

Market characterization of space heating heat pump and heat pump water heater Load Flexibility controls for residential applications in California

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ABSTRACT

Residential heat pump load flexibility (LF) represents a significant untapped potential for addressing California climate and grid needs. Residential space conditioning represents a large fraction of electricity, and water heaters (powered by heat pumps) act as thermal batteries, which can be pre-charged in anticipation of grid needs or absorb excess on-site renewable generation.

As part of a California Energy Commission (CEC)-funded emerging technology study, the authors conducted a market characterization of heat pump LF controls for residential applications in California. Through a comprehensive literature and product review and interviews with subject matter experts (SME), the authors collected data to describe the current and future landscape of the technical components (communication, control, and measurement infrastructure) and market mechanisms (utility programs and rate structures) that enable residential heat pump LF controls.

Market actors face numerous barriers to large scale adoption of heat pumps with LF and the enablement of these devices, although the expected growth of space and water heating heat pumps translate into enormous LF potential. Advanced and equitable technology solutions to enable connectivity and smart control are critical to drive mass market adoption. Aligning requirements between regulations would encourage widespread adoption by reducing cost to both requirements and manufactures. Regulatory efforts to create dynamic tariff rates and infrastructure for access to these tariffs would enable a consumer to harvest the financial benefit of LF. While the study was conducted in California, the findings that impact LF control adoption apply to other regions of the United States.

Introduction

Residential building technologies have significant untapped potential to provide cost-effective grid services through advanced demand-side management strategies. In California, the residential sectors represent 7% of California’s total greenhouse gas emissions (California Air Resources Board 2018). Rocky Mountain Institute estimates that grid-wide implementation of demand flexibility could save 10-15% of potential grid costs and reduce electric bills by 10-40% in the residential sector using rates and technologies already available in the market (RMI 2015).

In this paper, we focus on the LF potentials from space conditioning heat pumps (SCHP) and heat pump water heaters (HPWH).

LF by SCHP can play a critical role in addressing the grid’s needs by pre-heating and pre-cooling homes ahead of the morning peak in winter and afternoon peak in summer, respectively. The CEC’s Load Management Staff report (CEC 2021) estimated the statewide LF potential in residential buildings by using in-place advanced thermostats with programming and communication capability. They assumed 13.8% advanced thermostat ownership across

California, and 26% of smart thermostats will participate in control optimization in response to time-based pricing made available by the CEC rulemaking. Based on those assumptions, the CEC found that each year, 120 GWh of peak energy consumption could be shifted off peak resulting in 1,800 GWh of peak energy shifted over a 15-year period—for an annual cost savings average of \$6 million statewide.

HPWHs are expected to play a critical role in decarbonization, although the market adoption rate of HPWHs is currently only about 0.6% (DNV-GL 2021). HPWHs are well-positioned for LF. They can store additional thermal energy, like *charging* a battery, by preheating the water when demand price signals are lowest and available renewable generation is highest on the grid. *Discharging*, or delivering water, can occur when demand price signals are highest to minimize load on the grid and, subsequently, reduce electricity bill costs to consumers. Natural Resources Defense Council (NRDC) suggested that although there is only modest storage capacity per HPWH, the load shifting capacity can be significant in aggregate (Delforge and Vukovich 2018). The study found that when managed well, HPWHs could shift from a California coincident peak of 15% to only 1%, and a solar coincident from 55% up to 65%.

While the residential sector presents significant potential for LF services, there are significant technical and market challenges. This paper draws from a market characterization study of heat pump LF controls for residential applications in California. The objectives were to: 1) create a framework to describe the technology and market enablement components for residential heat pump LF services, 2) map out the current and future landscape of enablement components for SCHP and HPWH, 3) identify barriers, policy levers, and commercial considerations that impact market penetration, and 4) suggest actions for utilities and policy makers to facilitate LF controls for heat pumps. While the study was conducted in California, the findings that impact LF control adoption apply to other regions of the United States.

Methodology

In this paper, we classified LF capabilities as traditional or advanced. Traditional LF focuses on load shedding and is one-directional communication. Advanced LF entails two-way communication to provide a combination of load management strategies. We focused on advanced LF control that can provide shed, shift/shape and modulate as defined in the reports from the Department of Energy (DOE 2021).

Advanced LF for residential appliances is a rapidly evolving field. The research team conducted interviews with 14 market actors and SMEs, including 1 policy maker, 1 utility staff, 8 SMEs/researchers, 1 control vendor, and 3 manufacturers. Interviews focused on goals, needs, and targets for residential heat pump LF; policy and market drivers and barriers; estimates of current and forecasted market penetration; and current and future capacity for manufacturers to deploy LF controls. Most respondents were experts in specific topics, so we note the number of market actors that responded to each question when presenting results.

In addition, we conducted a literature review and online product review, including regulations and policy reports, market studies and research reports, manufacturer and industry trade publications, and utility websites (regarding programs and rates).

Background

Technology Framework

In this section, we create a framework to describe the critical technology elements for enabling LF services and then describe the current and future landscape of these elements specific to residential heat pumps LF services. In general, technology enablement requires the following components (Figure 1) (LBNL 2017):

- **Communications infrastructure:** components that receive demand response (DR) signals and for advanced LF, submit information back to the signal source.
- **Measurement infrastructure:** components for energy measurement (such as an electric meter), communication resource interface, and a communication gateway.
- **Control infrastructure:** components that translate DR signals into a control action and include cyber system and physical aspects (i.e., physical actuation or relays).

While traditional LF has been implemented in all commercial and residential sectors, advanced LF is still emerging. Advanced LF expands on the capability of traditional load management programs to provide more complicated grid services by allowing demand from the customer side of the meter to shift load and respond continuously, on much smaller timescales, to changing market conditions (DOE 2021).

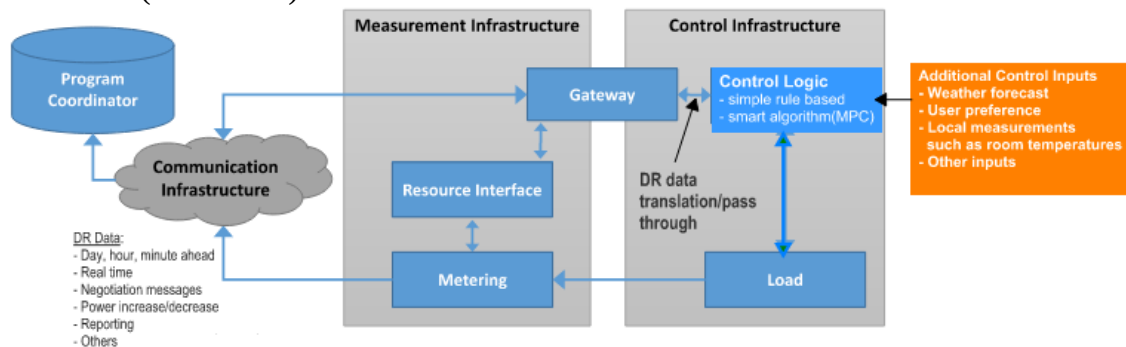


Figure 1: Basic elements of LF technologies (Modified based on (LBNL 2017))

Communication Infrastructure

To support advanced LF, communications components are required to collect and transmit granular energy data from end-use appliances back to the aggregator or grid marketplace operators in real-time on a small timescale. Two evolving aspects within the communication infrastructure are communication architecture options and communication protocol, as described below.

For communication architecture, heat pump LF frameworks have two main functional points: virtual top node (VTN) and virtual end node (VEN)¹. Figure 2 illustrates several options

¹ The terms VTN and VEN are developed in the framework of OpenADR, which is one of the open-standard DR communication protocols between utilities and end users. This report uses these two terms to refer to entities and components that perform the same functions as VTN and VEN. Definitions from the OpenADR Alliance: <https://www.openadr.org/faq#18>. VTN is a server that transmits signals to end devices or other intermediate servers. A VTN, which is typically the independent system operator (ISO) or utility, manages resources, creates/transmits

for DR signal transmission between VTN and VENs. The first option is the VTN, typically the independent system operator (ISO) or utility, which can communicate with a DR provider vendor (also “aggregator”), which communicates with residential appliances serving as the VEN. Another option, illustrated on the bottom side of the diagram, is for the VTN to communicate directly with the residential appliances serving as the VEN. For either option, a VTN can either directly communicate with the residential appliances serving as the VEN or with a third-party smart thermostat or home energy management systems serving as a VEN.

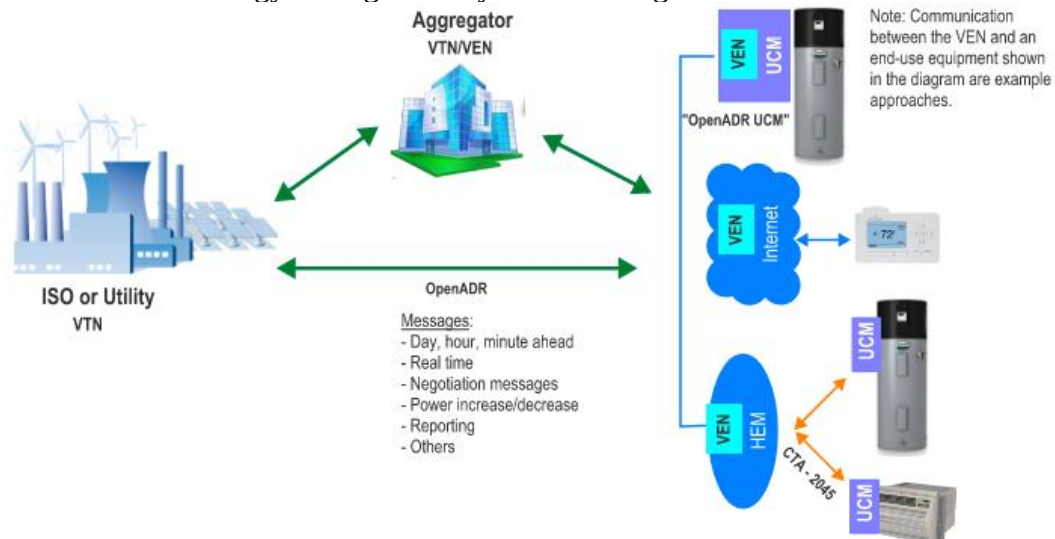


Figure 2: Overview of grid connectivity and residential appliances options, including OpenADR framework (Based on Diagram from: OpenADR Alliance)

For communication between a VTN and VEN, a translation step is usually necessary because different entities, their systems, and devices use different data formats. A communication protocol establishes a common message format enabling signal transmission and then interpretation by the local device control.

Interviewees most often discussed Wi-Fi-enabled Open Automated Demand Response (OpenADR) and CTA-2045 by Consumer Technology Association (CTA)² as the current communication technology. Historically, essential LF communications from utility to end users has been via OpenADR. The Alliance developed its 2.0b version with added specificity of DR responses that anticipates the rapidly expanding advanced LF market. CTA-2045 compliant implementation in a heat pump would entail that the appliance has a physical port to accept matching modules and thereby enables any demand flexibility languages to be used. Use of a CTA-2045 port and module combination still requires a communication protocol (such as OpenADR). Specifying a CTA-2045 compliant port does not lock the appliance into using a particular external communication method or another (i.e., Wi-Fi, ethernet, radio waves, etc.), which is considered an advantage over OpenADR. Interviewees provided mixed opinions on their preferred connectivity approach. One control vendor stated that manufacturers have historically chosen Wi-Fi as the communication path over other pathways. This was supported

events, and requests reports from resources. VEN is a client that can accept and responds to the signal from the VTN server. A VEN is responsible for translating messages to and from the control hardware.

² CTA is a trade association representing a large group of US consumer technology industry, and it produces the annual consumer electronics show events

by two HPWH manufacturers that stated that all of their HPHWs can connect to the internet and their cloud applications are internet-connected. However, three industry SMEs and another control vendor expressed concerns of using Wi-Fi to send and receive signals because:

1. Internet disconnections add cost to the utility to follow-up with customers for reconnecting their heat pump to the internet.
2. Cybersecurity is a concern when using Wi-Fi as a communication method.
3. Requiring Wi-Fi-enabled OpenADR for grid connection would create inequities for low-income residents that lack Wi-Fi from benefitting from LF bill savings.

Measurement Infrastructure

LF measurement infrastructure involves both capturing and delivering energy data, and it typically entails providing data with sufficient granularity, format, and precision for transacting flexibility services. For residential applications, measurement infrastructure and communication infrastructure are usually provided by the same device. For example, in California, smart meters are used for a residence-level energy metering, and they can pass the measurement to corresponding utilities as their primary function.

Control Infrastructure

Interviewees emphasized that for mass market adoption of residential appliances with LF, a control logic must be “under the hood”, so users do not manually engage with the LF function. Compared to the traditional appliances that make decisions based on local measurements and inputs, connected appliances also account for grid signals for decision making. Control automation is critical to achieve LF services. For example, a SCHP that is not controlled to a time of use (TOU) rate relies on a user’s behavior (manual change of a setpoint) to achieve load change. If the user is not aware of the tariff and how their usage aligns with the tariff, an SCHP cannot deliver any LF service to the grid. An SCHP controller with logic that considers a TOU rate can automatically adjust the setpoint and allow customers to financially benefit from the LF services provided by the appliances.

Based on our literature review and interviews, the control infrastructure could reside in the VEN platform—i.e., a smart thermostat cloud or a HPWH using its cloud-based original equipment manufacturer (OEM) controller, which also acts as the VEN. In some other cases, the VEN communicates the translated message to the control hardware via a gateway or proprietary data protocols. Appliance automation, especially with advanced control optimization capabilities, in residential buildings is currently quite limited.

Market Mechanism

Market mechanisms are critical to provide financial incentives for customers to use appliances with LF, and for grid operators to have a means of utilizing this LF. Broadly speaking, current LF market mechanisms can be separated into the following (LBNL 2017):

- Incentive-based programs, which pay or reward customers for managed electrical loads.
- Time-based utility tariff rates, which charge customers prices that better correspond to the true cost of electricity. Examples include TOU and critical peak pricing (CPP).

This section characterizes current participation mechanisms, rate structures, and impacts to market actors. It also investigates opportunities to promote residential LF uptake.

Demand Response Market and Programs

Flexibility services interact with the energy market at two levels in California: wholesale market (on a pilot basis) and retail market interactions. For both, participating customers are incentivized to reduce electricity consumption during certain hours, referred to as “an event”. During events, customers are remotely signaled to reduce consumption based on high energy prices or when system reliability is low due to high grid load (CPUC 2021).

There are two wholesale-level of demand flexibility services that residential heat pumps may provide: supply DR and load-modifying DR. For load-modifying DR, the California investor-owned utilities (IOUs) each design and run a portfolio of DR programs targeting all customer sectors to meet their system resource adequacy (RA) requirements. For supply DR, the California Public Utilities Commission (CPUC) implemented demand response auction mechanism (DRAM) pilots for the California IOUs since 2016. The DRAM pilots issue competitive solicitations for the three RA categories. Third-party aggregators, called demand response providers (DRPs), then bid their aggregated resources directly into the California Independent System Operator (CAISO) day-ahead energy market. Preliminary results from the DRAM pilots show the merits and challenges associated with direct participation from load-modifying DR resources in the wholesale market (CPUC, 2021). Along with behind-the-meter energy storage systems, residential heat pumps present the highest potential for LF services. Nonetheless, no DRPs include heat pump flexibility in their existing service offerings and plans for targeting or developing such capabilities for heat pump appliances are uncertain.

Retailed-level DR programs are another way to encourage LF, and they are generally implemented by utilities or third-party DRPs on their behalf. A customer may voluntarily participate by enrolling either with the utilities directly or via an active DRP in their utility service territory, with a contract between the customer and utility. Table 1 shows different types of DR programs available to residential and nonresidential customers.

Table 1. Load management DR programs in California

DR programs	Process	Residential customer participation
Load control program (LCP)	IOUs manage program and issue incentives	Direct residential and non-residential customer sign up
Base interruptible program (BIP)	IOUs manage program and issue incentives	Non-residential only
Capacity bidding program (CBP)	IOU manages the program and issues incentives; DRPs manage customer participation on behalf of IOUs	Residential customers via DRPs only

Utility Tariff Structures

Utility tariffs are an important tool to enable LF. They act as economic signals for users to schedule and optimize appliance operations to avoid high pricing at peak hours. Utility tariffs are structured such that they generally reflect the resource costs associated with meeting a load for a retail customer. For traditional LF, tariff structures are the only mechanism that provide

market pricing signals to which appliances with LF capabilities may respond. Currently, California utilities use a TOU tariff with lower rates that are available to CPP program participants. Current residential rate structures are transition schedules designed with minimal peak/off-peak price differentiation to avoid negatively impacting customers. The rate structure is very simplistic and does not fully leverage LF. In addition, interviewees noted that the automated DR capabilities that would enable appliances to respond to dynamic peak events are not integrated into most residential control devices like thermostats.

Future residential tariffs could be structured to encourage LF to help alleviate peak demand and load shift to dynamically reflect true electricity generation costs. Two industry SMEs in interviews stated that rates should be more granular for locations as well, since the needs and generation mix differ based on location. Implementation of day-ahead or real-time varying electricity rates would result in a more efficient retail market and lower overall costs to the end user. Time varying rates would reduce overall energy use and encourage adoption of load flexible technologies, as users have a strong incentive to install measures that reduce peak loads. Table 2 summarizes the status of residential LF market enabling components.

Table 2. Current Status of residential LF market enabling components

LF Services	Load Management Program	Utility Tariff
Shed	Direct sign-up or via DRP to LCP and CBP. Only covers SCHP.	CPP (TOU as a condition of CPP)
Shape and Shift	Not available.	TOU. Not effective, as TOU is relatively static to achieve shift. Not reliable as it depends on consumer awareness and behavior

Regulatory Context and Support

State and federal regulations are prioritizing increased adoption of LF technologies, standards, and dynamic rates. These trends are established through bills, orders, energy codes, and other regulatory decisions and can be grouped into the following types:

- **Legislation** that regulates utilities to provide **rate designs and tariffs** to promote clean energy technologies and address barriers to their adoption. CPUC Order Number 19-1113-7 was issued in November 2019 and established the CEC Load Management Rulemaking to consider amendments to “existing load management standards to increase flexible demand resources through rates, storage, automation and other cost-effective measures.” (CEC 2021). The CEC Load Management Standards consider three mechanisms to increase demand flexibility: 1) adjustment of rate structures to encourage use of electrical energy at off-peak hours or to encourage control of daily electrical load, 2) end-use storage systems that store energy during off-peak periods for use during peak periods, and 3) mechanical and automation technologies for control of daily and seasonal peak loads. The mechanisms would lay the foundation for the mass-market end-use automation to provide time- and location- specific demand flexibility
- **Legislation** setting goals for the adoption of specific **DR-capable technologies and DR programs**. In California, State Bill (SB) 49 requires adoption of flexible demand

appliance standards and alignment of DR programs with those standards. It also provides for incentivizing adoption of flexible demand appliances (State of California 2019).

- **Building energy codes mandate or features** encourage adoption of LF technologies by including performance and functional requirements in the standards. In California, building energy code Title 24, Part 6 provides performance credits for builders electing to adopt grid-responsive smart thermostats and HPWHs.
- Regulations by **trade associations or federal agencies** that establish technology **specifications and performance criteria**. Some regulations are voluntary, but the state and regional jurisdictions often adopt these regulations in energy codes. DOE (through the ENERGY STAR® program), Northeast Energy Efficiency Appliance, and AHRI are actively working on developing LF standards for space conditioning and water heating heat pumps. AHRI Standard 1380 (2019) establishes requirements for variable capacity HVAC systems 65,000 Btu/hr and less that are capable of supporting LF strategies to benefit the electric grid in a predictable manner. AHRI is also developing AHRI Standard 1430P. This is an analogous standard for residential electric resistance and HPHWs, but with a broader objective to establish a more comprehensive standard and to consolidate various patchwork requirements within the industry for water heaters.

The current state of the rapidly evolving field is a mix of inconsistent requirements with preemption questions. In interviews, manufacturers reported that inconsistent requirements cause confusion and higher costs for manufacturers, control vendors, and designers who must navigate multiple standards. In stakeholder comments in response to SB49, several manufacturers and trade organizations (including Bradford White, Carrier, General Electric, and AHRI) recommended aligning requirements with AHRI Standard 1380, 1430, and ENERGY STAR.

Results

Space Conditioning Heat Pump LF Technology Landscape

Current residential SCHPs are controlled to perform LF functions either with an external smart thermostat (provided by OEM or third-party) or by directly controlling the compressor (DOE 2019). LF controls using a thermostat are more prevalent.

Smart thermostats offer communication to DR servers (VTN), control using advanced algorithms, and compatibility with home automation systems. Smart thermostats provide the ability to introduce advanced controls for relatively simple heating, ventilation, and air conditioning (HVAC) systems. The smart algorithms are contained in the smart thermostat, which relays information about setpoint and current temperature to the HVAC system through a load control switch installed between the thermostat and SCHP equipment. In some cases, the smart thermostat can also communicate with a home management system, which then relays the control to the HVAC system. Based on a manufacturer's website and one vendor interview, smart thermostats may be more compatible with single speed heat pumps, because some thermostats may not allow for two-stage wiring (Goodman Manufacturing Company n.d.).

When the SCHPs do not use an external thermostat, all the necessary sensors and control algorithms are built into the equipment or accessed by the equipment itself via a built-in communication device that uses Wi-Fi to communicate directly with grid operators or utilities. LF services are normally provided by controlling the compressor of a heat pump using either a load control switch or DR signals that are sent directly to the outdoor unit. LF functions with the

compressor focus on reducing or increasing the power usage of the compressor rather than controlling temperature. Changes in power may be limited by a maximum indoor temperature offset. More advanced heat pumps, usually variable speed, may have a terminal block in the outdoor unit or indoor air handler, which can receive a LF control signal (EPRI 2017). The Air-Conditioning, Heating, & Refrigeration Institute (AHRI) Standard 1380 provides specifications for standardized communication systems between the HVAC system and the utility (or related entity) for variable capacity heat pumps. This standard specifies how a SCHP should operate based on signals received, such as through OpenADR.

For residential HVAC systems, traditional mass market residential LF control targeted conventional load shed DR programs. Both smart thermostats and SCHPs are expected to adopt more advanced LF capabilities soon. Table 3 summarizes the LF capabilities expected to be adopted in the near-future (one to two years) and that are under-development (more than two years). Smart thermostats and SCHPs LF future capabilities are based on the “Roadmap for Advanced Heat Pumps” by the Heat Pump Coalition, EPRI Common Demand Response Functions for HVAC report (EPRI 2017), and interviews conducted for this study. The interviewee commenting on control capabilities did not provide a timeline for when implementation is expected, but they expressed that these are active areas the manufacturer is working on.

Table 3. SCHP LF capabilities near-future adoption and under development

	Communication and Measurement	Control
Near-future	Controls with access to 24-hour forecasted weather data to allow pre-heating and pre-cooling at less extreme temperatures Control ability to access utility rate schedules by reading external internet data (RSS, RDF Site summary) Heat pumps with a CTA-2045 port or equivalent	Smart thermostats with algorithms and machine-learning models to maximize comfort and participation Edge computation³ to allow for local operations and commands, rather than from the cloud Controls integration—a control system with the ability to automatically integrate and prioritize different systems (i.e., auxiliary heating or cooling)
Under development	Hardware that enables automatic connection to utility DR system to allow easy and secure enrollment into utility DR programs Automatic internet connectivity with 5G cellular or satellite Wi-Fi advancements	Integrated energy storage: hardware included in product allowing for integration or connection to energy storage systems (heated or chilled building mass, phase-change material, heated or chilled fluid)

³ Edge computation is a distributed computing paradigm that brings computation and data storage closer to the location where it is needed to improve response times and save bandwidth.

	Communication and Measurement	Control
	Two-way communications between the utility and HVAC system	

Heat Pump Water Heater LF Technology Landscape

Unlike SCHPs—which have long used advanced control algorithms to improve thermal comfort and have a history of providing traditional DR services—HPWHs are a relatively new technology, and they currently have a very low adoption rate. Development of LF technologies for HPWH is encouraged by decarbonization policies and the urgency to reduce the costs from renewable energy curtailment. Most industry efforts have focused on communication infrastructure to achieve grid connectivity.

Communication infrastructure for HPWH is a rapidly emerging field. At a high level, HPWHs need to connect to an external system, using either external or internal communications, that can send DR signals from the VTN to VEN (Energy Star 2021). Based on interviews, considerations for technology development include the cost effectiveness of the approach to residential appliances, the capabilities to address basic vs. advanced LF needs, using current and developing infrastructure, and the potential for achieving mass participation.

On the control infrastructure side, HPWHs (like all water heaters) currently use simple logic to turn the compressor on and off, and/or turn an electric resistant element⁴ on and off to maintain a hot water supply temperature setpoint. Traditionally, the hot water temperature is a fixed temperature based on the user’s preference. For HPWHs to provide advanced LF services, complicated control algorithms would be needed to set hot water temperature setpoints. Currently, development of the LF control logics and the infrastructure to support their implementation has focused on providing shed service. We expect that recent changes in California Building Energy Standard Title 24, Part 6 will also drive advanced LF control logic development.

There are HPWHs with basic grid-connected capabilities on the market today, including through providing a CTA-2045 port and through proprietary approaches specific to each manufacturer. Many manufacturers are actively engaged in the industry regulation and policy rulemaking process. Future product offerings will largely depend on how the regulations (many of which are still under development) evolve. Currently, each manufacturer is developing individual proprietary approaches to implement DR signal responses. All major manufacturers (including A.O. Smith, Bradford White, General Electric, Rheem, etc.) are developing grid connection capabilities, including implementing CTA-2045 (Frontier Energy, Energy Solutions, and Larson Energy Research 2021). Based on interviews, manufacturers are considering the following developments for each of the LF technology components:

- Communication and measurement: 1) Full command set for CTA-2045-B messages: Currently, only the CTA-2045-A messages have been implemented. CTA-2045-B intends to achieve two-way communications between the utility and HPHW. 2) Response to real-time signals: HPWHs are technologically capable of responding to real-time signals, but

⁴ Many HPWHs are a hybrid system that uses heat pump mechanism and electric resistance to heat water.

they are currently only performing LF actions based on a DR signal or locally-stored utility rate schedule.

- Control infrastructure: The manufacturers did not identify any developments for shift. As energy codes, such as Title 24 JA 13, promote optimal controls that look ahead at the price signal to achieve lowest cost while minimizing runouts, this is an area that may receive increased attention from manufacturers and policy makers.

Barriers and Recommended Opportunities for Actions

This section summarizes market gaps to widespread adoption of heat pumps with LF and provides recommendations for how each can be addressed.

Overview of Opportunity Categories

In general, our study identified four main categories of opportunities to increase consumer adoption. Figure 3 shows how interviewees prioritized each type of opportunity.

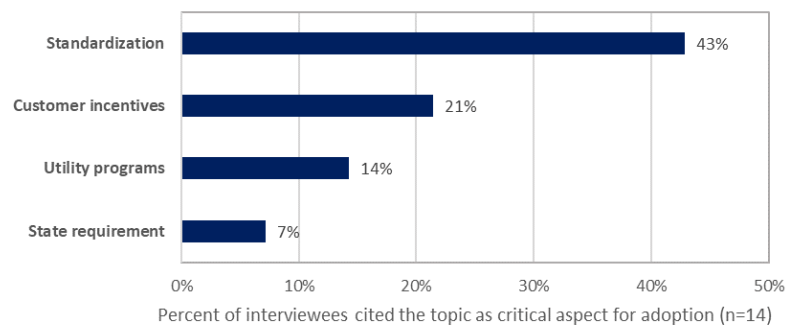


Figure 3. Important Opportunities for Large Scale Adoption of Heat Pump with LF

As Figure 3 shows, most market actors saw standardization as the most critical aspect for adoption, which reinforces the importance of harmonization between standards and regulations nationwide. They also noted the importance of customer incentives and code requirements.

Based on the market assessment findings, we summarize market gaps and recommend potential opportunities in three areas: technology and product features, market mechanism and engagement, and programs and code efforts. For each opportunity, we identify the lead market actor and supporting market actor that could execute the recommendation. At a high level, we recommend that a consortium of utilities, efficiency organizations, policy makers (state or federal agencies), and manufacturers collaborate on this topic, particularly for opportunities that require manufacture engagement. A utility, federal agency, or efficiency organization could sponsor and host this collaboration. In addition, we recommend exploring multiple solutions (e.g., CTA-2045 port and Wi-Fi alternatives) since a preferred solution is not clear, and different solutions may be preferable in different scenarios. While we list the “utilities” as carrying out many of these recommended opportunities, energy efficiency organizations could play this role instead. Regional utilities or regional efficiency organizations should lead development of those that are specific to programmatic tool development or local-market engagement.

Product Features and Installation

- **Barrier: Lack of standardization with multiple evolving regulatory requirements related to LF specifications causes high costs for manufacturers to implement necessary components**

Opportunity	Lead / Support
Enhance consistency between requirements and increase coordination between regulatory, programmatic, and industry standards-setting efforts. A consortium of policy makers, utilities, and manufacturers should develop recommendations for standardized regulatory requirements. These should allow manufacturers to produce appliances for a broader market, by reducing cost to both consumer and manufacturers.	Lead: Policy makers, utilities Support: Manufacturers
To set the stage for the collaboration above, assess performance data needs for determining standardization pathway to enable LF.	Lead: Policy makers or utilities

- **Barrier: It is challenging to efficiently aggregate end use devices at scale. LF service capability per customer is low, while high enablement costs are high.**

Opportunity	Lead / Support
Design programs to use communication protocols that allow programs to aggregate loads from the installed HVAC stock that existed prior to enforcement of LF standards, and work with manufacturers to design equipment that can comply.	Lead: Vendors/third-party aggregators Support: Manufacturers and Utilities
Encourage development of DR-ready products that have been designed upfront with LF programs in mind (i.e., HPWH with a CTA-2045 port or with OpenADR).	Lead: Manufacturers
Support projects that test various LF design and install/setup strategies, including the use of FM broadcast and other Wi-Fi alternatives to achieve connectivity. This could be through utility-supported demonstration projects.	Lead: Manufacturers, installers, building owners and developers Support: Utilities

- **Barrier: Contractors are concerned about high liability and training needs to overcome a steep learning curve.**

Opportunity	Lead / Support
Manufacturer design and contractor practices should create and test easier, plug-and-play installations and configuration solutions to increase customer adoption. Utilities could support streamlined solutions through case studies and incentives.	Lead: Manufacturers and contractors Support: Utilities

Market Mechanism and Engagement

- **Barrier: There are limited avenues and financial incentives for consumers and aggregators to capitalize on LF services.**

Opportunity	Lead / Support
Utilities should develop program resources and market rules (supported by policy) that allow third-party aggregators/vendors to easily monetize the value from LF value from dynamic pricing and convey anticipated market demand to encourage manufacturer investment in product & supply chain development.	Lead: Utilities Support: Policy makers
Utilities should create an education campaign to raise customer awareness, that includes demonstration projects, contractor training, and end-user education.	Lead: Utilities
Spur market demand by supporting policy favoring electrification, providing high incentives and sustained programmatic support for heat pumps with LF.	Lead: Policy makers Support: Utilities

- **Barrier: Market-based financial signals do not align with end user economics. Some customers do not connect peak energy use with environmental impacts.**

Opportunity	Lead / Support
Utility rate structures should evolve to become more granular, such as offering real-time pricing to customers and imposing residential demand charges.	Lead: Utilities and policy makers
Utilities should develop new programs that include a full range of potential LF measures or that use metrics to encourage LF measures.	Lead: Utilities

Programs and Codes

- **Barrier: Customers have low awareness of the value of heat pump LF, resulting in low customer demand for products.**

Opportunity	Lead / Support
Utilities should develop standards that enable opt-out participation, similar to existing pre-programmed thermostat schedules, or JA13-compliant HPWHs, which operate in demand-flexible mode by default. These will have much higher uptake by customers and implementers than opt-in.	Lead: Utilities
Regulatory agencies should require protocols that use advanced LF technologies such as CTA-245 b or the OpenADR 2.0 b standard to enable LF in appliances.	Lead: Policy makers

- **Barrier: Information on product availability and performances is not robust and generally inaccessible.**

Opportunity	Lead / Support
Support demonstration projects with building owners and developers, or pilot programs with program implementers that provide an opportunity to collect data to support program or rate design.	Lead: Utilities
Create and maintain a website for heat pump and LF technology information, tools, and resources, such as building owners/developers, consumers, installers, and program implementers.	Lead: Regulatory agencies Support: Utilities

Conclusions

Overall, residential heat pump LF represents significant untapped potential for helping to address California’s climate and grid needs. Residential space conditioning represents a large fraction of electricity, and water heaters (fueled by heat pumps or other technologies) act as natural thermal batteries, which can be pre-charged in anticipation of grid needs.

There are various strategies for implementing LF with heat pumps, including the utility connecting directly with the device; the utility connecting to another site-level device, such as a smart thermostat or home energy monitor; and the utility connecting with a third-party aggregator that connects with individual devices. Because these structures are developing in the market, any control logic should be capable of interfacing with any of these systems.

The current market penetration of heat pumps is low: approximately 4% for space heating and 1% for water heating in California. However, heat pump penetration is growing and should accelerate as state regulations and local mandates move to decarbonize buildings. Many heat pump products with grid-connected capabilities exist on the market today, including SCHP that connect to smart thermostats and HPWH through a CTA-2045 port or use a manufacturer proprietary approach. However, there are challenges for most customers to take advantage of the LF feature. Currently, customers can financially benefit from heat pump LF through load management programs and TOU rates. However, the financial incentives are too low to stimulate high participation, and customers are confused by program offerings. In addition, the lack of automated LF technologies in the residential sector means few users can take advantage of the benefits from a rate structure or utility programs. Using emerging LF technologies poses additional challenges, including uncertainty risk for aggregators (if predicted savings are not delivered) and evaluation risk for utilities (from uncertain baseline methodologies). Current TOU rates are blunt instruments—since they are typically binary rates (e.g., higher from 4:00 to 9:00 PM), although the CEC is creating standards for IOUs to establish dynamic tariff rates and the infrastructure for a database to allow transparency and ubiquitous access to these dynamic tariffs.

Manufacturers and control vendors are developing LF capabilities, such as hardware and software, that streamline the process for establishing signal connectivity, two-way communication, control optimization, and even utility program enrollment. Market actors face various barriers to large scale adoption of heat pumps with LF and the enablement of these devices. These include a high first cost of heat pump equipment and LF enabling technologies; multiple, evolving design targets for manufacturers, such as different regulations and appliance communication protocols; small amounts of load shifting available per customer; and additional barriers for low-income customers such as reduced access to Wi-Fi. Some emerging solutions are

becoming standardized, such as leveraging standardized communications protocols (such as OpenADR and CTA-2045). In addition, third-party aggregators are combining LF from appliances across thousands of homes to achieve a sizeable load shift.

While the challenges are significant, we identified various opportunities that policy makers, utilities, manufacturers, and others can take to increase adoption to heat pumps with LF. As one interviewee reported, the residential sector is an “11 out of 10” in terms of importance for managing the grid’s LF. Despite the challenges, tapping into the large potential offered by heat pumps with LF will be crucial to meeting California’s climate and grid goals.

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