. Limited electrical remediation sites with existing gas and propane water heaters are the low-hanging fruit for 120V heat pump water heaters.

Recommended Next Steps

Several lessons from this work could be used to support California and other states as they consider 120V heat pump water heater deployment and applications. This study identified key considerations for site selection and early adoption, constraints in the California market posed by the California Plumbing Code, limitations in California's Technical Reference Manual, and, importantly, a need for installer education to ensure proper installation, customer satisfaction, and support load shifting. NBI's Advanced Water Heating Initiative plans to support efforts happening in California and beyond. The 2023-2025 priority areas for 120V technology adoption include:

- Validation of the technology in multifamily and small commercial applications
- Adoption of the performance curves in the modeling software
- Support higher capacity compressor research
- Standardized load shifting (phase 2 of the study just starting)
- Permitting and code readiness support
- Market connections and mapping
- Use of low-GWP refrigerants
- More affordable products and install practices in the market

This program is part of the TECH Quick Start Grants (QSG) program, designed to fund targeted, innovative projects that test approaches to overcoming market barriers to heat pump space and water heating adoption.

If you have questions about this report's findings or seek additional support assessing lessons learned for scaling project concepts, please contact the TECH Clean California Team at tech.info@energy-solution.com.