Electrification Enablement via Load-Balancing Solutions Focused Pilot

Final Report

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Disclaimer

Executive Summary

The Electrification Enablement via Load-Balancing Solutions Focused Pilot was launched in early 2025. Its primary objective was to understand how load-balancing solutions or technologies were being used in existing electric vehicle supply equipment installations and validate load-balancing technologies' potential to enable additional electrification without requiring costly electrical panel or service upsizing. A review of California's existing building stock suggests that an estimated 33 percent of existing homes in California have a 100-ampere panels (CPUC 2024). The Electric Power Research Institute estimates that more than 50 percent homes have two or fewer open breaker slots in their existing electrical panel, resulting in the need for electrical modifications like adding subpanels to accommodate the new electrified loads.

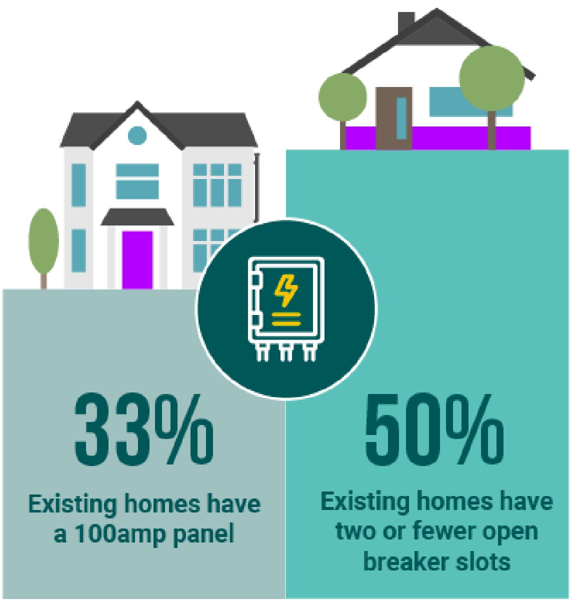

Figure 1: Electrical panel capacity for existing homes in California.

In residential homes, there has been a notable shift towards an increasing number of electric vehicle drivers using Level 2 home charging.[1] According to contractor survey findings, Level 2 electric vehicle chargers are one of the top triggers for electrical panel upsizing that can also translate to service upsizing.[2] The relatively new load-balancing technologies, with this validation can foster electrification without expensive panel and service upsizing. However, there is no comprehensive research that helps the market identify the right use case and installation applications for these technologies.

This pilot contains findings and recommendations to address barriers to integrating load-balancing technologies into electrification projects. These recommendations include ways that contractors,

[1] Level 2 charging adoption went up by 12% in 2024 (total 64percent) compared to 2019 when Level 1 charging was higher (48percent) (NREL, California Vehicle Survey 2024).

[2] Contractors reported that the top three triggers for an electrical panel upgrade that will trigger a service upgrade are Level 2 electric vehicle charging, solar photovoltaics, and an HVAC upgrade (NV5 2022).

customers, and program implementers can use load-balancing technologies to avoid a service upsizing. Due to the controllability and energy management features of load-balancing technologies, these homes can be future proofed for utility load management and demand response programs. The electrification enablement pilot participants are homeowners in California investor-owned utility service territories. The project team has completed the following activities listed below:

- Interviewed seven technology manufacturers, reviewed specifications and product literature to understand the unique features of load-balancing technologies, and developed a technology matrix.
- Reviewed National Electrical Code, California Title 24, and California's existing building stock to understand typical garage conditions, co-located loads, and the current electrical requirements for appliances and load-balancing technologies.
- Completed data collection surveys for 53 customers currently using one of the load-balancing technologies and 5 contractors who installed the load-balancing technologies in the pilot demonstration.
- Analyzed telemetry data from manufacturers on existing installations.
- Completed field demonstrations at nine participant sites covering circuit splitters, smart breakers, and smart panels.
- Facilitated three Technical Advisory Committee meetings with stakeholders from Southern California Edison; Pacific Gas and Electric; San Diego Gas & Electric; the California Market Transformation Advisory Board; University of California, Davis; and Energy Solutions.
- Developed a technology transfer plan and collateral and educational modules for workforce training for the Electric Vehicle Infrastructure Training Program.

Key Findings

Load-balancing technologies can help achieve and optimize scalable electrification of retrofits. Electrification of an electrical capacity-constrained home is possible without electrical infrastructure upsizing. Load-balancing technologies can help facilitate electrification and EV charger installations for homes with limited service capacity. Based on pilot demonstrations and load calculations, we found that for capacity-constrained homes with limited breaker slots and limited-electrification requirements, load-balancing technologies such as circuit splitters and meter collars provide slot flexibility. Load-balancing technologies such as smart panels and subpanels can meet customers' long-term electrification needs and support multiload control and management, providing flexibility to add future loads. As part of an energy management system, load-balancing technologies provide flexibility in the electrical load calculation requirement that would typically require service upsizing. The pilot found that the participants were able to add a Level 2 electric vehicle charger, electric heat pump water heater, and heat pump clothes dryers with existing solar and battery installations using load-balancing technologies without upsizing if the service. For market scalability, load-balancing technologies, efficient appliances, the right electrical load calculation tools, and most importantly, contractor and customer education, are critical elements to move the market in the right direction.

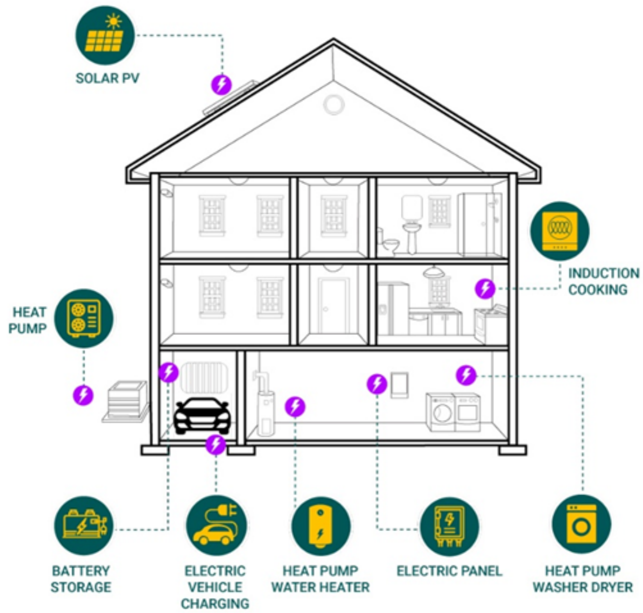

Figure 2: Potential home electrification measures with PV and BESS.

Load-balancing technologies can help electrify electrically constrained homes cost-effectively compared to service upsize. There is a wide spectrum of load-balancing technologies available, such as circuit splitters, smart panels, smart subpanels, and smart breakers, all of which feature service-upgrade-avoidance capability.[3] They are also a lower-cost alternative to traditional panel and service upsizing, averaging $600 to $7,500 [4] - this is addressed further in the economics of load balancing technologies section below. Due to the variability in capabilities, installation techniques, and the customer segments each manufacturer is targeting, load-balancing technologies come in a range of prices.

Load-balancing technologies successfully maintain the total system draw under the threshold value. Based on the pilot demonstration test results, the load balancing technologies successfully manage individual loads to maintain the system under the set threshold.

- The **plug-in circuit splitter** sheds the secondary load (EV charger) within seconds of the primary load (HPWH) drawing over the threshold. After the HPWH is turned off, the circuit splitter monitors the loads for a couple of minutes before powering the EV charger:
- The **smart panel** turns off the dryer when the system threshold is reached, followed by the EV charger when the panel draw reaches the threshold. The load shed priority sequence is customizable and determined through user input. The smart panel monitors the system continuously to make a decision on restoring the shed loads. The EV charger is seen to

[3] During interactions with the manufacturers of several load-balancing technologies, we found that they refer to the feature as service-upgrade-avoidance instead of service upsize avoidance. Therefore, we are using the term "service-upgrade-avoidance" when referring to the product features and capability.

[4] The customer can incur between $2,000 to $30,000 for electrical infrastructure upgrades (NV5 2022).

resume operation when the total panel draw is maintained below the threshold and there is enough capacity to accommodate the EV charger without exceeding threshold.

- The **smart subpanel** sheds the hot tub circuit when the total panel draw exceeds the system threshold. The load shed priority is based on a pre-programmed logic in the smart subpanel with inputs from the user on critical and non-critical loads. The smart subpanel continues to monitor the system to ensure there is enough capacity remaining so the shed load can resume without reaching the system threshold.
- The **smart breaker** turns off the highest amperage drawing (HPWH) when the total panel draw exceeds the threshold. The technology does not have the capability to auto restore the load when the system is maintained below thresholds and needs input from the user to turn the load on

More market education is needed among contractors to consider load-balancing technologies before upsizing electrical service or panels. Knowing the different types of load-balancing technologies, efficient appliances, and mapping those to the customer electrification needs are important first steps. It is equally important for contractors to use the right techniques in the electrical load calculations to avoid unnecessary electrical upsizing. The perceived need for service and panel upsizing often comes from conventional load calculations used by contractors. In the pilot demonstrations, participants were able to electrify their level 2 electric vehicle charging, heat pump clothes dryer, and heat pump water heater with existing solar and battery systems.[5] Stress tests conducted on the homes with all major appliances running in parallel at maximum capacity confirmed that the total panel draw reached 80 percent of the 100-ampere service limit. However, it is very unlikely that a home would see coincidental major load operation. On average, the maximum demand for existing homes is 20 percent to 30 percent of existing panel capacity, leaving ample capacity for electrification of water heating, space heating, electric vehicle charging, cooking, and laundry on the existing panel.

The current trends show electricians upsize or subpanel the electric infrastructure rather than considering other cost-effective alternatives, such as load-balancing technologies, or efficient appliances. Based on the focused pilot findings, we recommend using these power management and efficiency techniques. We also recommend standardized tools[6] to accurately estimate the electrical load with alternative solutions before taking unnecessary actions on electrical upsizing.[7]

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[5] Adding a solar and battery energy storage system was not a scope of this pilot. However, we had existing homes with solar and battery systems, where we were able to demonstration electrification within the 100 A service limit with load balancing technologies.

[6] Electrical load calculation tools that consider energy management systems and power efficient design in the load calculations. Some examples are Watt Diet Calculator and the Residential Electrical Service Upgrade Decision Tool.

[7] For more on how to optimize the use of an electrical panel, check out New tools and tech to prep your electrical panel for an all-electric home by Canary Media's Jeff St. John, Rewiring America's 100-amp electrification guide, Peninsula Clean Energy's design guidelines for home electrification, and Redwood Energy's pocket guide to all-electric retrofits of single-family homes.

The current electrical codes present no barriers to the integration of load-balancing technologies that are part of this pilot. The codes do not limit particular appliances from being load balanced by an energy management system. The code explicitly permits and provides pathways for energy management systems to manage and share electrical loads.

For load calculations, the traditional prescriptive National Electric Code (NEC) 220.83 methodology is more conservative and uses nameplate ratings with coincidental factors, triggering electrical panel and service upsizing when new loads are added. We recommend contractors to explore the alternative metering based approach like NEC 220.87, which allows for the use of a home's actual maximum demand to calculate existing loads, for optimal usage of the existing electrical infrastructure.

Load-balancing technologies for controllability and grid integration. The more advanced load-balancing technologies like smart panels, smart subpanels and smart breakers are working towards including grid integration features in addition to service-upgrade-avoidance. If supported by the right incentive programs, they will facilitate future demand flexibility for utilities. Note that several load-balancing technology manufacturer either has or is working on making their products bidirectional and grid interactive. With building and transportation electrification accelerating, utilities are seeking scalable, cost-effective solutions that can help mitigate costly distribution upsizing, increase system flexibility, and enhance customer affordability. These products are coming to the market at a critical time.

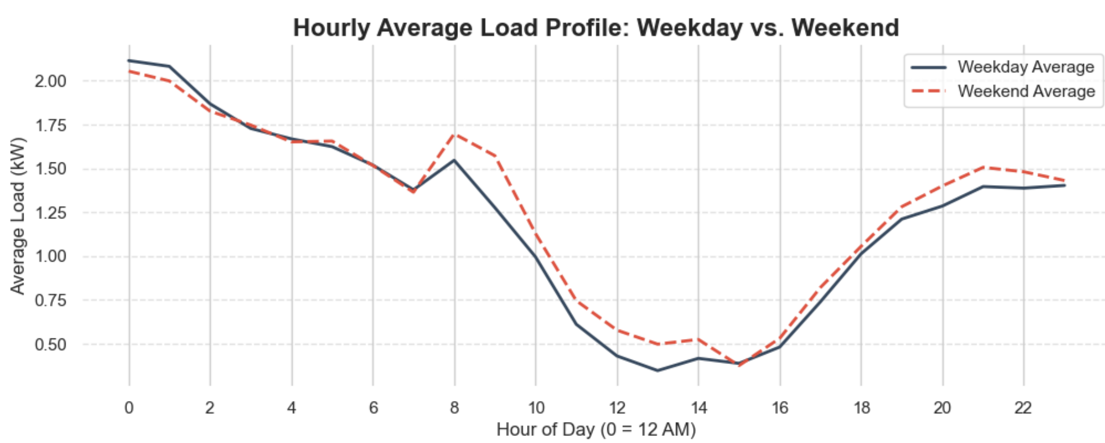

Figure 3: Hourly average load profile (N=18), weekday vs. weekend.

The Figure 3 is an average hourly load shape of the studied homes. We see a shift in load profile to early morning hours[8] due to electric vehicle charging to nonrenewable generation time when the greenhouse gas emissions are higher. Note that we observed a typical peak of 16-17 kW during the morning hours, if we multiply that by 700,000 homes with level 2 EV charging[9], 11.2 gigawatts of peak load is expected the grid. As the state transitions to a more electrified future, the demand for

[8] Compared to the infamous California duck curve, which was peaking at evening hours when people get back home from work.

[9] CEC estimates that more than 700,000 level 2 chargers are installed statewide in single family homes.

electricity is expected to increase dramatically. This increase in housing electric demand is driven by the growing number of electric vehicles on the road and their reliance on home charging stations for overnight charging.

The California Energy Commission projects that load growth from EVs, combined with impacts from time-of-use rate structures, may lead to a "timer spikes, where many vehicles in an area start charging simultaneously, causing a sudden increase in energy demand" in the late evening. Their projections show spikes of more than 1 GW in light-duty EV charging load around 9 p.m., and midnight due to drivers responding to lower cost rates, without more dynamic charging controls. (California Energy Commission 2024) These localized surges in demand could pose challenges particularly at certain constrained local distribution circuits.

Most load-balancing technologies give customers circuit-level visibility of a whole home and control over electricity use inside the home. **Our work with LBT manufacturers during this pilot allowed insight into where these advanced LBT's are innovating.** The future is pointing to dynamic signals and automated orchestration of loads, with the right integration of appliance controls, load-balancing technologies have the potential to help with that transition.

Recommendations

The focused pilot determined that load-balancing technologies **can be a key solution that can provide and expand opportunities in electrical systems for California homeowners wanting to electrify** and are a compelling technology that can support the adoption of California's 6 million heat pump adoption by 2030 (California Heat Pump Partnership 2024) and electrification goal of the residential retrofit market as well as for small commercial applications. Based on the pilot findings, we recommend the following to manufacturers, policymakers, utilities, and program implementers when designing policies and incentive programs for electrification with load-balancing technologies:

- **Manufacturers need to develop the right controllability and sequence of operation structure for load-balancing technologies and appliances.**
    - Load balancing technologies control at circuit level but each appliance manufacturer is also controlling their devices via their own industry's communication standards. For example, heat pump water heaters use the CTA2045/EcoPort communication standard, whereas space conditioning heat pumps are all moving towards AHRI 1380. The original equipment manufacturers of different technology categories need to collaborate further and develop the right controllability and sequence of operation. The manufacturer partnerships will help the industry to move in the right direction and support the technologies with advancement and market adoption.
- **Develop standardized tools and practices for service upsize avoidance.**
    - There are market solutions to cost-effective electrification, such as load-balancing technologies and efficient appliances. Depending on the customer's electrification journey needs, the customers and contractors need tools and templates to be able to map their project to the right solution. While there are many tools available on the market, it would be ideal to have statewide standardized tools for consistency in the market. This will also help original equipment manufacturers and contractors get visibility for product planning

and business operations. Note that currently there is a California Energy Commission and industry-funded project that aims to develop and demonstrate a decision tool that can provide homeowners with detailed information on their electricity use and panel capacity needs by 2027 A Decision Tool to Electrify Homes with Limited Electrical Panel Capacity.

- **Increase understanding of the real holistic benefits for load-balancing technologies and finding the right incentive programs for them.**
  - While this pilot through stress testing and M&V validated the service-upgrade-avoidance feature of load-balancing technologies, the technology category has many more use cases such as grid integration, controllability, load management of the circuits in homes. Due to the load management feature they have the potential to support bring total system benefit and greenhouse gas reduction benefits to the utilities. These technologies are at the juncture of enabling energy efficiency, electrification, load management, and future grid integration. With further investigation, it would be ideal to find the right incentive program for them.
- **Understanding the roadmap for grid integration, dynamic signaling, and validating the features of the technologies for whole home orchestration.**
  - Based on manufacturer interviews, load-balancing technologies are moving towards becoming home energy management systems. The latest California Public Utilities Commission proceeding[10] restarts the state's approach to demand response, shifting focus toward a more integrated load management framework. The California Public Utilities Commission will be creating the infrastructure to make load management functional by defining how price signals, interval data, and automation interact. The intent is to make load shifting under dynamic rates measurable, verifiable, and fully countable for grid reliability and resource adequacy. With building and transportation electrification accelerating, utilities are seeking scalable, cost-effective solutions that can avoid costly distribution upsizing, increase system flexibility with smart demand response and load management, and enhance customer affordability. Understanding and validating both the utility dynamic signals response needs and behind-the-meter technology capabilities further is important.
- **Contractor awareness and workforce development for adoption of right practices.**
  - Through the pilot we learned that installations could have been made more cost-effective if the installers were trained enough on the installation best practices and commissioning of the load-balancing technologies. Tighter alignment between manufacturers and installers is needed to ensure reliable operation and maintainability until these technologies are better understood. For optimized installation, we recommend creating a post-installation checklist and standardized commissioning procedures. This will help

[10] The California Public Utilities Commission's proceeding on Demand Response R25-09-004 is a foundational step toward aligning demand response, dynamic pricing, and automation under one cohesive framework and making flexible load management scalable and dependable across programs and market layers (California Public Utilities Commission 2025).

contractors to confirm the right sequence of operation and load management priorities. For load calculations, the traditional prescriptive National Electric Code (NEC) 220.83 methodology is conservative, we recommend contractors to explore the alternative metering-based approach like NEC 220.87.

- **Equity program opportunities.**
  - We recommend maximizing outreach about load-balancing technologies within low-income community contractors to ensure they benefit from the reduced cost burden provided by the panel upgrade avoidance feature. They are a great solution for direct install programs and are an option for moderate-income homeowners who are looking for solar installations.

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Abbreviations and Acronyms

Acronym	Meaning
AC	Air conditioner
A	Amp (Ampere)
BEV	Battery electric vehicle
CalMTA	California Market Transformation Administrator
CEC	California Energy Commission
CPUC	California Public Utilities Commission
EMS	Energy management system
EPIC	Electric Program Investment Charge
EPRI	Electric Power Research Institute
EV	Electric vehicle
EVITP	Electric Vehicle Infrastructure Training Program
EVSE	Electric vehicle supply equipment
HP	Heat pump
HVAC	Heating, ventilation, and air conditioning
IOU	Investor-owned utility
kVA	Kilovolt-ampere
kW	Kilowatt
LBT	Load-balancing technologies
M&V	Measurement and verification
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
PG&E	Pacific Gas and Electric
PHEV	Plug-in hybrid electric vehicle
RTU	Rooftop unit
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SFH	Single-family home
TAC	Technical Advisory Committee
V	Volt

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Introduction

The Electrification Enablement with Load-Balancing Solutions Focused Pilot aimed to validate and showcase the potential of load-balancing technologies (LBTs) to accelerate electric vehicle (EV) adoption and support further electrification. It leveraged existing load-balancing and EV supply equipment (EVSE) installations and gathered data to understand if the LBTs were being optimally used. The pilot also aimed to demonstrate optimal setups for load-balancing controls to manage loads within existing panel capacity for additional home electrification measure adoption. Below are the technology categories that were evaluated as part of this focused pilot.

- **Circuit splitters**, circuit level and outlet level, are devices that split the existing 240-volt (V) circuit into two identical ports sharing the same circuit. They are beneficial for existing 240 V outlets where common loads include an electrical dryer, EV charger, heat pump **water heater (HPWH), and/or split heat pump.**
- **Meter collars**, also known as a meter socket adapters, are installed between the residential electrical meter and the meter socket. They create a new interface between the meter and the socket, which allows devices to connect directly to the utility feed, bypassing the home's electrical panel. As a result, they help reduce the need for electrical panel upsizing. Current models support onsite photovoltaic (PV) generation and EV charging.
- **Smart panels** are electrical panels that use load management to reduce the need for upgrading the electrical service. The most common residential electrical panels are 100 amperes (A). Smart panels reduce the cost and time of upgrading the panel to 150 A or 200 A.
- **Smart circuit breakers and relays** are internet-connected devices that monitor and control electrical systems. They are typically installed in existing panels, replacing an older non-smart circuit breaker. They can be controlled with an app to remotely turn on and off breakers and schedule loads to be on during off-peak times. This ability to use existing electrical infrastructure prevents the need for a panel upsize.

In addition to piloting additional electrification through demonstrations, this pilot will help improve customer and workforce awareness. The findings from this pilot aim to inform future program design and other initiatives designed to increase electrification and EV adoption in California.

This focused pilot sought to address the research questions in Table 1.

Table 1: Research questions and methodology.

Research Question	Research Methodology
1. How can LBTs be deployed optimally to enable successful EVSE and reserve panel capacity for additional electrification?	• Participant survey • Market assessment • Manufacturer telemetry data analysis • Market assessment and pilot demonstration
2. What is the current retrofit garage landscape in California?	• Existing building stock review • Participant survey – market assessment
3. What is the current electrical code requirement for end use appliances in terms of circuit sharing requirements? Requirement for installing new electric equipment using LBTs?	• Existing California and National Electric Code (NEC) review
4. In what scenarios do LBTs help enable additional electrification measures? What are the initial costs with these solutions? 5. What are the configuration challenges? and user experience?	• Manufacturer interviews and technical data collections, like specification sheets, costs • Participant survey – market assessment • Project costs from contractors – pilot demonstration • Contractor surveys – pilot demonstration
6. What is the load shifting performance of LBTs? What is the load shifting (kW) magnitude and duration using these technologies?	• Pilot demonstration measurement and verification (M&V) data

Background

Electrification of the state's existing single family residential housing stock will be essential to meet California's goal to be carbon neutral by 2045, reducing carbon emissions by 85 percent from 1990 levels (Assembly Bill 1279, statutes of 2022), and requiring 100 percent of electricity by 2045 to be from renewable energy and zero-carbon resources (Senate Bill 100, statutes of 2018). Reducing the carbon emissions from burning fossil fuels in homes requires "home electrification" (e.g., switching to electricity as the fuel source for heating, hot water, cooking, and clothes drying).

A key barrier to home electrification is cost and time delays associated with the perceived need to upsize electrical panels and utility services to accommodate new electrical loads. Increasing household peak electric demand also leads to increased grid infrastructure, such as replacement of transformers, distribution wires, and additional generation, increasing future costs for all ratepayers.

The need to upsize panels can result from physical space and/or electrical load constraints in currently installed panels. These constraints are most common in homes with electrical panels rated less than or equal to 100 A. Current estimates suggest 33 percent of California's single-family housing stock falls into this category (CPUC 2024) and lower-income households are disproportionately affected. If these homes were all to upsize to 200-A service and panels, it would add approximately $10 billion in costs—at a conservative estimate of $4,500 per panel—without adding costs for utility infrastructure upsizing, which could be orders of magnitude higher.

See Figure 4 below for potential immediate impact of service upsizing for residential homes. Successive costs for panel upsizing may trigger service line capacity increases and/or transformer and/or pole upgrades, creating additional ratepayer burdens from a rate base that is already increasing, which further discourages electrification adoption.

Figure 4: Potential impact of an increase in household electrical demand.

Additionally, there is not enough market awareness for alternative solutions to these costly electrical infrastructure upgrades. There is also a lack of market ready and scalable solutions that customers can implement.

Pilot Objectives

The key objective of this pilot was to evaluate optimal use cases for the different LBTs available on the market and drive market adoption. The goal was to use these LBTs to optimally enable EVSE installation and reserve panel capacity for additional electrification measures.

Through the project, the project team evaluated and demonstrated scalable and cost-effective electrification solutions for California. The goal was to present cost-effective alternatives to panel upsizing in order to minimize barriers to electrification and mitigate grid impacts. The research team leveraged data from existing LBT installations to identify the optimal use cases for each technology type. Pilot demonstrations in 10 homes highlighted interventions to address market and technology barriers.

The project team is working with Electric Vehicle Infrastructure Training Program (EVITP) to integrate findings of this pilot into their trainings for electricians installing EVSE. We will also determine if the load-balancing solutions can be transferred to inform the forthcoming Viable Electric Alternatives (VEA) proceeding, and demand response and load management programs.

Table 2 summarizes the targets and actual completed sites per task of the pilot.

Table 2: Pilot task targets and actuals.

Task	Target	Actual Completed	Incentives
Technology/Market Assessment Study and Pilot Phase 1	40	Participant survey – 53	$35–$75
		Manufacturer telemetry data – 15	-
Pilot Development and Demonstration	3–10	Demonstrations – 9 Participant survey – 9	Up to $14,000
		Contractor surveys – 5	$35

Load-Balancing Technologies Description

The project team collected information on LBTs through interviews with manufacturers, product literature reviews, and online research. There are many LBTs on the market to meet different electrification needs for all customer types. Based on the customer's partial versus full electrification needs and financial means, they will have options to make the right selection of LBTs. The objective of the pilot was to validate the technologies for the right customer base and increase awareness. The capabilities, features, applications, cost, and market availability of each technology included in the pilot are summarized in Table 3:.

Table 3: Load-balancing technologies matrix.

Technology subcategory	Circuit splitter – plug-in	Circuit splitter – hardwired	Circuit splitter – meter collar/ meter socket adapter	Smart panel – whole home	Smart panel – subpanel	Smart breaker
Integration with existing systems	Plugged in to an existing 240 V receptacle	Hardwired on existing 240 V circuits (up to 2)	Installed between the electrical meter and the meter socket	Replaces existing electrical panel	Installed downstream from the existing electrical panel	Installed in series with existing circuit breakers. Product could either fit into any standard electrical panel or be compatible with specific brands
Controllable end-use loads	EV charging, washer, dryer, and other plug-in loads within the rated amps	Any loads within the rated amps	EV charging only[11]	Any loads on the electrical panel	Any loads on the electrical panel	Any loads on the electrical panel
Maximum amperage	240 V at 50 A per load	240 V primary at 50 A and secondary up to 32 A	50 A	100 A and 200 A panels with 16–48 breaker slot options.	Same as existing breaker rating – can control up to 12 circuits per panel. 60 A per load for 6 circuits and 30 A per load for 6 circuits	Same as existing breaker rating
Load management method	Controls a primary and secondary load. Pauses secondary load when primary load is over 10 A	Appliance to appliance circuit share: Controls a primary and secondary load - pauses secondary Load when primary load is turned on.	Pauses EV charging if the panel draw is above 80% of panel rating (or set threshold)	Automatically manages appliances/loads to stay below the threshold for the total panel consumption. Automatically restores circuits when total load drops below the Threshold and stabilizes over several minutes		Automatically manages controlled appliances/loads to stay below the threshold for the total panel consumption. User to manually restores circuits through the app for one product, while the other

[11] There are separate solar meter socket adapters on the market. They are not covered as part of this pilot scope.

Technology subcategory	Circuit splitter – plug-in	Circuit splitter – hardwired	Circuit splitter – meter collar/ meter socket adapter	Smart panel – whole home	Smart panel – subpanel	Smart breaker
		Whole home circuit share: Controls only one load - pauses secondary load if the panel draw is above 80% of panel rating (or set threshold)				automatically restores circuits When total load drops below the threshold
Connectivity	No remote control, but can monitor power for the connected loads through an app	No remote control or monitoring	Remotely monitor and control loads for individual circuits through an app			

Load-Balancing Technologies Application

Circuit splitter—plug-in: This technology is best suited when electrifying one to two loads and only when two plug-in loads are co-located, such as an EV charger and a heat pump clothes dryer in the garage. This technology allows circuit splitting when there are not enough breaker slots available in the electrical panel or if the homeowner is looking for a low-cost alternative to running new electrical conduits for 240 V loads. For example, if the homeowner wants to install an EV charger and a heat pump clothes dryer in the garage, but has only one 240 V outlet, they can install a plug-in circuit splitter and share the same circuit between the EV charger and clothes dryer. This technology can be used to share circuits between any plug-in appliances, such as EV chargers, washers, clothes dryers, water heaters, or heat pumps. The user or contractor can identify and select the connected loads. No further user input is required at installation or during operation. Plug-in circuit splitters are currently available on the market to purchase directly from the manufacturers or through distributors.

Circuit splitter—hardwired: This technology is best suited when electrifying one to two loads and the loads may or may not be co-located, for example, an EV charger in the garage and an induction cooktop in the kitchen. This technology allows two configurations—circuit sharing between two appliances and whole home circuit sharing. One limitation of this technology is that the current configuration does not allow both the primary and secondary circuits to run in parallel. The user or contractor can identify and select the connected loads. No further user input is required at installation or during operation. Hardwired circuit splitters are currently available on the market to purchase directly from the manufacturers or through distributors.

Meter collar: This technology offers a low-cost solution to add an EV charger to your home, without any electrical work or changes to your existing electrical panel. The meter collar is installed on your utility meter, which adds an EV meter socket to connect the EV charger. This solution is recommended for homeowners who want to add an EV charger to their home and do not have enough breaker slots or capacity with existing electrical panel. Meter collars are currently available on the market to purchase directly from the manufacturers or through distributors. They have been approved by SCE and are in the approval process with PG&E and SDG&E. Unfortunately in the time period of pilot we could not find a site within SCE territory to showcase Meter Collar device

Smart panel: Smart panels offer a lot more control and features in addition to service-upgrade-avoidance. The current smart panel products have 32 and 40 circuits as options. This technology is recommended when the homeowners are considering long-term electrification of multiple appliances and if they are planning to install solar and/or battery energy storage systems. Also, homeowners should consider this solution if the existing electrical panel is old and not in good condition. Smart panel technology selected in this pilot let the user provide inputs on setting the load priority sequence at installation or modify it as needed during operation. Smart panels are currently available on the market to purchase directly from the manufacturers or through distributors.

Smart subpanel: This technology is recommended when the homeowner is considering long-term electrification of multiple appliances. One smart subpanel can control 1 to 12 circuits. This solution is recommended only if the existing panel has empty breaker slots to accommodate the new electric loads of the subpanel. The smart subpanel technology selected in this pilot offered preprogrammed algorithms for load shedding sequences. This algorithm considered metrics such as equipment type, the impact of shedding on the equipment life, and determining the load shed priority. The technology currently does not allow users to customize the load shedding sequence but does allow you to configure which loads are critical and which are non-critical. Smart subpanels are currently available on the market to purchase directly from the manufacturers or through distributors.

Smart breakers: This technology is recommended when the homeowner is considering long-term electrification of multiple appliances. It's ideal when the existing panel is in good condition and has empty breaker slots in the existing panel to accommodate the new electric loads and the smart breaker modules. One of the smart breaker technologies does not have a load shed priority sequence programmed into the system but automatically sheds the highest draw load when the panel threshold was reached and needs user input to manually restore the loads. While another technology allowed the user to provide inputs on setting the load priority sequence at installation. Only one of the smart breakers is currently available on the market to purchase directly from the manufacturers or through distributors.

Methodology and Approach

The pilot included the following tasks:

- **Technology/Market Assessment Study and Pilot Phase 1**: This phase of the pilot leveraged existing LBT installations and evaluated the opportunities and limitations for each technology category. In this phase, the project team leveraged partner manufacturers' existing telemetry data and customer base for at least 40 sites.[12] It included collecting data on existing installations to determine if the technologies were being optimally used, conducting customer surveys, and collaborating with manufacturers on the product specifications and performance. In addition, the project team also reviewed existing electrical and energy codes to evaluate the feasibility of using these LBTs. As part of this phase, the project team analyzed the existing California single family building stock to understand the market potential and barriers.
- **Pilot Development and Demonstration**: The project team conducted demonstrations for up to 10 selected sites and demonstrated additional electrification measures along with EV charging with LBTs without the need to complete major electrical infrastructure upgrades. The sites selected prioritized circuits and loads in the garage since many single-family homes have laundry and EVSE loads in that location.
- **Technology Transfer**: Under this task, the project team created and executed a technology/knowledge transfer plan to disseminate the results of the pilot with key stakeholders and provided recommendations for measure package development.
- **Workforce Development**: As part of this task, the project team developed collateral and educational modules for the EVITP.

Market Actor Outreach

The project team identified the LBT categories and products available or in development during the research plan through online literature review and discussion with major manufacturers supporting LBTs. Several of the LBTs are available on the market with installations across the United States. The

[12] The telemetry data on the existing installations from the manufacturers will be anonymized. In addition, the manufacturers have also signed mutual non-disclosure agreements (NDAs) with the project team to participate in the pilot.

overall goal was to obtain the technical details for the LBTs from the manufacturers, understand user experience, and determine the applicability and potential of various technologies to avoid panel upsizing. This section describes the outreach methodology for these market actors.

Manufacturer Outreach

The project team conducted multiple interviews with seven manufacturers representing each of the technology categories. The goals of the interviews are listed below:

- Understand the features and functionality of each technology.
- Collect data on existing installations.
- Evaluate the existing customer database for conducting surveys.
- Recruit sites for pilot demonstration.

MANUFACTURER TELEMETRY DATA ANALYSIS PLAN

The project team requested historical telemetry data from all manufacturer partners capable of providing it, evaluated its capabilities and the operation of field-installed systems. The project team's goal was to assess overall system performance, identify specific large loads—with a focus on main panel power and EV charging—and, where applicable, evaluate if these technologies were being used optimally. Table 4 provides details on the telemetry data received from each manufacturer partner.

Table 4: Manufacturer data collection summary: Telemetry data.

LBT Product	Smart Panel	Smart Breaker	Smart Subpanel
Number of sites	5	3	3
Data granularity	1-minute	5-minutes	1-minute
Duration	1 year (hourly data) Sporadic events (1-minute data)	8 months+	8 months+
Number of average controlled breakers per panel	Approx. 20+	Approx. 10+	Approx. 5−12

Customer Surveys

The project team also sent survey requests to existing customers using the partnering manufacturers' customer base. The project team defined the survey questions with the following objectives:

- Understand LBT user experience and satisfaction.
- Collect data on the electrical infrastructure in existing homes with LBTs, such as the existing electrical panel size, type of EV charger, and other typical home characteristics.
- Recruit sites for pilot demonstration and testing.

To find residences with LBTs already installed in the home, the project team partnered with seven load-balancing technology manufacturers. The project team then developed outreach materials for the manufacturers to use to contact their customer base, informing them of the pilot and online survey. Out of the seven partner manufacturers, six had direct connections to their customers. One circuit splitter manufacturer did not have data on the existing customers and could not send out the customer survey request. Out of those six manufacturers, four sent out the survey requests. The project team received 53 total respondents from partner manufacturers' customers. Table 5 below shows the manufacturers, products included in the pilot, and a summary of the data collection progress per manufacturer.

Table 5: Manufacturer data collection summary—customer surveys.

Product	Number of Completed Surveys
Plug-in circuit splitter	30
Hardwired circuit splitter	0
Meter collar	0
Smart panel	20
Smart subpanel	0
Smart breaker	3
Total	**53**

Additionally, the project team conducted outreach through social media platforms like LinkedIn and shared the survey forms with individuals who expressed interest in participating. From this recruitment method, the project team received 5 additional survey respondents, resulting in 58 total survey respondents.

Because the online survey served dual purposes of aiding in pilot site recruitment and gathering information about homes with LBTs, the project team targeted the following group of residential homes.

- Home type: single-family, townhouse, duplex, or triplex.
- Garage type: attached or detached.
- EV charging: EVs charged at home using a Level 1 or Level 2 charger.
- Charger location: garage, driveway, or carport.

Respondents who did not meet these criteria were terminated from the survey and were not included in survey results or analysis. See Appendix B for the survey questions.

The project team also conducted surveys for contractors who installed the LBTs at pilot demonstration sites. In addition, the project team interviewed code officials and building inspectors to evaluate their awareness and perspectives regarding smart electrical panels.

Utility Data Analysis

The project team analyzed utility interval data for 11 of the customers surveyed. The data was collected through Utility API, a third-party utility data collection platform. The project team was able to get 15-minute interval data for a recent 12-month period. The overall objective was to estimate the peak panel draw data and see how it compares to the current panel size. We conducted the analysis to determine if these high peaks would warrant using a LBT to add future electrical loads.

Existing Building Stock Review

The research methodology involved a data-driven approach to identify whether a significant portion of the existing California housing stock includes garages and potential electrification appliances that could benefit from LBTs for electrification enablement. The research questions associated with each topic area are outlined below in Table 6.

Table 6: Research questions: Existing building stock review.

Topic	Research Questions
Garage availability	• What is the frequency of garages in single-family homes (SFH)? • What is the frequency of types of garages in SFH (single, two, three cars, attached vs. detached)?
Appliance/end-use location	• What is the frequency of clothes washers/dryers in SFH? • What is the frequency of gas vs. electric dryers in SFH? • What is the frequency of gas vs. electric water heaters in SFH? • What are the locations of clothes washers/dryers and water heaters? • What is the frequency of these appliances located in the garage?
Panel size	• What are the frequencies of different panel sizes? • What is the frequency of panels with limited additional capacity for electrification measures? • Where are panels located within the house?
EVs and charging	• What is frequency of EVs in households, and multiple EVs? • What is the frequency of charging by type (Level 1, Level 2, low-power Level 2)? • What is the frequency of location of charging (garage, driveway, other)?

The project team identified five publicly available datasets with information relevant to the research topics and questions addressed below. The project team conducted analysis on the raw published data to answer the questions outlined above. These datasets are included in Table 7.

Table 7: Data sources for existing building stock.

Data Source	Geographic Sample and Year	Number of Respondents
US Census American Housing Survey (AHS)	California (2023)	N/A
US Census State of Construction Survey (SOC)	Census Pacific Division (CA, WA, OR, HI, AK) (2020)	3,655
TECH Clean California Program Participant Data (TECH)	California (2021–2025)	9,837
California Energy Commission (CEC) Residential Appliance Saturation Survey (RASS)	California (2019)	~29,800 (varies by topic)
CEC/National Renewable Energy Laboratory (NREL) California Vehicle Survey (CVS) – 2019 and 2024	California (2019, 2024)	2019: 2,629 (non-EV), 394 (EV) 2024: 2,105 (non-EV), 949 (EV)

The project team did not do any weighting of source data and only analyzed the raw data as published.

Existing California and National Electric Code Review

The project team reviewed the California electrical code requirements, the relevant parts of Title 24, and the National Electrical Code (NEC) to identify dedicated versus shared circuit requirements, code allowance for sharing circuits, and panel loading guidance.

Appendix C below has the detailed code review methodology and findings. This iterative and focused methodology ensured a comprehensive analysis across both current and upcoming code editions, specifically targeting provisions related to electrical load management and the potential for sharing capacity between diverse appliances and technologies.

Pilot Demonstration—Site Selection

Based on the pilot's goals and objectives, the project team set the following eligibility criteria for selecting the sites for pilot demonstration:

- Existing EV charger installed in or near the garage.
- Single-family home or townhome.
- Attached or detached garage.
- Available gas-fired equipment in the garage to electrify, such as a water heater or clothes dryer.

The project team also considered adding an eligibility criterion of not having existing solar or battery energy storage systems (BESS) installed. However, based on subject matter expert (SME) and Technical Advisory Committee (TAC) feedback, this criterion was excluded for the following reasons:

- Overlap of customers having EV charging and solar.
- Overlap of customers interested in electrification and existing solar.
- Market movement to solar and BESS adoption.

The project team recruited most of the sites for pilot demonstrations through screening surveys for customers with installed LBTs. Some customers were recruited through manufacturers, contractors, or outreach on social media platforms. Installation sites 2,5, and 6 were selected by the University of California, Davis (UC Davis) at the UC Davis Bodega Marine Laboratory, providing distinct test environments for the pilot. Specific test protocols were followed since these sites had more time, access and therefore the ability to focus on load profiles, and specific LBT performance (specific results in attached appendices for sites 2,5,6) The Bodega Marine Laboratory campus offers a remote, coastal setting with residential and temporary facilities that are representative of real-world electrification retrofits.

The summary of the pilot demonstration sites is presented in Table 8Table 8 below. For more details on each site, please refer to Appendix D.

Table 8: Pilot demonstration site summary.

Site ID	Location	Site Type	Existing Panel Size	Existing LBT	Gas-Fired Equipment
Site 1	Rohnert Park	Single-family home	100 A	None	Clothes dryer, water heater, furnace, stovetop, range, or oven
Site 2	Bodega Bay	Dorm	200 A	None	Stovetop
Site 3	San Francisco	Single-family home	100 A	Smart panel	Water heater, furnace, stovetop, range, or oven
Site 4	Rocklin	Townhome	125 A	Plug-in circuit splitter	Clothes dryer, water heater, furnace, stovetop, range, or oven
Site 5	Bodega Bay	Duplex	100 A	None	Water heater, stovetop
Site 6	Bodega Bay	Duplex	100 A	None	Water heater, stovetop
Site 7	Oakhurst	Single-family home	100 A	Plug-in circuit splitter	Water heater, furnace

Site ID	Location	Site Type	Existing Panel Size	Existing LBT	Gas-Fired Equipment
Site 8	Carmel Valley	Single-family home	200 A*	None	Clothes dryer, space heating and domestic hot water heater, stovetop, range, or oven
Site 9	Oakland	Single-family home	100 A	None	Clothes dryer, water heater, stovetop, range, or oven
Site 10	Jurupa Valley	Single-family home	200 A*	None	Clothes dryer, water heater, furnace, stovetop, range, or oven

*These sites have existing 200 A service and panels. These sites have unique features such as resistance strip heaters, pools/spa, and multiple EV chargers. Based on NEC load calculations, these sites go over 80 percent of the panel size with EV chargers and electrification.

Pilot Demonstration – Electrification Plan

The project team developed custom electrification plans for each site to document the recommendation, including the LBT to be installed, the gas appliance to be electrified, and the loads to be controlled by the LBT. The electrification plans also document the existing conditions for each site. The project team conducted interviews with each site owner to identify their needs and overall electrification goals, then used the information to recommend the appropriate technologies per site.

Table 9**Error! Reference source not found.** below summarizes the demonstration plan for each of the sites. For more details on each site, please refer to Appendix E.

Table 9: Pilot demonstration electrification plan and status.

Site ID	LBT installed	Electric Appliance Installed	Loads Controlled by LBT	Load shed sequence
Site 1	Plug-in circuit splitter	HPWH, HVAC heat pump, Level 2 EV charger	HPWH, Level 2 EV charger	Level 2 EV charger
Site 2	Smart panel	Induction range, Level 2 EV charger	Induction range, EV charger, electric clothes dryer	EV charger, induction range, dryer
Site 3	Smart panel	HPWH	All loads connected to the main panel	HPWH, EV charger, dryer (top 3)

Site ID	LBT installed	Electric Appliance Installed	Loads Controlled by LBT	Load shed sequence
Site 4	Smart panel	HPWH	All loads connected to the main panel	HPWH, EV charger, dryer (top 3)
Site 5	Smart subpanel	Induction range, Level 2 EV charger	Induction range, EV charger	EV charger, induction range
Site 6	Smart subpanel	Induction range, Level 2 EV charger	Induction range, EV charger	EV charger, induction range
Site 7	Smart subpanel	HPWH	EV charger, stove, hot tub, HVAC, dryer, heater, dishwasher, fridge	Hot tub, EV charger, stove, HVAC, dryer, heater, dishwasher, fridge
Site 8	Smart breaker	Level 2 EV charger, electric space heaters	EV charger 1, EV charger 2, HPWH (future load), electric space heaters, hot tub, HVAC, pool pump	EV chargers, hot tub, electric space heaters, HVAC, pool pump
Site 9	Smart breaker	HPWH, heat pump clothes dryer	HPWH, range (future), HVAC, heat pump clothes dryer	HPWH, HVAC, heat pump clothes dryer
Site 10	Smart breaker*	HPWH	EV charger	EV charger

*The LBT and electric appliance was installed but not commissioned for this site.

Pilot Demonstration Measurement and Verification (M&V) Plan

The overall objective of the demonstration task was to demonstrate the capability of LBTs to allow additional electrification without the need for major electrical infrastructure upgrades.

M&V APPROACH AT SITES 1, 3, 4, 7-9

The ideal way to demonstrate these capabilities for the selected sites would be to follow typical M&V protocols and monitor and analyze the system performance over an extended period of time—three to six months. This would have given the project team actual insights into the home load profiles and the frequency of events that require the LBTs to intervene to keep the sites demand under a set threshold. Due to the time constraints, this extensive data collection was not feasible with all the demonstration sites. Therefore, the project team achieved the overall research objectives through:

- Implementing real-time tests and manufacturing service panel load threshold events, which triggered LBTs and showcased how LBT's manage loads

- Conducted post installation surveys for customers and contractors; all LBTs selected for the field installation had data collection and data storage capabilities

Table 10 below summarizes the M&V and test plan for the demonstration sites.

M&V APPROACH AT SITES 2, 5, AND 6

These sites were selected earlier in the project so the method was not subject to the same time constraints as the others identified above. As a result, the testing method adopted was different, as described below.

Business as Usual (BAU)

The research team recorded the energy load profiles of each demonstration site to characterize the typical usage patterns of all metered appliances. Amperage was measured across both the main service lines and individual circuits during normal operation. Residents were permitted to use their appliances naturally, without external influence or intervention, to ensure that any load-shed events were captured as they occurred under real-world conditions.

TEST EVENTS

Manufacturer Telemetry Data Validation

The manufacturer's telemetry data at time of installation we validated during installation by using an external ammeter. The contractor spot checked all major loads including the EV charger, HPWH, HVAC, and clothes dryer, and then compared the measured values to the manufacturer's dashboard readings.

Pre-Test Activities (M&V Readiness)

Prior to the test day, the project team performed maximum load characterization for all major loads in the home. Participants were asked to run the major loads at their peak and report the time to determine the home's demand when all the major appliances were turned on at full capacity for subsequent testing and sequencing. The project team used this data to determine:

- Need to lower the system threshold value for the service panel load threshold event
- Loads to be selected and in what order to trigger a service panel load threshold event.
- What would characterize a worst-case system load scenario

Service Panel Threshold Test Scenarios

The project team orchestrated a maximum load scenario for the demonstration sites by turning on all the major appliances, such as the EV charger, HPWH, induction range, resistive loads, clothes dryer, or HVAC to validate the capability of the LBT to shed loads when the system threshold is reached. The service panel threshold (SPT) test collectively tested the LBT’s load-balancing ability as well as the ability to shed load when the set service panel threshold is reached.

Table 10: M&V and test plan summary.

Site ID	M&V Equipment	Data interval	Data Collection Duration	Testing Approach
Site 1	Manufacturer-recorded data	Event based data – 1 millisecond	10/10/25–11/15/25	Service panel load threshold test
Site 2	eGauge data loggers	1 min – monthly 1 sec – daily	8/15/25–11/15/25	• Business as usual (BAU) • Service panel load threshold test
Site 3	Manufacturer-recorded data	1 min	09/27/25–11/15/25	Service panel load threshold test
Site 4	Manufacturer-recorded data	1 min`	10/10/25–11/15/25	Service panel load threshold test
Site 5	eGauge data loggers	1 min – monthly 1 sec – daily	8/15/25–11/15/25	• BAU • Service panel load threshold test
Site 6	eGauge data loggers	1 min – monthly 1 sec – daily	8/15/25–11/15/25	• BAU • Service panel load threshold test
Site 7	Manufacturer-recorded data	1 min	10/01/25–11/15/25	Service panel load threshold test
Site 8	Manufacturer-recorded data	5 min	09/25/25–11/15/25	Service panel load threshold test
Site 9	Manufacturer-recorded data	5 min	09/30/25–11/15/25	Service panel load threshold test

Workforce Development

The workforce development component of this project focused on equipping electricians, contractors, and inspectors with the knowledge and tools necessary to install and commission LBTs such as smart panels, smart subpanels, and circuit splitters. These technologies play a crucial role in California's transition toward a fully electrified and decarbonized building sector by managing electrical loads and supporting distributed energy resources (DERs) such as EV chargers, solar inverters, and battery systems. Because LBTs interface directly with service equipment and utilize software-based commissioning platforms, the project emphasized training that combines traditional electrical skills with modern digital competencies. Workforce development activities included identifying key market actors, evaluating existing training programs such as the Electric Vehicle Infrastructure Training Program (EVITP), and creating supplemental educational materials covering topics such as UL 3141 compliance, NEC code alignment, circuit prioritization, and load calculation procedures. By integrating LBT-related training into established programs, the project aimed to accelerate installer readiness and ensure that California's workforce can meet growing electrification demands safely and efficiently.

Methodology and Approach

The workforce training materials were developed with the explicit goal of aligning with the structure, delivery model, and technical rigor of the EVITP. EVITP is a national electrician-training and certification platform focused on safe, code-compliant installation of EV supply equipment. Its curriculum is delivered primarily through Joint Apprenticeship and Training Centers (JATCs)—local training organizations jointly administered by the International Brotherhood of Electrical Workers (IBEW) and the National Electrical Contractors Association (NECA). JATCs function as the central training hubs for apprentice and journeyman electricians. This made EVITP the natural home for introducing the Service-Upgrade-Avoidance via LBTs training materials.

CLTC approached the development of the LBT curriculum by drawing directly on its prior experience designing and deploying technical training programs for IBEW/NECA. Over the past decade, CLTC has produced multiple statewide electrician-training programs—including the California Advanced Lighting Controls Training Program (CALCTP)—and program materials—including the Western Electrical Cybersecurity Apprenticeship Training (WECAT) Program materials, which contain newer or updated courses covering advanced lighting control systems, smart-building energy-management strategies, and cybersecurity for electricians. These programs are currently taught at more than 15 JATCs across California and Nevada and have established CLTC as a trusted curriculum developer within the IBEW/NECA training ecosystem.

This background informed both the structure and development workflow for the LBT training. CLTC incorporated findings from its CalNEXT-funded laboratory evaluation of smart panels, smart sub-panels, and smart breakers, as well as lessons learned from the field demonstration. The lab evaluation revealed several installation and commissioning nuances that are critical for workforce training—for example, the dual-application commissioning model used by many manufacturers, including an installer app with configuration authority and a separate homeowner app with limited visibility. Installers must have compatible mobile devices and must complete manufacturer-specific certification courses to receive the credentials required to access installer-level settings. The evaluation also clarified where key parameters are controlled: maximum allowable current limits and load-shed priorities are configured exclusively through the installer interface and are not visible through the homeowner portal.

CLTC documented performance characteristics relevant to field installers, including the timing, consistency, and reliability of automated load shedding during over-current conditions and the dependence of some systems on stable cloud connectivity. The pilot installations reinforced these findings under real-world conditions. CLTC installer team experienced firsthand how critical a stable network connection is for full system functionality—particularly for commissioning, remote overrides, and restoring circuits after a shed event. The pilot also provided practical context for performing real-world load calculations to determine when LBTs are necessary to avoid a service upsizing during electrification retrofits. Additionally, the pilot demonstrated how load-shed priority lists operate during actual household scenarios, and how the quality of those configurations directly influences user acceptance. Properly assigning cooktops, dryers, and EV charging circuits to the correct priority tiers proved essential to balancing safety, comfort, and usability. These lab and field insights were synthesized into practical installer guidance within the LBT curriculum, covering physical and electrical installation approaches, commissioning steps, device limitations, and expected system behavior during shed events in real residential settings.

Stakeholders and Collaborators

Development of the LBT curriculum required coordinated engagement with multiple stakeholder groups, each contributing different perspectives on installation practice, code requirements, and workforce needs. CLTC interacted extensively with load-balancing technology manufacturers to verify system specifications, clarify recommended installation and commissioning workflows, and understand how real-world installers interact with their products. These discussions were informed by both the laboratory evaluation and the field pilot. CLTC provided direct feedback to manufacturers on software usability, commissioning obstacles, and observed failure modes—including the relay-state persistence bug encountered during the one installation, where relays defaulted to the open position after a power interruption. Manufacturers subsequently issued a firmware correction based on this feedback, and those lessons were incorporated into the training materials to highlight the importance of software maintenance and verification after power restoration.

CLTC also engaged with local building inspectors and code officials to identify permitting and compliance challenges associated with this emerging technology class. Inspectors emphasized the need for clear documentation, visibility into software-controlled settings, and consistent understanding of UL listings and NEC references. These insights were built into the curriculum by adding explicit sections on UL-3141, labeling requirements, and load calculation guidance.

To align the LBT curriculum with established workforce pathways, CLTC drew on its ongoing relationships with IBEW, NECA, and EVITP, as well as regular communication with instructors at several JATCs. Based on these interactions, instructors emphasized the growing need for clearer guidance on code-compliance considerations and software-based commissioning steps—topics that are becoming increasingly common as more electrical equipment incorporates networked controls. These insights helped shape the LBT curriculum by ensuring that commissioning procedures, load-priority setup, and software verification received appropriate attention alongside the physical installation tasks that electricians are already familiar with through standard apprenticeship training.

Results

The LBT training materials directly address the objective of informing contractors and installers on the proper design, installation, and use of LBTs as an alternative to electrical service panel upsizing. The curriculum translates laboratory findings, field-demonstration results, and stakeholder input into practical guidance that electricians can apply in residential electrification projects. Key content areas include service-limit configuration, commissioning workflows, load-priority logic, and code-compliance considerations.

While the curriculum has not yet been taught through EVITP's training providers, CLTC designed the material to be fully compatible with EVITP's instructional structure and JATC delivery model. CLTC plans to schedule a curriculum review and deployment discussion with EVITP in the near future to determine the most appropriate pathway for adoption. No formal feedback has been received yet, but the EVITP alignment process is underway.

LBTs remain a priority topic for CLTC, particularly in the context of statewide workforce-development needs as more homes transition to electric end-uses. CLTC intends to pursue future funding to expand this training, refine the material based on instructor feedback, and potentially scale the curriculum in a manner similar to the WECAT program. This includes opportunities to broaden LBT content for additional JATCs, incorporate emerging technologies, and deepen the emphasis on commissioning and software-based configuration workflows that installers will increasingly encounter in the field.

Implementation Results and Findings

This section summarizes the findings from market actor outreach, existing building stock analysis, California and national code review, installation, performance analysis from the monitored and surveyed study data, and technoeconomic analysis from the pilot program.

Retrofit Market Potential for Load-Balancing Technologies to Avoid Service Upsizing

Through the existing building stock review, customer survey data, and existing code review, the project team discovered that load-balancing technologies have the potential to electrify existing housing in California and add load management control without electrical infrastructure upgrades. The optimal use of these technologies will help the customers electrify with avoidance of service upsizing and add load management controls.

Current Retrofit Landscape and Existing Infrastructure

This section summarizes the existing building stock findings from a variety of sources (see section on the Existing Building Stock Review in the Introduction, and customer survey findings to determine the potential opportunities and limitations of LBTs with respect to the actual installation conditions in California. The existing building stock captures a larger landscape of the conditions, whereas the customer survey provides insight into load management technology early adopters. These survey results are not representative of the population of California because the project team had limited access to the survey of customers who have load management technologies, live in a single-family home or duplex with a garage, and charge EVs at their home. Even with these limitations, the survey results provide insight into a segment of Californians who are currently using load management technologies. Understanding these two groups will help inform manufacturers and program designers on how to incorporate key learnings into their offerings and programs. Each section summarizes the findings from the two datasets.

EXISTING EV CHARGING INFRASTRUCTURE

Alongside the accelerated adoption of EVs in California over the past five years,[13] a greater proportion of those EV drivers are now electing to install and use Level 2 charging in their homes. As of 2024, 64 percent of EV drivers reported having Level 2 charging at home, up from 52 percent in 2019. Conversely, 37 percent reported using Level 1 charging in 2024, down from 48 percent five

[13] According to Veloz' analysis of CEC market data, EV sales approached 30percent of new vehicle purchases in Q3 2025, an approximately four-fold increase from EV market penetration rates in 2019–2020. The CEC's Vehicle Population Dashboard indicates that just under 6.5percent of all light-duty vehicles in California were electric in 2024.

years earlier (NREL 2024), as shown in Figure 5

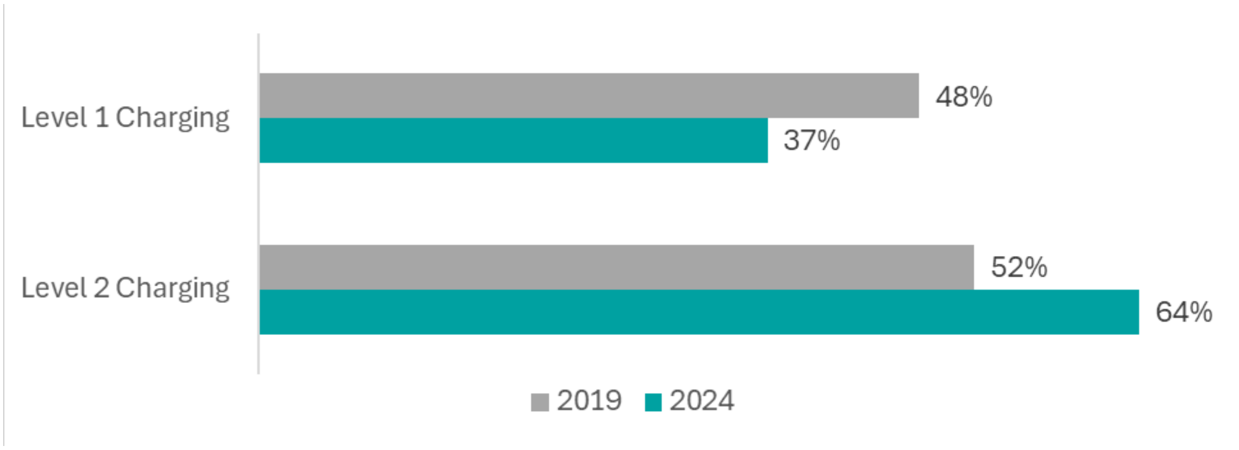

Figure 5. Split of Level 1 and Level 2 charging reported by California EV owners in 2019 and 2024.

Source: (NREL 2019) (NREL, California Vehicle Survey 2024).

Level 2 charging at 40 A and 240 V requires four times more panel capacity than a Level 1 charger. As part of a study on residential service upgrades conducted by NV5, contractors reported EV charger installations were the most common reasons for panel upgrades that will also require a utility service upgrade, followed closely by solar and HVAC projects (NV5 2022). A survey of 15 Pacific Gas and Electric (PG&E) customers who recently underwent a service upgrade also found EV charging was the most frequent trigger, involved in 40 percent of the upgrades.[14] Among 34 respondents from PG&E and San Diego Gas & Electric (SDG&E) service territories, 88 percent indicated they did not consider an alternative to the service upgrade (NV5 Inc. 2022). The growing rate of Level 2 home charging use—combined with data on existing homes' panel sizing presented below—points toward an increasing opportunity for LBTs that can reduce panel or utility service upsizing for customers installing EV chargers alongside other electrification measures.

EXISTING HOME ELECTRICAL INFRASTRUCTURE

Homes with smaller electric panels are more likely to require a panel or service upsizing when adding a Level 2 EV charger or other 240 V appliances. For example, a 40 A Level 2 EV charging circuit would consume nearly half of the available capacity on a 100 A panel. While most newly constructed

[14] Some customers indicated multiple reasons that triggered the service upgrade, for example, installation of an EV charger may have coincided with an addition to the home, or replacement of another appliance. Among SDG&E customers, solar PV installations were the most common trigger reported (9 of 19 respondents).

single-family homes built today use 200 A panels, 100 A panels were prevalent until the 1970s.

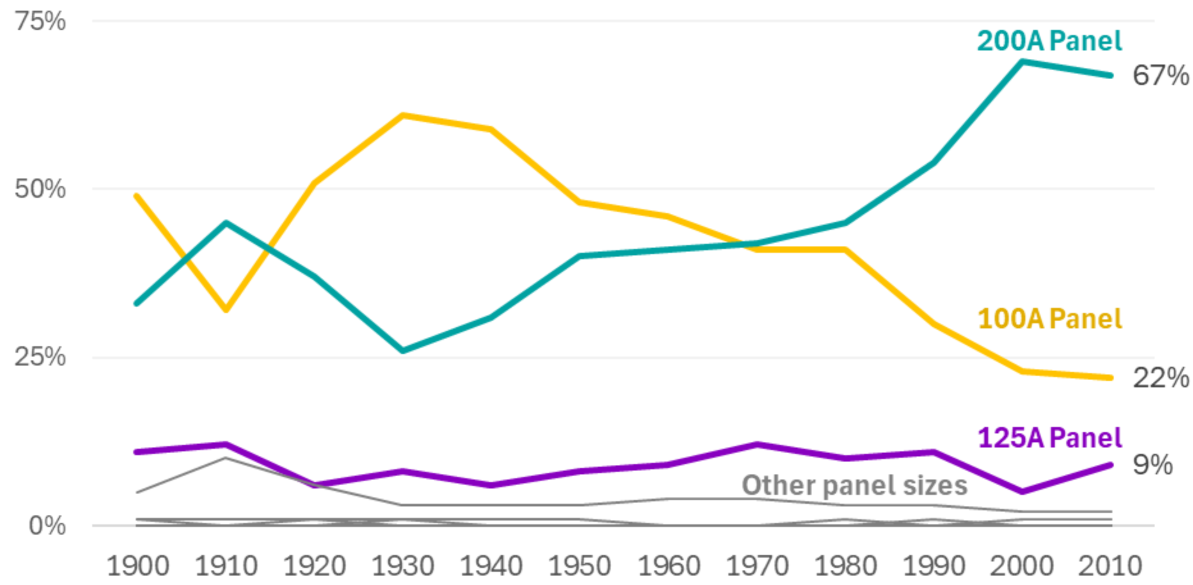

Figure 6 shows the prevalence of panel sizes currently in homes built in each decade, beginning in 1900 through the 2010s, using data from 7,724 single-family homes that participated in the TECH Clean California program[15] (TECH Clean California 2025).

[15] Data on electric panels in homes by decade the home was built are representative of the panel size currently installed in those homes, not what was installed when the home was built. While older homes were likely built with a smaller 100 A (or less) panel, many have likely been upgraded in recent decades as a result of code requirements, additions, or new appliances or solar installed. The TECH Clean California program data used here may also not be representative of the general population, given these early adopters of heat pumps may also be more likely to have already installed solar or other electric appliances that previously triggered an upgrade to a 200 A panel.

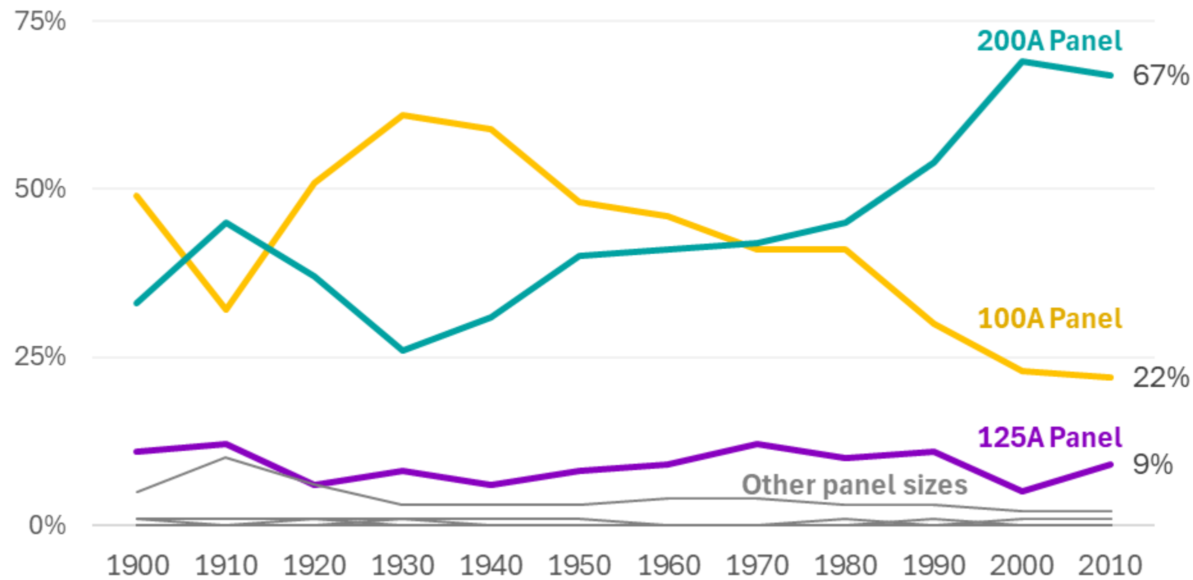

Figure 6. Prevalence of panel size (amps) by decade home was built.

Source: TECH Clean California, 2025

As shown in Figure 7Figure 7, 60 percent of California's housing stock, representing an estimated 5 to 6 million homes, was built after 1970 (United States Census Bureau 2023).[16] Beginning in the late 1960s, California began to require a minimum 100 A panel in newly-built homes, meaning this significant portion of the state's housing stock has panels and utility services sized for 100 A (NV5 Inc. 2022), which may support electrification measures with the aid of LBTs.

[16] The Census Bureau's American Housing Survey (AHS) data for California does not allow for disaggregation by single-family homes. Data presented represents all housing units, including multifamily units and manufactured homes. These non-single-family homes represent 36percent of the 14.76 million homes included in the census data. 8.66 million homes in the data were constructed after 1970; based on 36percent non-single-family homes, TRC estimates the post-1970 single-family housing stock to be 5.5 million units.

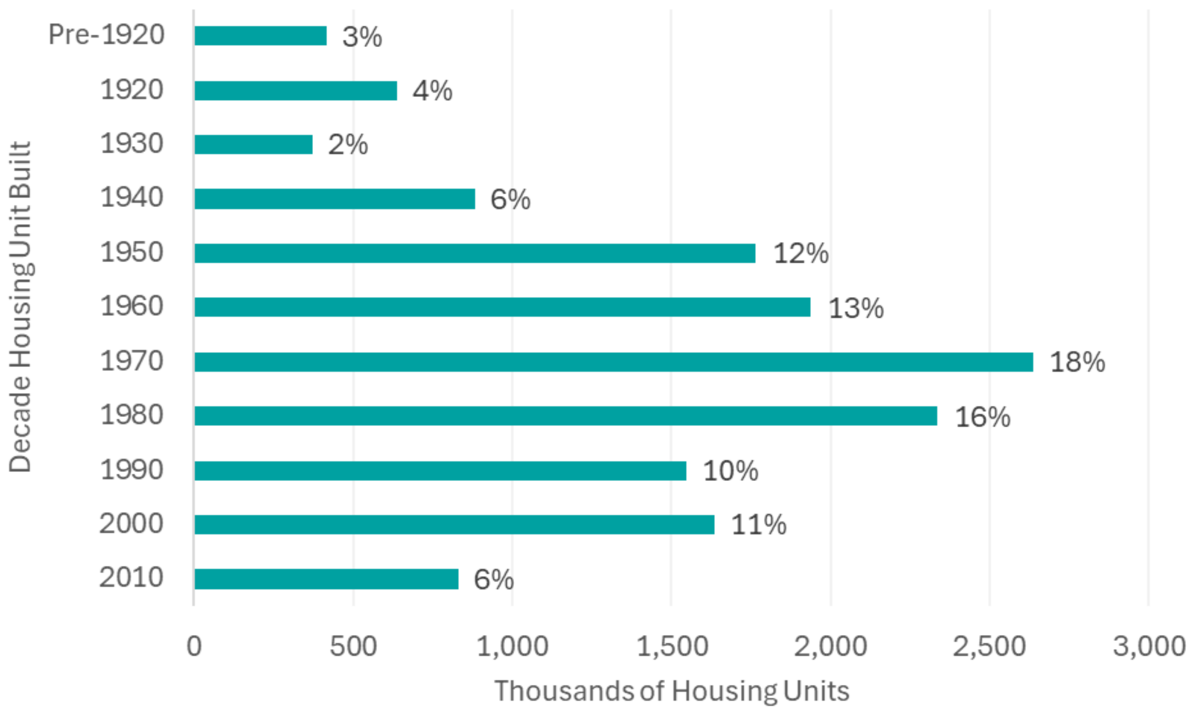

Figure 7. Distribution of California housing units by decade built (United States Census Bureau 2023).

Estimates of the current prevalence of 100 A panels in California single-family homes range from 21 percent to 42 percent, though each of the three data sources used in this assessment had deficiencies.17 A 2024 study by California Public Utilities Commission (CPUC) Energy Division staff analyzed 1,480 residential panels and found that approximately 27 percent had 100 A panels, and an additional 6 percent had panels smaller than 100 A (California Public Utilities Commission 2024). A survey by the Electric Power Research Institute (EPRI) found 21 percent of homes had panels of 100 A or less (Electric Power Research Institute 2023). Analysis of TECH Clean California program installation data found 42 percent of homes had 100 A panels, prior to the installation of HPWHs, and another 1 percent of homes had panels less than 100 A (TECH Clean California 2025).

[17] The CPUC's dataset did not clearly delineate single-family homes from multifamily homes, which are more likely to have 100 A panels. Thus the estimate of single-family homes with 100 A panels may be higher when excluding multifamily homes. EPRI's presentation of survey data on home panel sizing included homes across 13 "West" region states. States outside of California may have different frequencies of panel sizes due to differences in climate, home sizes, and building codes. 21percent of EPRI survey respondents could not identify their main breaker amperage, so the rate of 100 A panels is likely higher than the 21percent reported. TECH Clean California program data may not be representative of the wider building stock, as these program participants are early adopters of heat pumps, which may also be early adopters of other electrification technologies (e.g., solar, EV). This may indicate these customers had already upgraded their home panels to 200 A to accommodate earlier electrification measures.

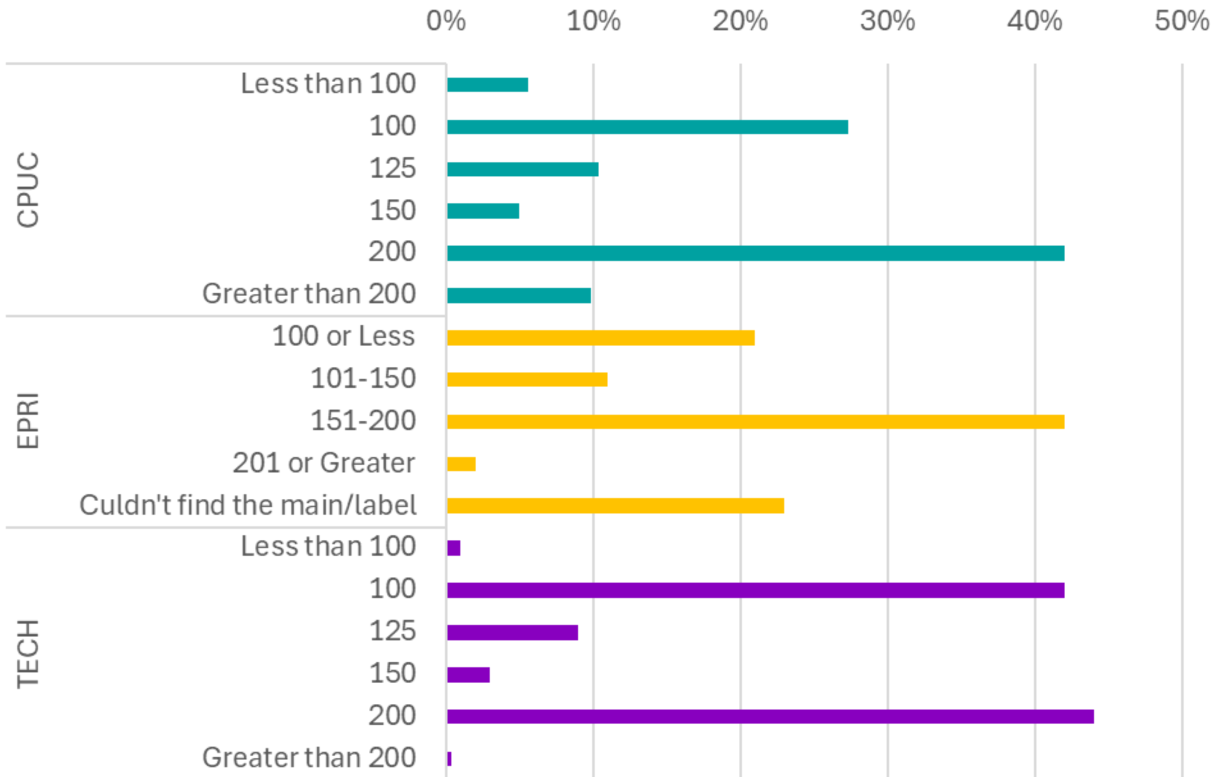

Figure 8 shows that all three datasets consistently estimated the incidence of 200 A panels around 40 percent to 45 percent.

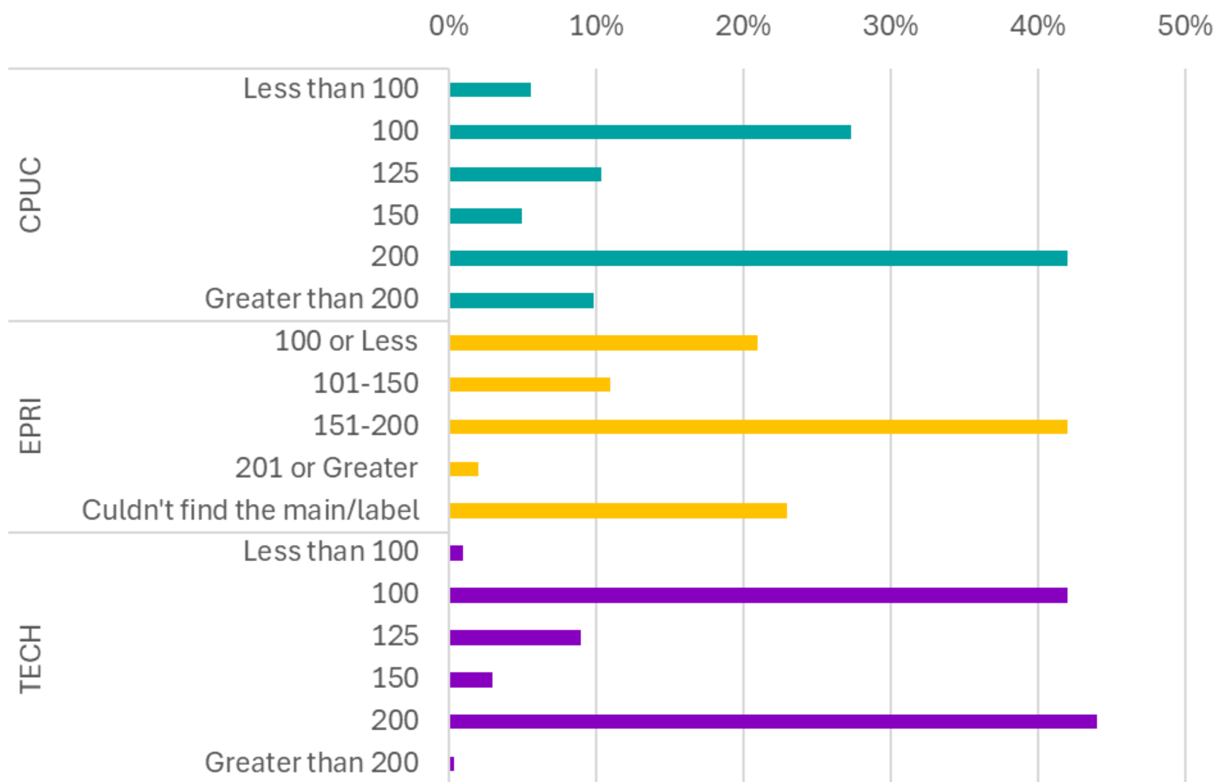

Figure 8. Analysis of existing home panel sizes across California.

Source: (California Public Utilities Commission 2025) (Electric Power Research Institute 2023) (TECH Clean California 2025).

These three data sets shown in

Figure 8 indicate that anywhere from one to two in every five homes have a smaller panel that may not easily accommodate additional electrification measures such as EV charging and a heat pump or electric clothes dryer, and could be a candidate for LBTs to facilitate those electrification measures.

CO-LOCATION OPPORTUNITIES FROM EV CHARGING AND ELECTRIC APPLIANCES

Some of the LBTs studied in the pilot are only applicable for loads that are co-located in the same room. For example, plug-in circuit splitters require two appliances, such as an EV charger and a clothes dryer or water heater, to be in close enough proximity that both can plug in to the same outlet splitting device. In this instance, the appliance would need to be located in the garage where the EV is charged. These circuit splitting plug-in LBTs are among the simplest and lowest-cost LBTs for customers or contractors seeking to avoid a panel or service upsizing.

Housing stock data analysis indicates that there is an opportunity for such LBTs to split the circuit between an EV charger and an appliance in a garage, though not all homes or EV drivers are able to accommodate this type of solution.

Garage access is common among California drivers: 83 percent of non-EV owners and 86 percent of EV owners have access to a garage at their single-family home; the majority are attached garages. (NREL, California Vehicle Survey 2024) However, despite having a garage, EV drivers do not always use it for their charging. As shown in Error! Reference source not found., current EV drivers were equally likely to indicate they charge their vehicle in their driveway (49 percent) or in their garage (47 percent) (NREL 2019). For the half of these drivers who charge in their driveway, a circuit-splitting outlet may not be feasible if the charger is installed outside the garage. For these customers, a different LBT option, such as a smart panel or breaker, may be more appropriate. Most non-EV drivers surveyed by NREL indicated their attached garage (59 percent) would be the most likely location for charging an EV if they purchased one, followed by their driveway (13 percent) and a detached garage (7 percent). Nearly 19 percent of non-EV drivers indicated that, though they have a garage, they park on the street instead. (NREL, California Vehicle Survey 2024). These drivers may currently use their garage for purposes other than parking – it is unclear whether they would be willing or able to change to accommodate garage charging if they were to become EV drivers.

A small proportion of existing EV drivers—eight percent—indicated they had no access to home charging.[18] Among non-EV drivers, 16 percent estimated they would have no reliable place to charge at home (NREL, California Vehicle Survey 2024). **Error! Reference source not found.: Garage and charging access and use among EV drivers and non-EV drivers in single family homes and townhomes.**

Sources: NREL 2024 and NREL 2019

The prevalence of large appliances, such as clothes dryers or water heaters located in a residence's garage, also varies. Data on clothes dryer locations within homes is lacking for the entire building stock. However, the US Census' State of Construction survey has collected data on laundry in new construction homes since 2010. From the last survey in 2020, only 1 percent of new construction homes had laundry appliances in the garage. The first survey to ask this question in 2010 indicated 3 percent of homes with laundry in the garage (United States Census Bureau 2020). This low incidence of garage-based laundry means there is likely a limited opportunity for circuit-splitting outlets for this situation in newer homes. The research team did not find data on the locations of laundry in homes built prior to 2010.

Water heaters present a more prevalent opportunity for circuit-splitting outlets paired with EV charging. Over two-thirds of the HPWH installations completed through the TECH Clean California program were located in the participants' garages. Garage-based water heater installations were common in houses built across all decades, particularly from the 1950s and beyond, and across most counties in California (TECH Clean California 2025).[19] This high frequency of garage based water heaters indicates this may be a good opportunity for circuit splitting outlet devices.

Given the variety of home charging locations reported by drivers and data on appliance locations within the home, appropriate LBTs may vary significantly from home to home.

Load-balancing Technology Customer Survey Findings

In addition to reviewing published data and literature for the California building stock assessment, the project team also surveyed customers with LBTs installed to understand more about the homes and appliances where these technologies have seen initial market deployment.

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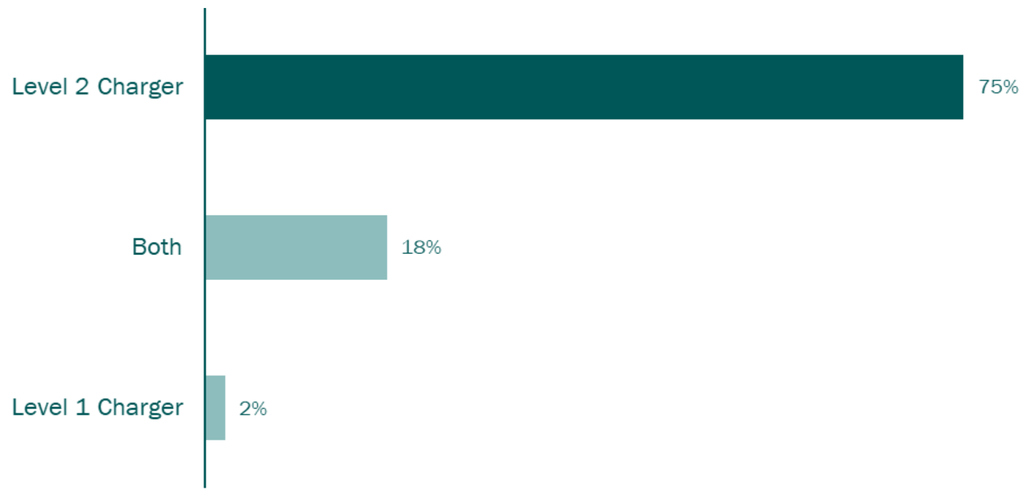
[18] There is potentially some selection bias inherent in EV drivers' access to home charging – those without reliable home charging are less likely to purchase an EV, so it is expected that a high percentage of early adopting EV drivers have home charging.

[19] The TECH Clean California program incentivized HPWH installations, and as a result may overrepresent the location of water heaters in garages. HPWHs are optimally located in unconditioned spaces such as garages, and not in other areas of the home.

EXISTING EV CHARGING INFRASTRUCTURE

The customer survey was restricted to customers who charged at least one EV at their residence and had a charger located in the garage, driveway, or carport. Over half of the 57 survey respondents reported charging one EV at home (56 percent), but some respondents reported charging 2 EVs (32 percent) or 3 or more EVs (12 percent) at their home. Of the 57 survey respondents with EV chargers, most had Level 2 chargers (75 percent), some had both Level 1 and Level 2 chargers (18 percent), and a few had only Level 1 chargers (2 percent), as shown in Figure 9Figure 9. Most respondents had EV chargers located in the garage (93 percent), with some located in the driveway (11 percent) or carport (5 percent). Five of these respondents noted having a charger located in the garage and another charger located in either the driveway or carport. A significant portion of the survey sample included homes with circuit-splitting outlet LBTs, which are typically used for EV chargers located in the garage; this may have influenced the large proportion of customers with garage-located chargers.



Base: All respondents, n = 57 respondents. **Question b4**: Which of the following EV chargers are installed at your home? Select all that apply. Note, responses may not add to 100% due to rounding.

Figure 9: Chargers installed in survey respondent homes.

EXISTING HOME ELECTRIFICATION INFRASTRUCTURE AND EV CHARGING

The survey was restricted to single-family homes, townhomes, duplexes, and triplexes with garages. Of the 53 respondents who completed the survey, 91 percent had a single-family home and 9 percent had a townhouse, duplex, or triplex. Nearly all respondents had an attached garage (95 percent).

Similar to the TECH Clean California data on home panel sizes, there was a generally positive correlation between newer homes and the prevalence of larger, 200 A panels. 88 percent of homes built after 2010 had a 200 A panel or larger. Conversely, 60 percent of homes built prior to 1950 had 100 A or smaller panels, as shown in Figure 10, though the sample for these oldest homes only included five units. Notably, 23 percent of the homes built between 1951 and 2010 had panels sized at 125 A or 150 A, roughly double the rate of those sizes of panels found in the TECH Clean California dataset during those decades. These small-to-mid-size panels, particularly those at 125 A, may also be good candidates for LBTs.

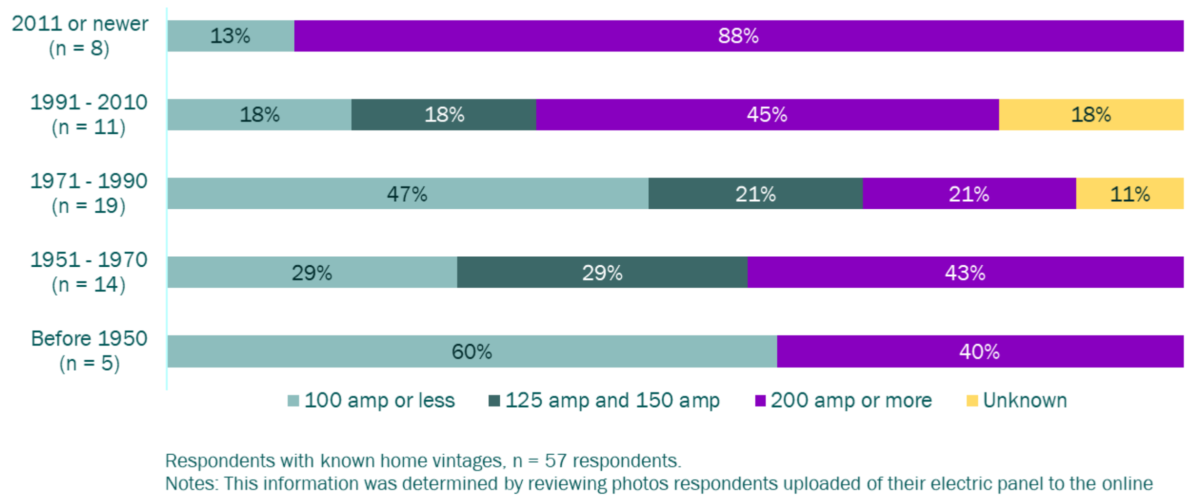
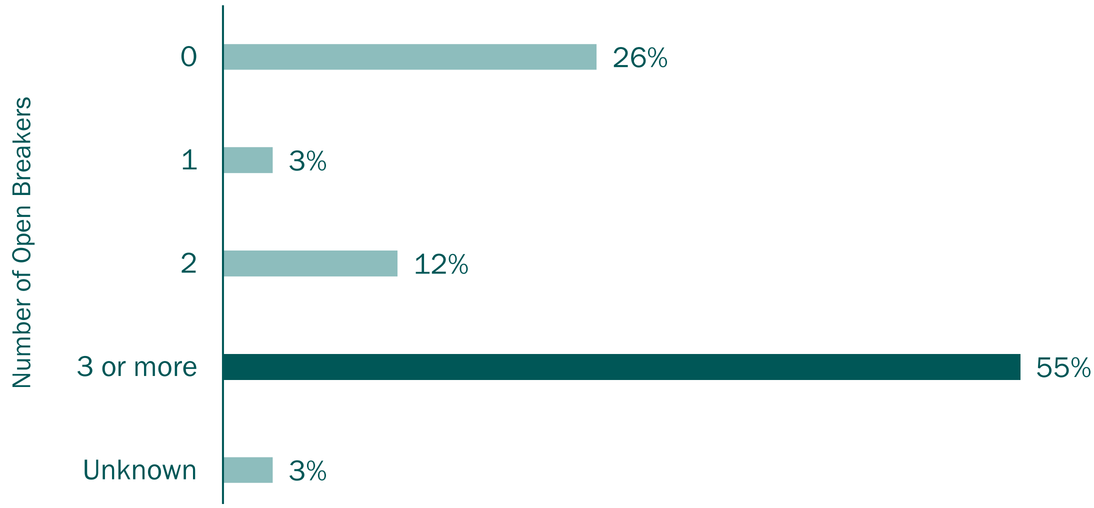


Figure 10: Panel size and home vintage.

Homes with a Level 2 EV charger or other 240 V appliance require two open breaker spaces on the panel to create a new circuit for that appliance. Without available breaker spaces, an electrician would need to modify the existing circuits on the panel (if feasible) to create open spaces, or install a sub-panel, both of which can add cost to electrification projects. Two-thirds of respondents had at least two open breaker spaces, and more than half (55 percent) had at least three open spaces, as shown in Figure 11. Notably, around a quarter of survey respondents had no open breakers. While these customers may require additional work on their panel, a sub-panel, or full replacement of their existing panel to accommodate additional electrification measures, an LBT solution could still help them avoid having to upsize that panel and potentially avoid a service upsizing due to the panel upsizing.



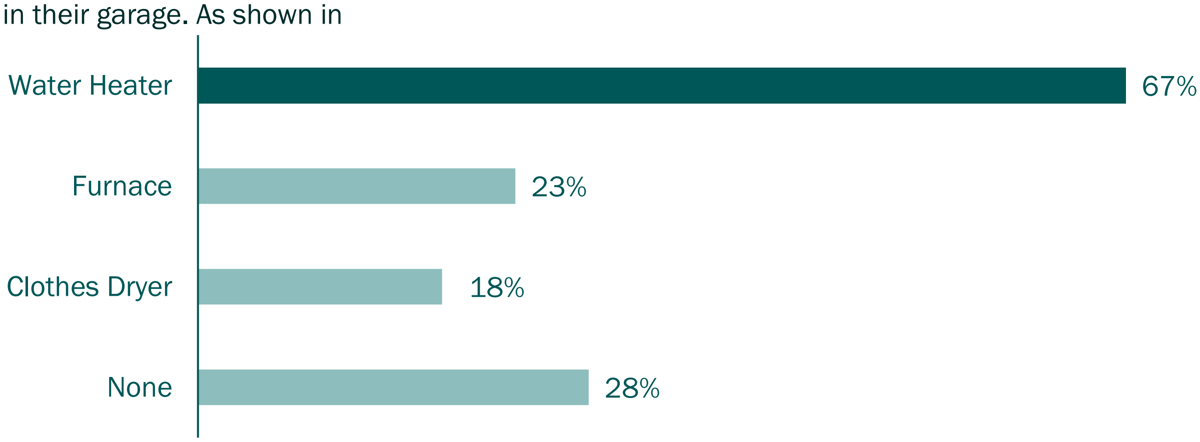
Base: All respondents, n = 58 respondents. **Notes: This information was determined by reviewing photos respondents uploaded of their electric panel to the online survey.**

Figure 11: Number of open breakers.

Forty-seven percent of survey respondents had solar and BESS, 17 percent had solar only, and 2 percent had battery only in their homes. Only 34 percent stated they had no solar or BESS in their home. This aligns with feedback from SMEs and the TAC that there is increased penetration of solar and BESS among customers with EVs.

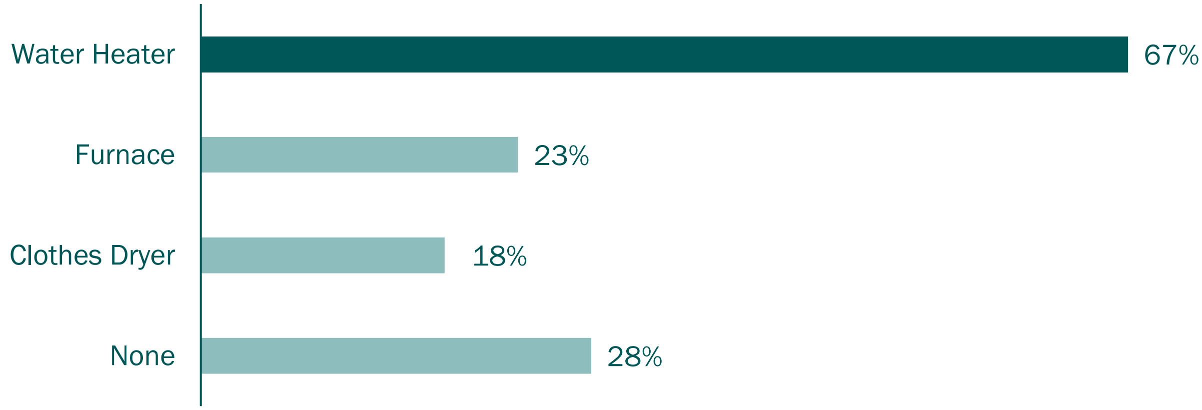
CO-LOCATION OPPORTUNITIES FROM EV CHARGING AND ELECTRIC APPLIANCES

Like the building stock assessment findings, about two-thirds of respondents had a gas water heater in their garage. As shown in



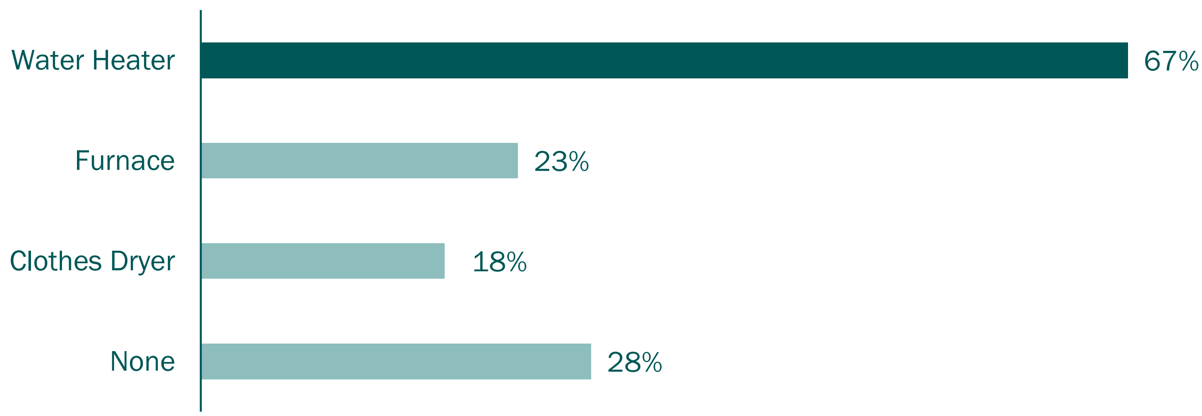
Respondents with natural gas appliances, n = 57 respondents.
Q: Which of your natural gas appliances or equipment, if any, are located in your garage? Select all that apply.

Figure 12



Respondents with natural gas appliances, n = 57 respondents.
Q: Which of your natural gas appliances or equipment, if any, are located in your garage? Select all that apply.

Figure 12, a smaller proportion of respondents had gas furnaces (23 percent) or gas clothes dryers (18 percent) installed in their garage. Twenty-eight percent had no gas appliances in their garage. The incidence of clothes dryers in the garage is significantly higher than what was identified in the State of Construction survey data, which only factored in new construction homes built after 2010. While the sample in the customer survey is limited, all 10 customers with clothes dryers in the garage reported homes built prior to 1991, indicating this garage-laundry setup may be more common in older homes than those built in the last 30 years.



Respondents with natural gas appliances, n = 57 respondents.
Q: Which of your natural gas appliances or equipment, if any, are located in your garage? Select all that apply.

Figure 12: Gas appliances in the garage.

INTEREST IN FUTURE ELECTRIFICATION

To understand LBT customers' interest in future electrification measures, the project team asked which electrical appliances or vehicles respondents were interested in purchasing in the next two to three years. As shown in Figure 13, over half of the 58 survey respondents had an interest in electrifying one or multiple loads in their home. Notably, only 5 percent had no consideration for electrifying additional appliances or their vehicle.

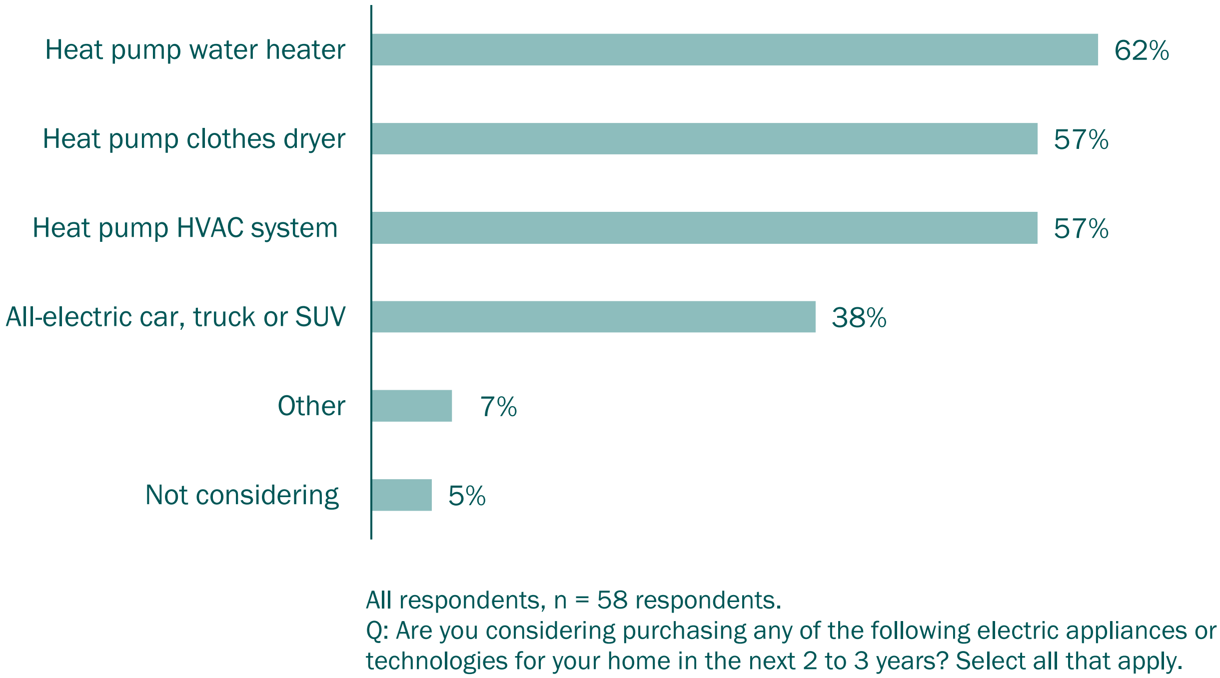


Figure 13: Respondents' interest in purchasing electric appliances or vehicles.

Current Building Peak Load—Utility Interval Meter Data Analysis

The project team reviewed the utility meter data for some of the customers who participated in the phase 1 survey to estimate what their current metered maximum load is and what capacity is available for future electrification. Table 11 shows the maximum demand data recorded at each customer's utility meter. The amperage was calculated from the power draw, assuming a 1.0 load factor. Several of the customers who agreed to share their utility data had an existing solar and/or BESS. As a result, for those customers, the utility meter data shows the net consumption instead of the total consumption for the home.

Table 11: Maximum demand data recorded at each site's utility meter over a year.

Meter #	Max Demand (kW)	Calculated Demand (amps)	Existing Electrical Panel Size (amps)	Date and Time of Max Demand	Solar	BESS
1	7.62	35.3	125	9/10/24 6:00 a.m.	No	No
2	4.37	20.2	100	10/8/24 12:00 a.m.	No	No
3	4.03	18.7	100	11/16/24 9:00 a.m.	No	No
4	5.69	26.3	100	6/30/24 5:30 a.m.	Yes	Yes
5	3.12	14.4	100	1/25/25 5:00 p.m.	Yes	No
6	2.72	12.6	100	5/30/25 8:15 a.m.	Yes	Yes
7	4.15	19.2	125	12/14/24 8:15 a.m.	Yes	Yes
8	2.94	13.6	100	5/31/25 12:30 a.m.	Yes	No
9	2.51	11.6	100	9/4/24 12:15 a.m.	Yes	Yes
10	6.21	28.8	100	1/21/25 8:15 a.m.	Yes	Yes
11	5.81	26.9	100	6/12/25 10:00 a.m.	Yes	No

For customers without solar and BESS, the maximum demand recorded at the meter is in the range of 20 percent to 30 percent of the panel capacity, which is relatively low. This indicates that these customers can probably add new electrical loads without exceeding the actual service limit.

For customers with solar and/or BESS, this data does not reflect the actual home demand, so it can't be used to determine if they would exceed their electrical service capacity upon adding new electric loads.

Home Energy Analytics analyzed 22,000 customers to estimate how many electric panels need to be upgraded to support electrification, as shown in Figure 14. Based on their analysis, 86 percent of homes have a peak under 50 A and 48 percent under 30 A. This shows there is much greater panel capacity than has been commonly assumed (Schmidt and Schmidt 2024).

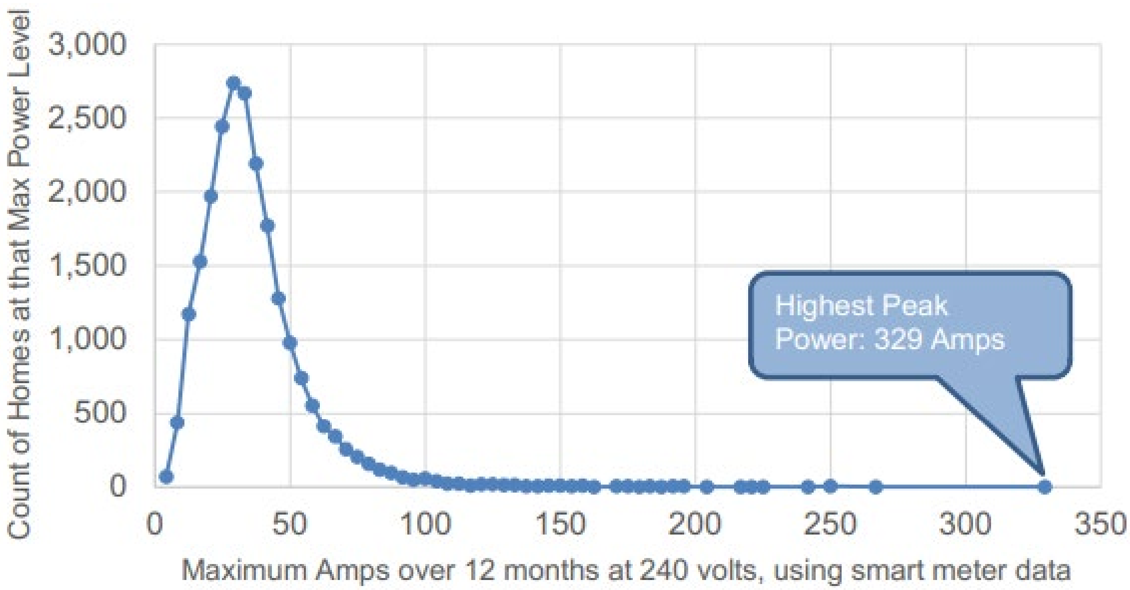


Figure 14: Count of peak power levels in amps across 22,442 California homes.

Existing California and National Electric Code Review

The current electrical codes present no barriers to the integration of LBTs that are part of this pilot. The code explicitly permits and provides pathways for energy management systems (EMS) to manage and share electrical loads. The ability for EV branch circuits to be shared with other loads when an EMS is present and the allowance for an EMS to limit total current drawn from a service directly support the functionality of these smart load-balancing solutions. In addition, the codes do not limit particular appliances from being load balanced by an EMS.

As part of this pilot, the project team conducted a comprehensive review of relevant building and electrical codes. We reviewed California Title 24 and the National Electric Code (NEC) to ascertain the alignment of these products with prevailing state and national standards. The findings from this assessment show that current codes do not impede the deployment of LBTs.

The project team reviewed the 2023 edition of the NEC, which is adopted as the 2025 California Electrical Code (also referred to as Part 3 of Title 24). We determined that the 2025 edition of the California Electrical Code is written to allow for load sharing between appliances and other technologies. The 2023 NEC has three new sections that clarify how to use load-management technologies. Table 12 details codes sections related to load sharing and circuit restrictions.

Table 12: California and National Electric Code review findings.

Section	Topic	Details	Findings
210.22	Dedicated vs. shared circuit requirements	Only this section addresses dedicated, shared; no other sections of Part 3, 6, or 11 set limits for circuits.	An individual branch circuit can supply any load for which it is rated, provided the total load does not exceed that circuit's ampere rating. Essentially, if a circuit serves only one piece of equipment, that equipment can use the full power capacity of that dedicated circuit.
210.23	Dedicated vs. shared circuit requirements.	Sets limitations on sharing circuits.	NEC Section 210.23 outlines permissible load limits for branch circuits, particularly distinguishing between general-purpose and individual circuits. For individual branch circuits (210.23(E)): If a circuit is designed to supply only a single piece of utilization equipment (e.g., a dedicated appliance), then that equipment's load may draw up to the full ampere rating of the circuit.
625.40 & 42	EV branch circuit.	Clarifies that EV branch circuits can serve multiple EVSEs.	Section 625.40, generally mandates that EV branch circuits must be dedicated feeds, serving no other outlets. However, an exception is provided in Section 625.42: if an EMS is installed and complies with Section 750.30 requirements, the EV branch circuit may then be shared with other Loads.
220.70	Code allowance for sharing circuits.	Sets limitations on sharing circuits.	NEC 220.70 allows an EMS to limit the total current drawn from an electrical service, using its maximum setpoint for load calculations. This enables homes to add high demand loads like EV chargers without needing costly service upsizing.
750.30	Code allowance for sharing circuits.	Sets limitations on sharing circuits.	Energy management systems shall be permitted to monitor and control electrical loads.

Section	Topic	Details	Findings
408.2(a)	Panel loading guidance.	Panel space is a high priority for California's new construction electric readiness measures, but not a focus of load calculations or management in the electrical code.	Requires circuit breaker space for: HPWHs, heat pump space heaters, electric cooktops, and electric dryers. This is part of the California Electric-Readiness measure for new construction homes.

It's important to note that the codes do not limit any appliance from being load balanced by an EMS, as their focus is on the overall safe management of electrical loads rather than dictating the specific load management of individual appliances. The emphasis of 408.2(a) is panel space for specific high-demand appliances in California **new construction.** This includes HPWHs, heat pump space heaters, electric cooktops, and electric dryers, which primarily impacts physical planning and service capacity readiness rather than limitations on the intelligent load management capabilities. The codes, by allowing for and defining EMS, permit these systems to balance any connected load as long as the total circuit and service ratings are not exceeded, and safety requirements—such as ground-fault circuit interrupter (GFCI) protection where required by 210.8(D) for specific appliances such as ranges and dryers—are maintained. Ultimately, the 2022 California Energy Code and the NEC establish a flexible and forward-thinking framework that not only accommodates but actively enables the safe and efficient deployment of these advanced LBTs.

Motivation for Choosing Load-Balancing Technologies

Table 13 below summarizes the number of existing installations in the United States for each LBT category based on the data provided by the manufacturers during interviews.

Table 13: LBT manufacturer and product summary.

Technology Category – Subcategory	Product	Approximate Number Of Installs To-Date In the United States
Circuit splitter – plug-in	Plug-in circuit splitter	7,000+
Circuit splitter – hardwired	Hardwired circuit splitter	1,000–2,000
Circuit splitter – meter collar/meter socket adapter	Meter collar	Limited installs for EV use case (12 existing installations)
Smart panel – whole home	Smart panel	1000s
Smart panel – subpanel	Smart subpanel	120+

Technology Category – Subcategory	Product	Approximate Number Of Installs To-Date In the United States
Smart breaker	Smart breaker	Manufacturer #1: 175 installs (pilot) Manufacturer #2: In field testing, service-upgrade-avoidance software available soon

Of the 53 respondents from partner LBT manufacturers customer database, 98 percent stated that they had the LBT installed (Figure 15). As described in Methodology and Approach in the Customer Surveys section, the LBT manufacturers sent survey requests to their customers, so this response aligns with expectations. As shown, most have a plug-in circuit splitter or smart panel.

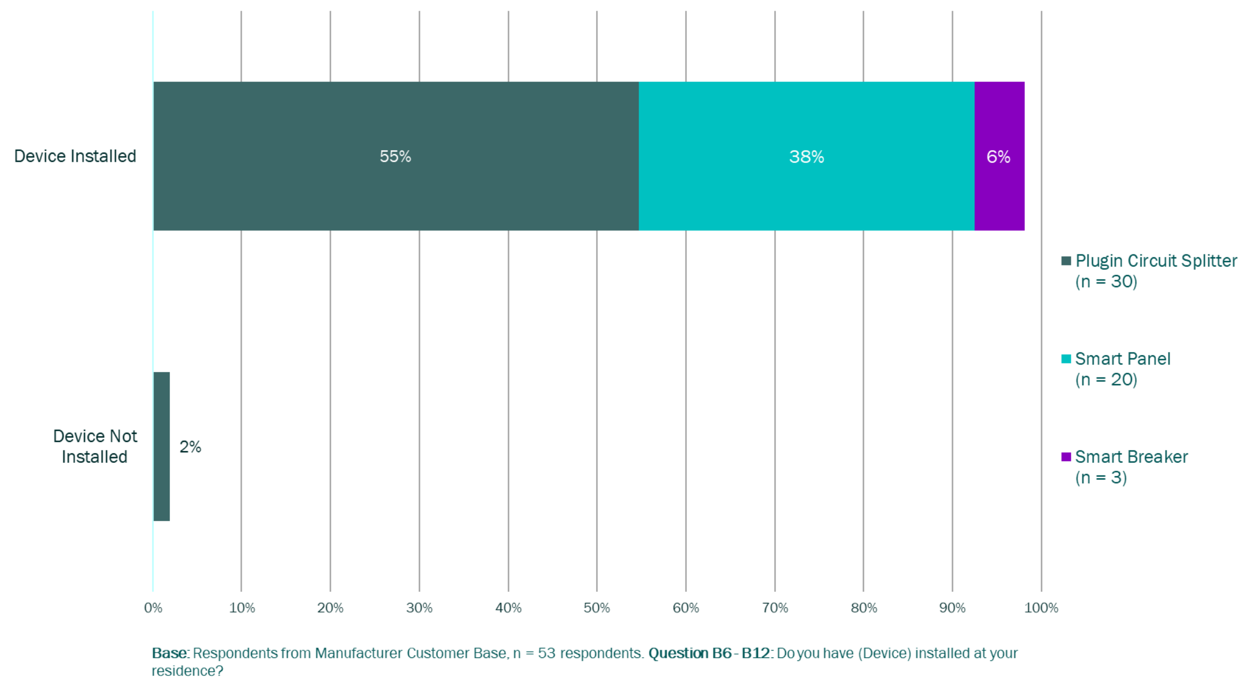


Figure 15: Use of LBTs.

Among 51 survey respondents, the top motivations for installing the LBT were the ability to install an EV charger, the ability to control appliances during a power outage, and generally because the electric panel capacity was too small.

Figure 16 splits the results for individual LBTs. Respondents could select multiple options, and some customers had more than one reason to install the LBT. The majority of the respondents installed a plug-in circuit splitter to install an EV charger. The project team found that respondents with battery backup were interested in the smart panel primarily for controlling appliances during planned power outages. Several of the respondents with smart panels also had solar and BESS installed. It is worth noting that only the plug-in circuit splitter product was installed specifically for the load-balancing use case to share the circuit between two appliances or an EV charger and an appliance. Smart panels and smart breakers have other use cases in addition to load-balancing for service upsize avoidance.

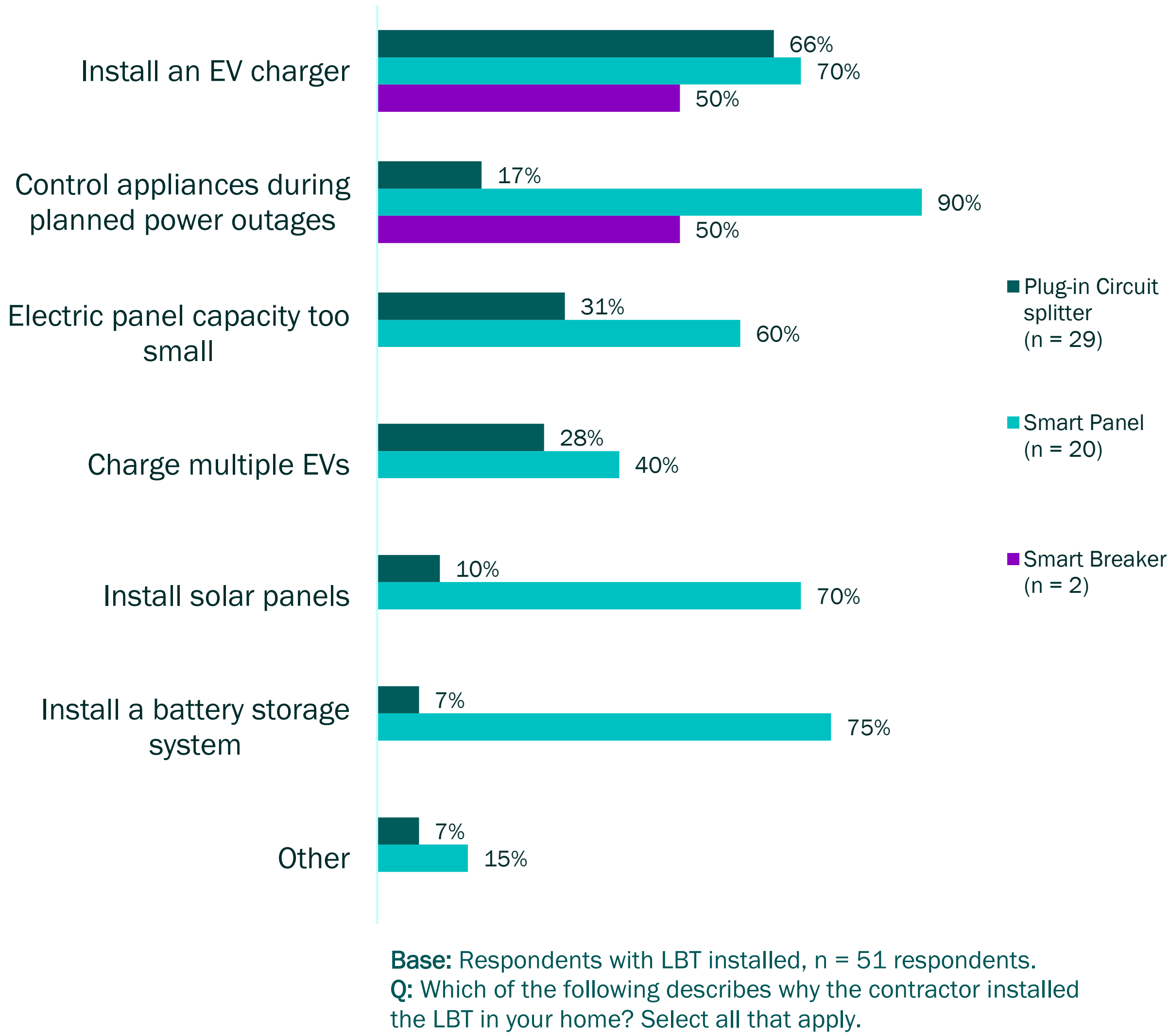


Figure 16: Motivations for installing LBT.

Performance of Load-Balancing Technologies

The sections below summarize the performance of LBTs based on service panel threshold tests conducted at pilot demonstration sites. It also highlights the magnitude of load shift in terms of panel capacity to showcase the load management and service-upgrade-avoidance capabilities of these technologies. While the focus of the pilot was to evaluate and validate the service-upgrade-avoidance feature, all these technologies have load management and demand response capabilities, support real-time homeowner interactivity, and present a potential pathway towards grid integration.

Due to time constraints, the project team concluded that, by showing how each LBT manages the individual loads to maintain the service thresholds at the entire home level, it also shows how LBTs would manage loads between appliances by setting operation schedules and logic. All the more advanced LBTs have appliance load management capabilities. Below are the results for select sites for each category of LBT. All the results for all the sites are located in appendices. Each site below begins with table indicating the threshold amperage for when the LBT would trigger a load shed, the load that was shed, and a magnitude of the amperage of the load shed once threshold was reached. Load Shed Sequence and Future Updates

Each LBT evaluated in this pilot has unique algorithms to shed loads. A smart breaker sheds load with max draw when the threshold is reached, while a smart subpanel has a pre-programmed algorithm to prioritize and shed load. Some technologies, such as smart panels, allow the homeowner to customize the load shed priority sequence. The project team also found that one of the smart breaker technologies can auto-shed load when the service threshold is reached, but needs user input to restore the loads.

The LBT industry is dynamic. Solutions are diverse, encompassing advancements such as appliance level circuit sharing, the integration of smart technology into electrical breakers, enhanced load shed efficiency, and the deployment of systems capable of managing the entire electric system. Several of these technologies send homeowners notifications when they are approaching peak or have hit peak, so the customer is aware and can take action to avoid load shed. They also notify homeowners which loads are being disabled or turned off due to capacity limitations. Some of the LBTs also play the critical role of managing power during an outage. The system uses the smart breakers to perform load shedding, automatically and remotely switching off non-critical circuits to conserve stored battery or generator power while maintaining operation of essential or "critical loads" for maximum resilience.

A key finding is that these technologies are moving in the same direction toward similar goals. The simpler circuit splitter systems are becoming more complex, and the more complex systems are adding features. For example, in the short duration of this pilot, all the circuit splitter technologies were developing solutions to manage more loads or the entire home. Concurrently, all smart breakers and panel technologies are under development to offer grid interactive capabilities.

Plug-in Circuit Splitter

“The (smart splitter) is very easy to install, plug-and-play. What I like most about it is the companion…mobile app. It helps track charge stats and helps control when is the best time to charge my cars” (Customer 2025).

The plug-in circuit splitter model LBT works by allowing the homeowner to safely share a single existing 240 V outlet—such as a dryer outlet—between two large devices, such as a dryer and an EV charger that are usually located in a garage. The plug-in circuit splitter LBT serves a specific market need, a simple solution to a simple problem for homeowners to share a single that needs to share an existing 240 V plug/circuit between two appliances.

Table 14: Operating logic—plug-in circuit splitter.

Load	Rule (Primary vs. Secondary)
Primary	Always takes priority. If it is drawing a high load (greater than 10 A), the secondary is immediately powered down.
Secondary	The secondary only receives power when the primary load draws less than the threshold value (10 A or lower) and the combined draw for the both loads is less than the total circuit capacity (30 A in this case). When the primary load exceeds the threshold or the combined draw exceed the circuit capacity, the secondary load is temporarily shut off.

Table 15: LBT performance test results summary—plug-in circuit splitter.

Site #	Threshold (A)*	Load shed	Magnitude (A)
1	10 A	EV Charger	19

Table 15 above shows the summary of the performance test results for the plug-in circuit splitter. The table summarizes the threshold, the load that was shed during the test, and the magnitude of load shed achieved. The duration of load shed was not captured and is not relevant for the pilot demonstration sites, as these were targeted tests and not BAU operation. For more details, please refer to Appendix D.

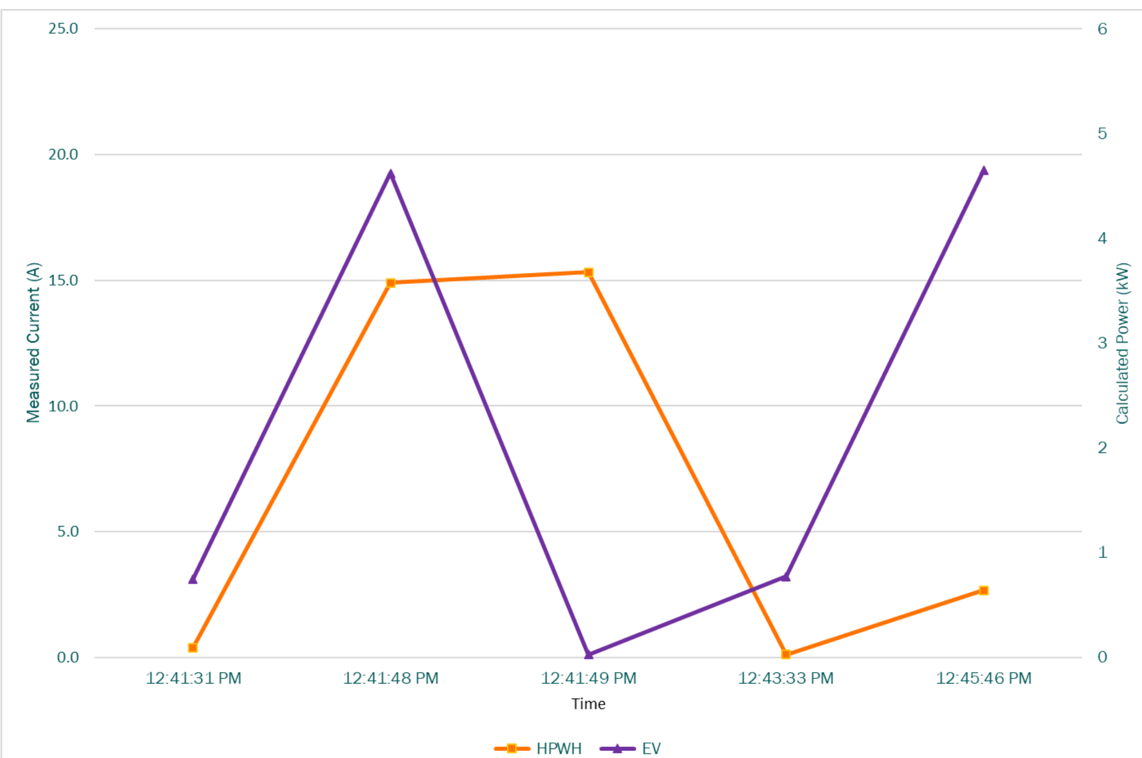


Figure 17: Plug-in circuit splitter maximum draw event—pilot demonstration site #1.

As seen in Figure 17, the plug-in circuit splitter sheds the EV charger within seconds of the HPWH drawing load over the threshold—10 A in this case. After the HPWH is turned off, the system monitors the loads for a couple of minutes before powering the EV charger.

Smart Panel

"High visibility of electrical usage on all circuits and control for prioritization of battery use during high-cost time-of-use (TOU) times" (Customer 2025).

A smart panel is an upgrade to a typical circuit breaker box. Rather than just distributing power, it acts as a "smart" hub to the home's entire electrical system. It is Wi-Fi-connected and equipped with technology to monitor and control every circuit in real time via a smartphone app. This gives the homeowner total visibility into where and how energy is being used. The smart panel manages the total power load by prioritizing circuits, including high-demand systems such as EV chargers, solar, or batteries. This intelligent **load management** helps prevent circuit overloads and allows the system to direct power to only essential devices during an outage, and often allows homes to avoid expensive utility service upsizing.

Table 16: Table 16 below summarizes the service panel threshold test results for the smart panel pilot demonstration sites. For more details, please refer to Appendix E.

Table 16: LBT performance test results summary—smart panel.

Site #	Threshold (A)*	Load shed	Magnitude (A)**
2	50	EV charger	32
3	50	HPWH	20
4	50	Dryer	30

Figure 18 below shows the key circuits controlled by the smart panel during the service panel threshold test for one of the demonstration sites. The data shows that the smart panel manages the controlled loads to keep the panel draw below the threshold, which is set at 50 A.

*Threshold: the threshold is the trigger amperage needing to be reached in the Service panel test,

** Magnitude: the magnitude was drop in amperage once the threshold was reached

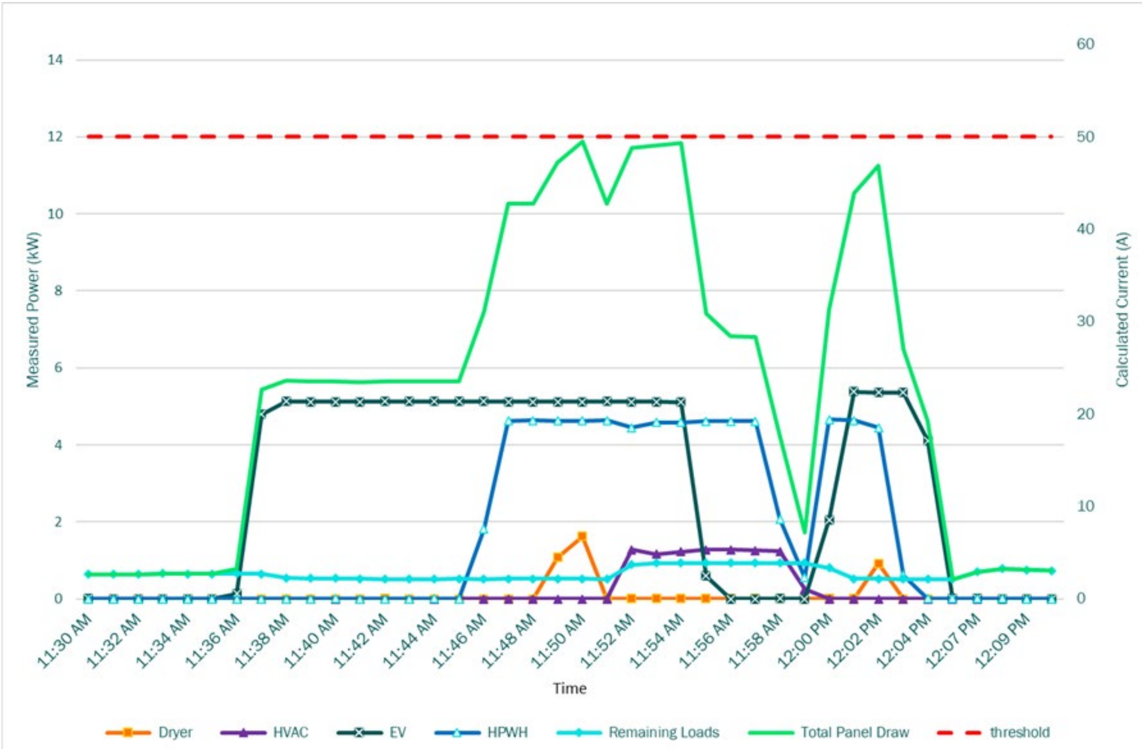


Figure 18: Smart panel SPT event—pilot demonstration site #4.

As seen in Figure 18, the test began at 11:37 a.m. with turning on the EV charger, followed by the HPWH at 11:46 a.m. The dryer turns on at 11:49 a.m. and in a minute the system threshold is reached. This results in the dryer being turned off at 11:51 a.m. The test concluded after 11:51 a.m., but we continued to monitor the system for a few minutes. It can be seen that the EV is shed at 11:55 a.m. when the total panel draw reaches the threshold. The EV charger is seen to resume operation when the total panel draw is maintained below the threshold and there is enough capacity to accommodate the EV charger without exceeding threshold.. Please refer to Appendix E for more details of the SPT test.

Smart Subpanel

This pilot had one LBT solution that is in the smart subpanel category. The subpanel is made up of power modules that are installed between the main service and the existing breaker, essentially adding "smarts' to existing "dumb" breakers. The brains of the system are informed by current transformers on the main panel. These current transformers allow the smart subpanel to measure the overall energy profile of the main panel/home. The individual loads/breakers are managed by modules in the smart panel and creating a very effective LBT.

Table 17 below shows the summary of the load-balancing event and testing for the smart subpanel.

Table 17: LBT performance test results summary—smart subpanel.

Site #	Threshold (A)	Load shed	Magnitude (A)
5	80	EV charger	32
6	80	EV charger	32
7	50	EV charger	20

Error! Reference source not found. Figure 19 below shows the key circuits controlled by the smart subpanel during the service panel threshold test for one of the demonstration sites. The data shows how the smart subpanel controls the existing loads to keep the grid draw below 50 A.

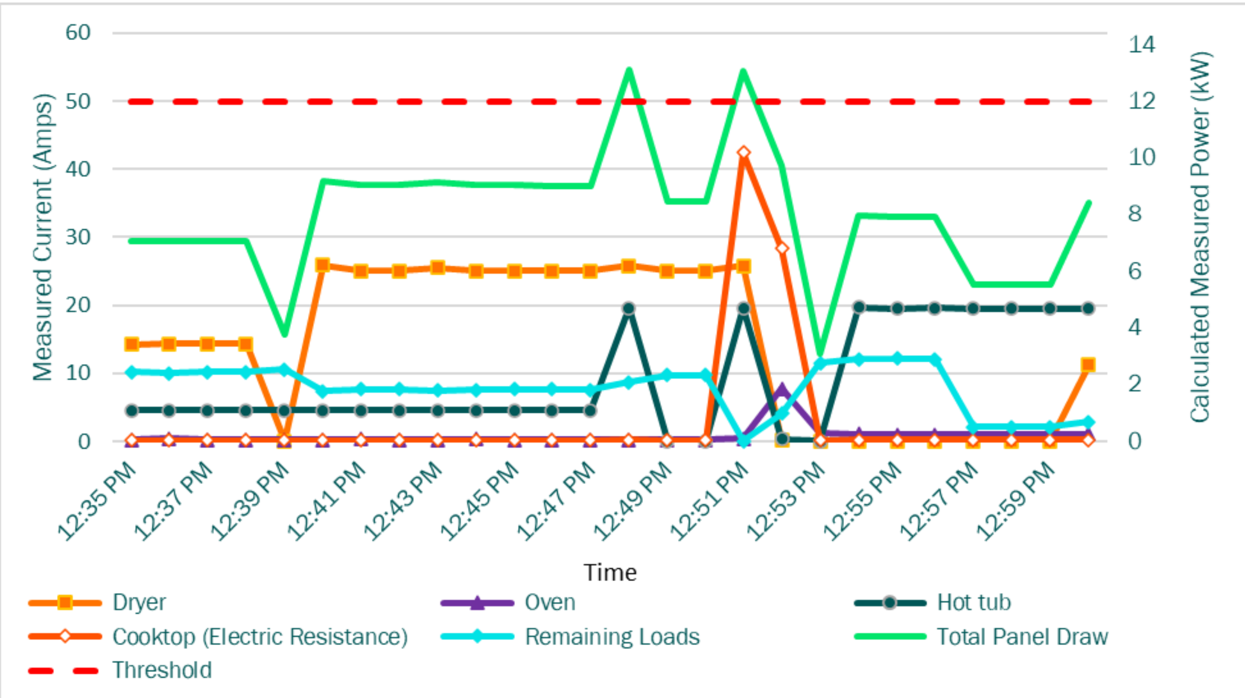


Figure 19: Smart subpanel SPT event—pilot demonstration site #7.

During this SPT test, the homeowner turned on the hot tub, dryer, and cooktop. The total panel draw was maintained below the service threshold until the hot tub heater turned on at 12:48 p.m., resulting in the total panel draw exceeding the service threshold. As a result, the smart subpanel shed the hot tub circuit. After a few minutes, the smart subpanel restores the hot tub circuit, However, the cooktop coming on at the same time draws the total panel draw over the threshold, resulting in the hot tub circuit being shed again. The smart subpanel continues to monitor the system to ensure there is enough capacity remaining so the shed load can resume without reaching the system threshold. At 12:54 p.m., the smart subpanel senses that the system is no longer close to the threshold and has enough capacity to accommodate the hot tub load and resumes hot tub operation. Please refer to Appendix F for more details of SPT test.

Smart Breaker

"During extended power outages, I am able to ensure the solar and battery system are able to power the house for multiple days by shutting off appliances that aren't needed and phantom loads throughout the house" (Customer 2025).

Smart breakers function by replacing standard circuit breakers to provide real-time, energy monitoring at the individual circuit level. These devices transmit precise usage data back to the central system. The central system is also measuring whole home energy at the main breaker, giving homeowners insight into the energy consumption of the home and every appliance with a smart breaker. The central system can be programmed to turn off or turn on based on time or conditions when other loads are on, resulting in a load-balancing feature. The smart breaker technology evaluated in this pilot sheds the appliance with the most amperage, and requires the homeowner to manually restore the appliance once load has been shed, via the app or at the service panel. The manufacturer is working towards updating technology to allow homeowners to select the load(s) that can be shed and which cannot, and to turn loads back on automatically once the home is below the service panel threshold.

Table 18 below summarizes the service panel threshold test results for the plot demonstration sites. For more details, please refer to Appendix G.

Table 18: LBT performance test results summary—smart breaker.

Site #	Threshold (A)	Load shed	Magnitude (A)
8	90	EV	35
9	70	HPWH	15

Figure 20 below shows the key circuits controlled by the smart subpanel during the service panel threshold test for one of the demonstration sites. The data shows how the smart subpanel controls the existing loads to keep the grid draw below 70 A. At the point when this test was taken, the homeowner did not have an EV charger connected to the LBT directly; the EV charger was still impacting the service panel threshold as it was communicating with LBT central system. The EV electrical impact is captured under "remaining load." The load order Load 1 HPWH was turned on Load 2 EV charger.

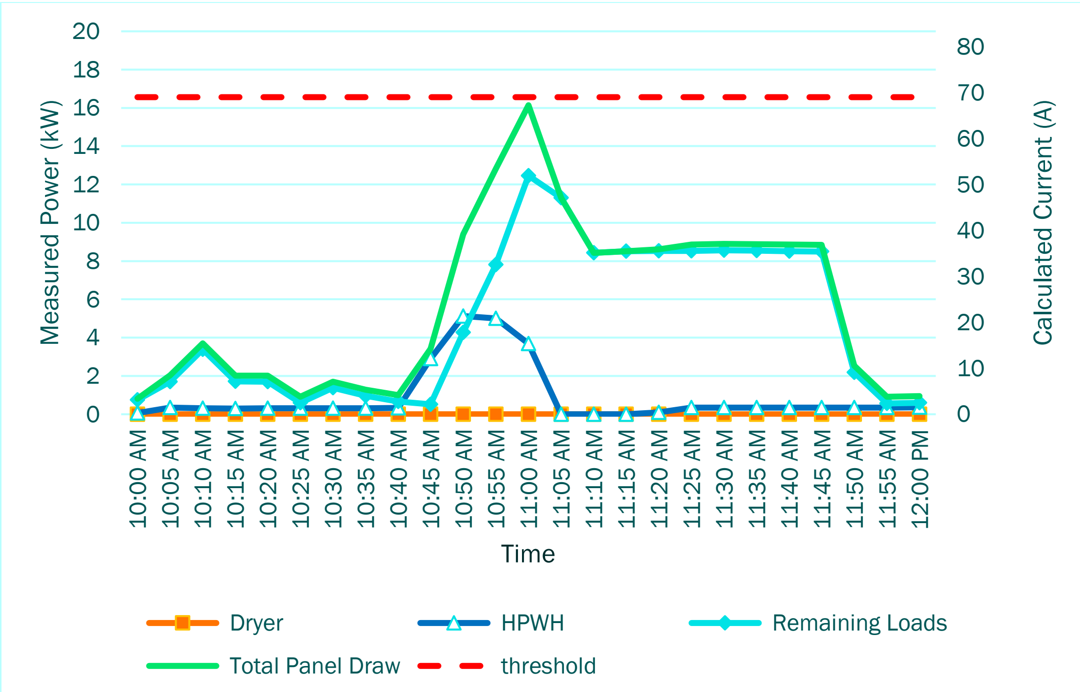


Figure 20: Smart subpanel SPT event—pilot demonstration site #9.

During this SPT test, the homeowner turned on the EV charger and HPWH. The total panel draw was maintained below the service threshold until 11:00 a.m. The smart breaker sheds the HPWH so the panel draw stays below the system threshold. The technology does not have the capability to auto restore the load when the system is maintained below thresholds and needs input from the user to turn the load on. Please refer to Appendix F for more details of SPT test.

Installation Lessons Learned

The 10 installations with different LBTs provided key lessons about the technologies and their market adoption barriers.

Electrical Load Calculations Findings

The project team performed electric load calculations for the pilot demonstration sites using the CalNEXT residential electric service upgrade decision tool to determine the total service load (amps) in the following scenarios:

1. Baseline: Load without any EV charger or electrification measures
2. Baseline and EV: Load after adding EV charger to the baseline
3. Baseline, EV, and pilot electrification: Load after adding EV charger and the electrifying end use loads as proposed in the electrification plan (see Pilot Demonstration – Electrification Plan)
4. Baseline, EV, and full electrification: Load after adding EV charger and electrifying all the gas-fired appliances.

For scenarios 3 and 4, we also demonstrated the impact on the total service load with and without LBTS installed. The load calculation results are summarized in Table 19:.

Table 19: Total service load calculations for pilot demonstration sites.

Site	Existing Service Capacity (A)	Total Service Load (A)					
		Scenario #1: Baseline	Scenario #2: Baseline + EV	Scenario #3: Baseline + EV + Pilot Electrifica-tion w/o LBT	Scenario #3: Baseline + EV + Pilot Electrifica-tion w/ LBT	Scenario #4: Baseline + EV + Full Electrifica-tion w/o LBT	Scenario #4: Baseline + EV + Full Electrifica-tion w/ LBT
1	100	69.8*	103.2	111.0	102.7*	137.9	131.4
3	100	65.1	115.1	122.9	62.2	154.6	80.8
4	125	67.4	107.4	115.2	55.7	142.3	78.5
7	100	88.6	128.6	136.4	59.7	155	78.3
8	200**	74.7	140.7	155.9	59.1	234.3	72.1
9	100	58.5	90.5	104.2	86.3	166.4	93.5
10	200**	80.6	120.6	135.1	95.1	194	125.3

*Based on one-year metered data, site #1 has a maximum demand of 18.7 A, and can use 220.87 pathway to add new electrical loads instead of the traditional 220.83
**These sites have existing 200 A service and panels. These sites have unique features such as resistance strip heaters, pools/spa, and multiple EV chargers. Based on NEC load calculations, these sites go over 80 percent of the panel size with EV chargers and electrification.

As can be seen in the table above, most sites had 80 percent of panel capacity after adding an EV charger. With the electrification measures implemented in the pilot demonstration, most sites went over the service limit (except sites #8 and #10), resulting in the need for service upsizing. Adding an LBT helps to keep these sites under the service limit, thereby avoiding the costly infrastructure upgrades.

With the electrification of all gas appliances, all the sites go over the service limit in the absence of LBTs (site #10 is close to the service limit). All sites with smart panel, smart subpanel, and smart breakers installed were able to stay below 80 percent of the service limit.

While NEC 625.14 treats EV charging as a continuous load for circuit sizing (1.25), the calculation tool used to model the panel demand uses 1.0 to better represent typical diversity and usage.

Permitting Requirements

The implementation of LBTs introduces varying requirements for building permits, which must be considered when deploying. Generally, the installation of circuit splitters, smart breakers, or smart subpanels does not necessitate a building permit, unless the project involves altering the homes load capacity or relocating or rewiring loads to a new subpanel location. Furthermore, meter collar devices will require both a building permit and direct support from the utility, as their installation requires temporary removal of the utility meter and affects the service meter connection point. The installation of a full smart panel requires a building permit, since this entails coordinating service shut-off and connecting the main service.

System Reliability Issues

Field observations revealed the degree to which smart sub-panel reliability depends on consistent firmware management and vendor support. During testing, one system experienced a loss of user-interface control due to a missed software update, preventing operators from re-enabling a shed circuit until the manufacturer issued a remote patch. Separately, a relay-state issue following generator power restoration was also corrected through a firmware revision, after which all systems operated normally. These incidents demonstrate that while the panels function as conventional hardware during outages, their advanced capabilities are software-dependent and can degrade without timely updates or cloud connectivity.

Installer Education and Awareness

Most LBT manufacturers have a certification that contractors must complete before they are authorized to install the system. The certification also includes the commissioning process and homeowner handoff process. With LBT's being a relatively new technology, this certification process is crucial. During the pilot demonstration, we found that some installers did not set up and configure the system correctly.

- The project team found that for two demonstration sites the service-upgrade-avoidance feature to shed load was not enabled.
- For one site, the panel size was set to 200 A in the app, when the service was limit was 100 A. This could have resulted from the smart panel model being 200 A capacity, even though the service was rated at 100 A.
- For two sites, the installer had labeled the controlled loads/circuits incorrectly.
- The total installed cost for smart breaker technologies in the pilot's demonstration sites ranged from $5,000 to $7,900, which is comparable to the installed cost of a smart subpanel or a smart panel. For each of these sites the smart breakers were not added to the existing panel, either the existing panel was replaced with a new traditional panel or a new subpanel was added and electrified loads moved to the new subpanel and smart breakers added to new panel/subpanel. This likely resulted in higher installed costs. After discussion with manufacturers, it was found that this installation could have been done more cost-effectively if the installers were trained enough on the installation best practices.
- All LBTs advertise capability to control all major appliance, including constant and variable speed compressor loads. However, the contractor needs to be educated/aware of ensuring that the compressor loads are designated critical and are lower on the shedding priority sequence (or completing avoid shedding) to mitigate any concerns with the appliance operation impact.

These findings suggest that proper installer training and education are critical for successful installations.

Local Support

Some of these technologies are relatively new, and getting certified installers/contractors in remote or rural regions might be a challenge. For example, the pilot demonstration site in Oakhurst, the project team was not able to find a certified LBT installation in the region. The closest installer was a 170 mile driving distance from the site, thereby impacting the overall installed cost of the LBT.

Table 20: Installation lessons learned.

Challenge	Lessons Learned
Load calculations findings	Electrification measures, especially of gas appliances and EV chargers, pushed sites over the service limit, but adding an LBT helped prevent infrastructure upgrades. While NEC 625.14 treats EV charging as a continuous load for circuit sizing (1.25), the calculation tool used to model the panel demand uses 1.0 to better represent typical diversity and usage.
Permitting requirements	Implementing LBTs often requires permits for installation. However, an electrical load calculation was not required for the permit, reflecting a disconnect between jurisdictions and contractors. We recommend further investigation into when load calculations are required.
System reliability issues	Reliability depends on consistent firmware management and vendor support. While it works as expected during outages, the advanced capabilities are software-dependent.
Future updates	Updates being made include: better load management efficiency, appliance level circuit sharing, integration of smart technology, and whole home management.
Installer education and awareness	Proper installer training and education is critical for successful installations.
Local support	Getting certified installers/contractors in remote regions may be challenging, or may increase the cost of the project if contractors need to travel a large distance for installation.

Economics of Load-Balancing Technologies

The project team established the material and installation costs associated with LBTs. These costs were estimated using contractor quotes, online retail pricing, and inputs from manufacturers. The objective of installing LBTs is to enable cost-effective electrification by avoiding expensive utility and infrastructure upgrades. The section below compares the cost of the different LBT categories and the cost associated with utility service upsizing.

Circuit Splitter Costs

In Table 21, the project team provides the equipment and installation cost summary for different types of circuit splitters. Across all the LBT categories, circuit splitters are the lowest cost option available. Customers with short-term electrification goals or who want to electrify one to two appliances can install these to avoid a service upsizing.

Table 21: Equipment and installation cost summary—circuit splitters.

Technology Subcategory	Plug-in Circuit Splitter	Hardwired Circuit Splitter	Meter Collar
Number of controlled circuits	2	1–2	1
Equipment Cost	$399–$449	$749	$1,200
Installation Labor Cost	$200	$200	$1,000[20]

Smart Panel and Subpanel Costs

Here we provide the equipment and installation cost summary in Table 22 for smart panels and subpanels. Smart panels and subpanels provide most flexibility to the customers in terms of load control and optimization, however, they are the most expensive solutions across the technology categories in this report. Customers with long-term electrification goals or who plan to add solar and BESS with electrification should consider installing smart panels and subpanels.

Table 22: Equipment and installation cost summary—smart panel/subpanel.

Technology Subcategory	Smart Panel	Smart Subpanel
Number of controlled circuits	16–48	1–12
Equipment cost	$2,550–$4,100	$2,000–$3,000
Installation labor cost	$2,700–$3,450	$1,500–$1,800

Smart Breaker Costs

In Table 23 we showcase the equipment and installation cost summary for smart breakers. Smart breakers provide the customer with flexibility to choose the circuits to monitor and control with a lower cost compared to smart panels. Smart breakers are cost-effective only if the existing panel is in good operating condition and does not need replacement.

[20] Meter collars are installed directly between the utility meter and the meter socket and they require utility inspections, resulting in higher installed costs compared to other circuit splitter technologies.

Table 23: Equipment and installation cost summary—smart breaker.

Technology Subcategory	Smart Breaker
Number of controlled circuits	1+
Equipment cost	$500 - $800 + $120-$500/controlled circuit
Installation labor cost	$1,500–$2,000

Utility Service Upgrade Costs

Table 24 shows the typical costs associated with increasing electrical capacity in residential retrofits in three main categories.

Table 24: Utility service upgrade costs for homeowners.[21]

Category	Cost Description	Range
Utility service upgrade cost	Upgrade transformers; pole replacement	$15,000–$19,000
Customer-owned equipment costs	Service upgrade fees; Panel upsizing; Adding new circuits	$2,600–$10,000 $250–$700 per circuit
Other miscellaneous project costs	Permitting; Trenching and conduits	$625–$1,000 $5–$15 per linear foot

Cost-Effectiveness of Load-Balancing Technologies

In conclusion, LBTs are a cost-effective solution to electrification in comparison to service upsizing. Depending on the customer need and budget, they can choose LBT solutions starting from $600 to $7,550, while service upsizing could cost a homeowner up to $30,000.

Customer Experience

Based on customer feedback, the majority of customers installed LBTs to support EV charging, existing panel size limitations and to control their appliances during outages.[22] There were also a

[21] The total cost for all three categories was reported to range between approximately $2,000 to well over $30,000 or more (NV5 2022).

[22] Based on the survey results we deduce that these are the customers with BESS.

significant percent of customers who installed LBTs when they installed solar system and BESS.. Among the 51 survey respondents with LBTs, the majority were satisfied with their LBT, with 92 percent selecting satisfied or very satisfied on a 5-point satisfaction scale. Each manufacturer showed similar trends with satisfaction scores over 90 percent, as shown in **Figure 21**

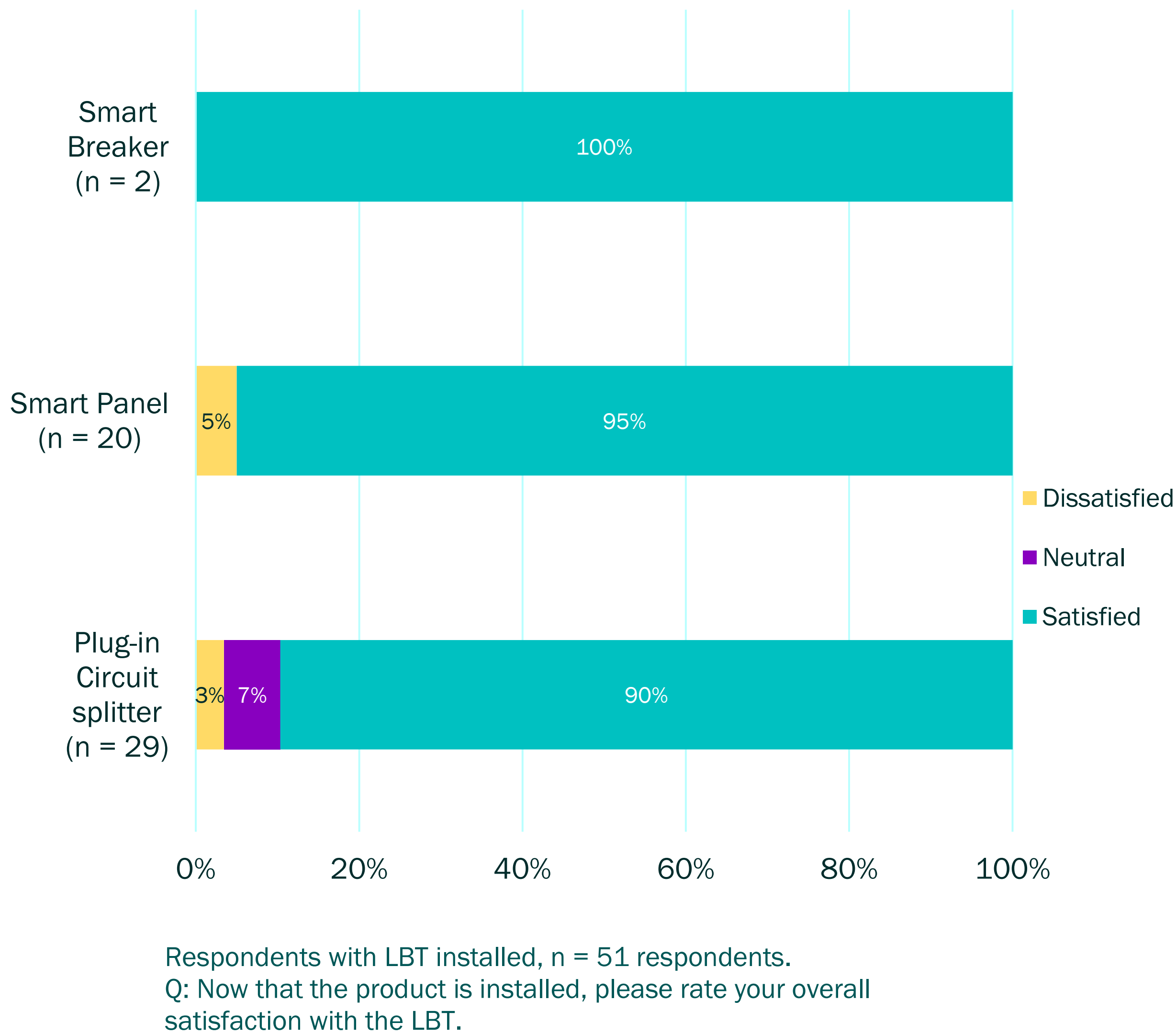


Figure 21: Satisfaction with LBTs.

The customers were asked an open-ended question in the survey to share their feedback on the LBTs they had installed. Some positive feedback from customers includes the ease of installation, ease of use, and ability to monitor devices remotely, as shown in Table 25. Some negative feedback from customers includes loss of Wi-Fi and connectivity, limited integration capabilities, and a lack of knowledge about the product from contractors, listed in Table 25. While over half of respondents (54 percent) noted no installation challenges, around one-third (34 percent) noted the high upfront cost as a challenge to installing LBTs.

Table 25: LBT customer feedback.

Technology	Plug-in circuit splitter (n = 29)	Smart panel (n = 19)	Smart breaker (n = 2)
Positives	Easy Installation – Self-installation possible, ability to use existing 240 V plug, no electrical modifications needed. Remote monitoring and control – mobile app. Easy to use and track usage data. Ability to charge two EVs. Affordable.	Smooth installation. Works well during power outages. Ability to monitor energy.	Easy Installation – Can be added to existing panel. Ability to shut off non-critical appliances during outages.
Negatives	Difficulty with software upgrades. Communication loss with mobile app. Product not working as intended. Slow customer support response.	Unstable software Limited functionality and limited API integration – Could include smart timer based controls, integration with solar and EV charging. Inability to discharge batteries to the grid. No remote control when Wi-Fi connection lost during power outages. Installer is not very knowledgeable on the product and its features.	None.
Customer Response Highlights	"The (smart splitter) is very easy to install, plug n play. What I like most about it is the companion … mobile app. It helps track charge stats and helps control when is the best time to charge my cars." "It works gives me usage information that is clear and easy to understand."	"Has served me well through multiple power outages and also allowed me to monitor what is really using power in my house and maybe change that as necessary" "High visibility of electrical usage on all circuits and control for prioritization of battery use during high cost TOU times."	"During extended power outages I am able to ensure the solar and battery system are able to power the house for multiple days by shutting off appliances that aren't needed and phantom loads throughout the house."

Respondents with LBT installed, n = 51 respondents.
Q: Please tell us about your overall experience with the LBT that resulted in the satisfaction rating you selected.
Open-ended response.

Pilot Demonstration Participant Survey Findings

The project team surveyed six[23] of the completed site participants to gather initial reactions to the

[23] The project team did not survey the participants that were installed by UC Davis.

installation and operation of their LBTs and new electric appliances and general feedback on the pilot process. Participants were highly satisfied with the pilot, with all but one respondent selecting the highest rating, “extremely satisfied,” and one respondent selecting “somewhat satisfied” with the pilot overall. Participants appreciated the flexibility, support, and communications from the project team, with one noting “everything worked the way we had thought it would.” Two participants appreciated the ability to receive new electric appliances due to the pilot.

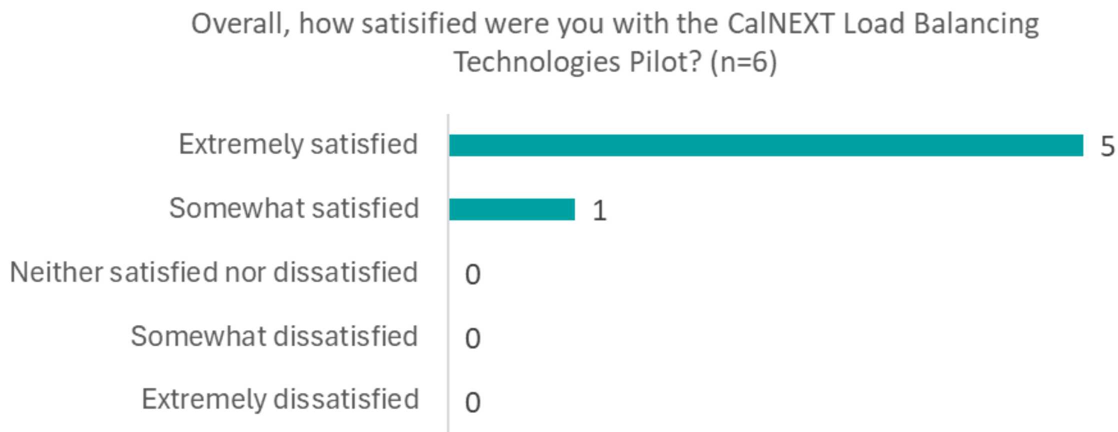


Figure 22: Participant satisfaction with LBT pilot.

While participants were largely satisfied with all aspects of the pilot, they noted challenges large and small, primarily experienced during the installation and commissioning process, that could be improved. Two participants suggested contractors could better familiarize themselves with the LBTs to be able to educate the customer, and to aid in installation and commissioning process. Two suggested contractors better assess the specific context in which they are installing the LBT or electrification equipment and one suggested contractors could better understand what loads and LBTs best work in what scenarios for the customer's needs. One participant highlighted the setup of the LBT could be streamlined for or by the contractor. One participant also would have preferred additional time to find a better contractor, while another wished they could have gotten a better understanding of the true cost of their system, which ended up being significantly higher than what was originally estimated.

All six participants noted they were either somewhat or extremely likely to recommend the LBT installed in their home to friends and family.

Pre-Installation

Prior to participating in the pilot, four of the six respondents were previously familiar with LBTs like the one installed in their home and had previously researched such products. One respondent was generally familiar with LBTs but had not looked into them for their home. Two participants, both receiving smart panel products, had were not previously aware of such technologies. Most participants were generally satisfied with both the process of finding a contractor and scheduling their equipment installation, with only one respondent rating the process to find and hire a contractor as “neither satisfied nor dissatisfied.”

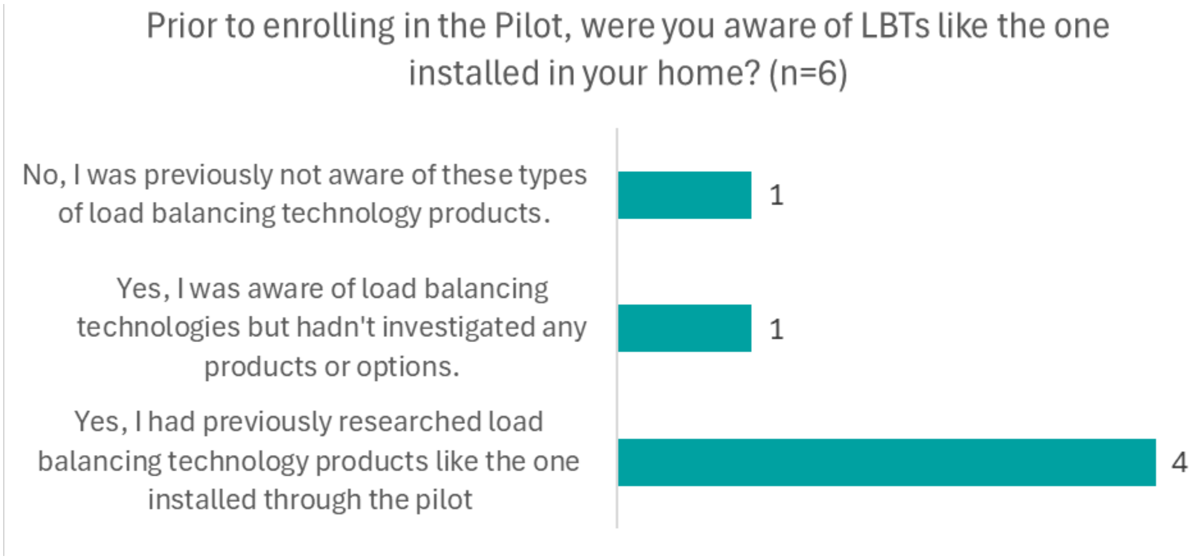


Figure 23: Awareness of LBTs prior to pilot participation.

Installation and Commissioning

Five of six respondents were extremely satisfied with the installation process, though one participant was "somewhat dissatisfied," and noted several issues they experienced with the contractor that detracted from their experience. Participants highlighted a variety of issues experienced during the installation from minor inconveniences to larger workmanship issues. One participant receiving a smart breaker product, noted the LBT required software updates upon installation, but felt those types of "bugs" were to be expected for a new technology or newly installed product. Another mentioned that their contractor expressed hesitation with the LBT due to concerns about acceptance from the building inspector. The participant who rated their installation poorly noted that the contractor installed an incorrectly sized panel for their smart breakers, did "shoddy" work with the water heater disconnect, and incorrectly wired the smart breaker modules.[24]

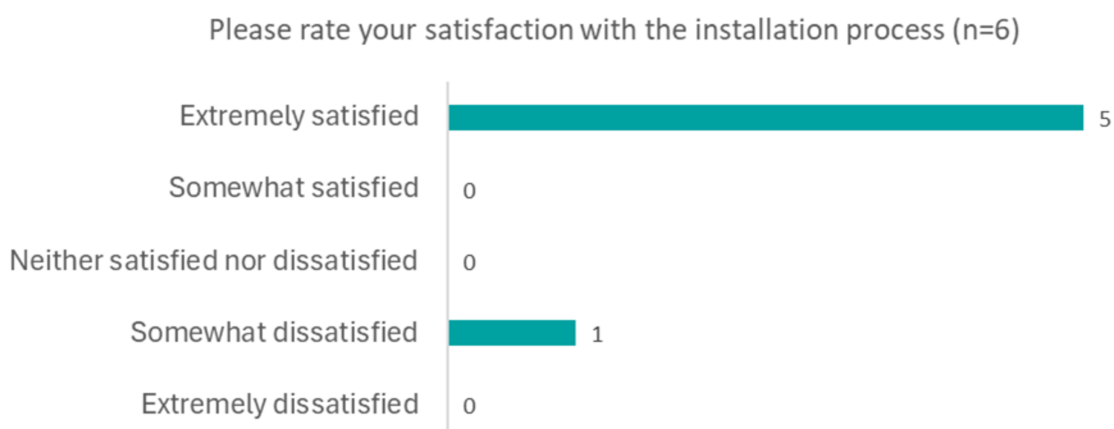


Figure 24: Participant satisfaction with contractor installation process.

[24] The project team provided participants with contacts for certified contractors in their region and asked participants to select a contractor, or choose to work with their own preferred contractor. In the case of the lone participant who rated their installation poorly, this participant chose a contractor different from the recommendation provided by the project team and LBT manufacturer. This contractor obtained certification from the LBT manufacturer on their product prior to completing the installation.

All but one participant provided their contractor with input for which equipment should be controlled by the LBT in their home. The one participant who did not was also the only participant who was not aware of LBTs prior to participating in the pilot. Two participants also told the contractor how to prioritize the end-use electric equipment controlled by the LBT. Two participants said they set up the prioritization themselves, while the other two said the contractor set the prioritization for them.

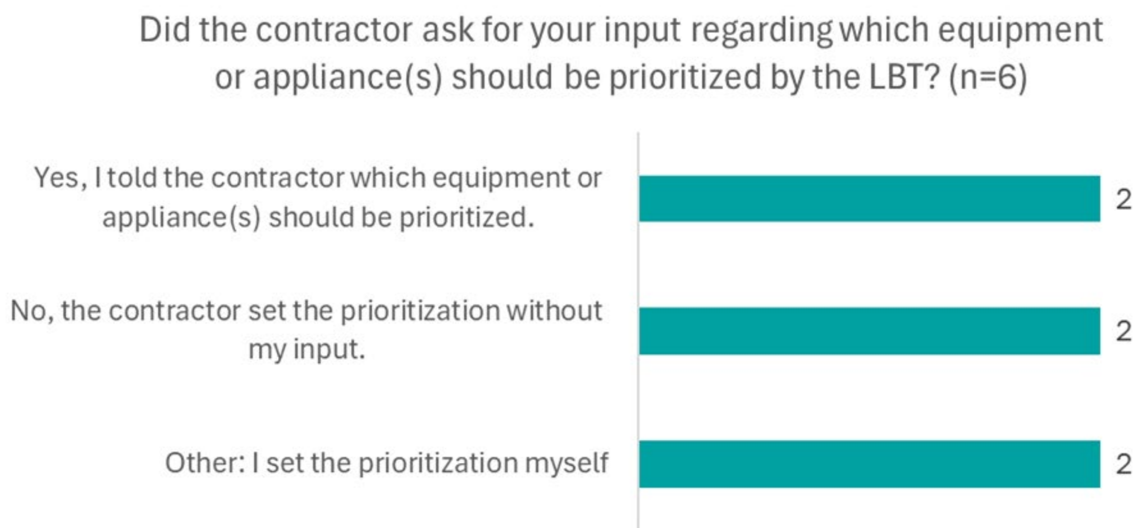


Figure 25: LBT load prioritization by contractors and participants.

Five of five responding participants were highly satisfied training and instruction they received on the new equipment installed in their home. However, when asked if they were provided with adequate training or instruction on their new equipment and LBT, half of the participants responded that they were not. One commented that they wish they received more training on the LBT, while another noted they were “tech savvy” and were able to easily learn their smart panel device. A third said their contractor wanted to finish as quickly as possible, but they were able to get excellent support from the LBT manufacturer to set up the smart breakers on their own.

Post-Installation

Most participants were also either somewhat or extremely satisfied with any post-installation support from their contractor; the respondent who had problems with their contractor’s installation was also somewhat dissatisfied with this post-installation support. Four participants had no post-installation issues with their LBT or equipment installed. One required their contractor to return to rewire smart breakers after discovering it was installed incorrectly, and a second participant noted that one of the circuits controlled by their smart breakers was not working and their contractor was returning to assess the issue.

One respondent suggested that in addition to contractor technical assistance, building departments could also use education on LBT devices to help streamline permitting and inspection by the authority having jurisdiction over electrical work.

Contractor Survey Findings

The project team also collected data from contractors that completed the pilot LBT installations via short questionnaire and survey to assess their experience and any challenges identified during the installation. Five contractors provided responses about their projects, representing three smart panels, a smart breaker module installation and one smart outlet splitting device. Four of the five contractors had limited experience installing the LBT products utilized on their project – with 0 to 2 prior installations. The fifth contractor had significant experience with smart panels, having previously installed approximately 120 of them.

Installation project durations vary widely across LBTs, with smart splitting outlet technologies only taking 1 hour to install, while panel and smart breaker technologies took from 4 to 15 hours. Some sites took significantly longer than the contractors estimated was typical for an installation, while others were shorter than the typical project. Other factors, like needing to install a sub-panel, can impact projects to make them more complex than the typical installation. In all cases except the smart splitting outlet, the electrician had an additional person helping them with the project. shows the typical and pilot-project installation times reported by the contractors.

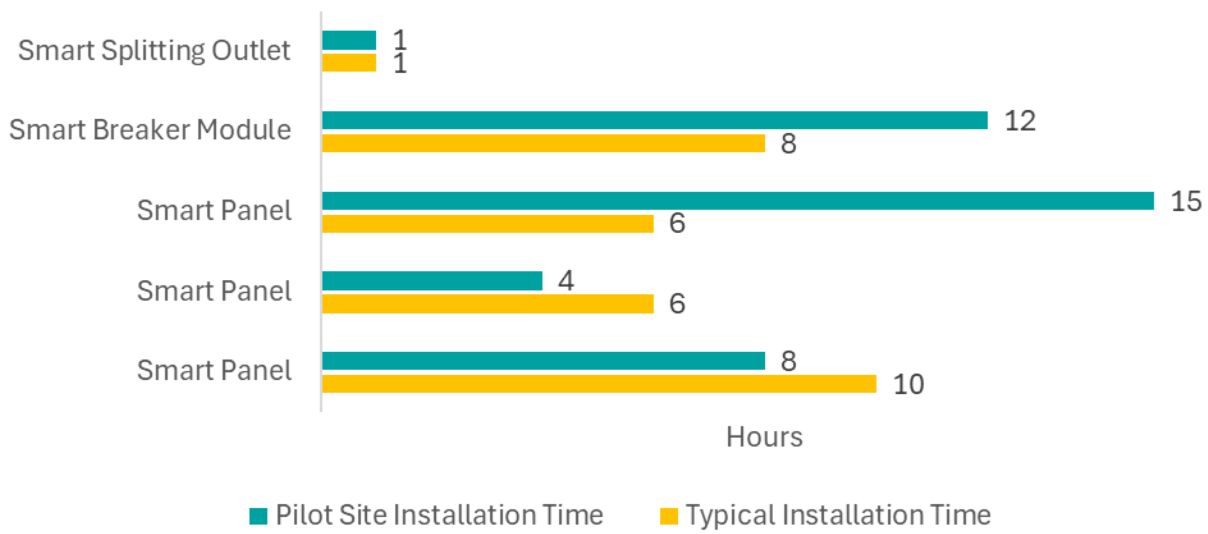


Figure 26: Contractor-reported installation time for pilot projects and typical LBT projects by type.

Three of the five electricians said they experienced no challenges with the pilot project installation, including one who had no prior experience with the smart panel product they installed. For the smart splitting outlet project, the contractor indicated the location of the water heater, which was splitting power with an EV charger, was not convenient for a typical EV charger installation but “we made it work.” The other contractor noted that commissioning the customer’s smart panel device took much longer than expected and had difficulty connecting to the device. The contractor indicated that commissioning can be “hit or miss with these kind of products,” with challenges establishing connections, time spent typing information of a phone, and one or both electricians on site being idle for much of that time.

Other typical challenges identified by electricians for these types of products include re-routing of existing circuits for smart panels and replacing old equipment so new smart breakers can fit in existing equipment.

Contractors also provided several suggestions for how to improve the efficiency of installations based on their experience. Two suggested ideas for improved ease of commissioning the smart product. One contractor suggested that LBT manufacturers add features to avoid some of the tedious or problematic steps in setting up the device, including using Bluetooth instead of WiFi for easier connectivity, and adding automation that could read a picture of the panel schedule to fill out app forms automatically. Another suggested ensuring sufficient and reliable ethernet access at the panel would save time. Another suggested that knowing which circuits, if any, need to be relocated would save time.

All five responding contractors said they were likely to recommend the installed product to a customer in the future. Two contractors who installed smart panels and one installing a smart breakers said they were extremely likely to recommend it, while one smart panel installer and one smart splitting outlet said they were somewhat likely to recommend those products. shows the contractors' reported likelihood of recommending the products they installed in the future.

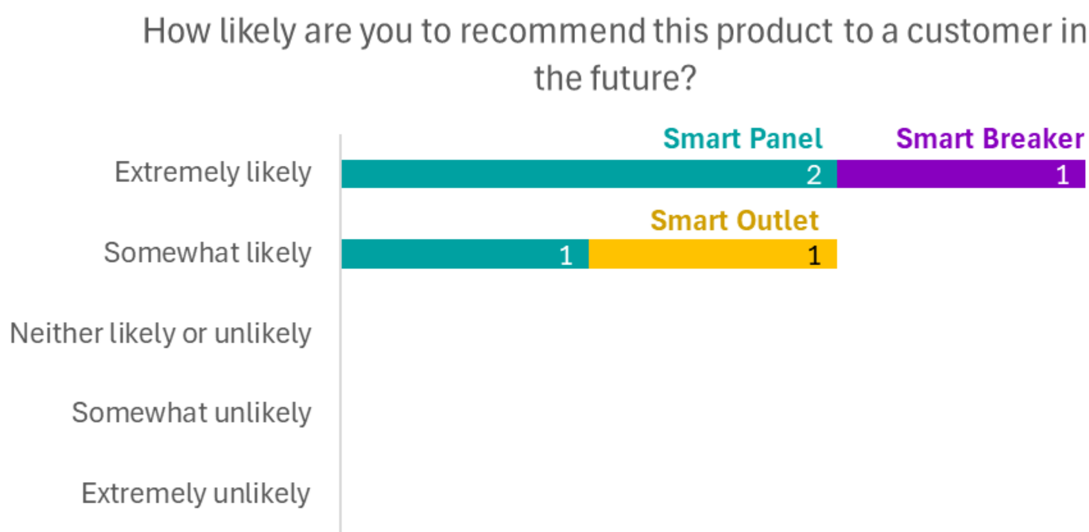


Figure 27: Likelihood contractors would recommend LBT products to future customers.

Code Official and Building Inspector Interviews

As smart panels are the only LBTs requiring permits at the time, the project team interviewed code officials and building inspectors to evaluate their awareness and perspectives regarding smart electrical panels. Preliminary findings indicate limited familiarity with smart panel software, reliance on manufacturer documentation during field inspections, and concerns about long-term software visibility and access. One respondent—an experienced inspector—emphasized the need for qualified personnel to access programming settings and highlighted potential risks if homeowners or contractors lack adequate oversight of system configurations. Additionally, the inspector underscored that current inspection workflows do not provide visibility into the software logic driving automated load control decisions.

The interviews further revealed that most smart panel inspections were performed on smart panel products and that inspectors typically rely on product labeling and manual web searches to verify compliance in the field. The lack of centralized documentation or a compliance registry was cited as a barrier to consistent enforcement and safety assurance.

Stakeholders across all groups demonstrated general awareness of smart panel technologies, but most lacked direct experience with their installation, configuration, or operation—particularly regarding software-driven functionality. Key adoption barriers identified include high upfront cost, insufficient contractor training, lack of clarity in applicable codes, and limited transparency in how software-controlled load management operates. To address these challenges, stakeholders emphasized the need for standardized installation guidelines, hands-on training, and improved access to system diagnostics to reduce uncertainty and facilitate smoother installation and inspection processes. Inspectors specifically raised concerns about the limited visibility into smart panel software, secure access restrictions, and the risk of system obsolescence if vendor support is withdrawn. Future engagement efforts will expand the pool of interviewed officials across California and aim to generate actionable recommendations to inform policy, workforce training, and technical documentation to accelerate market readiness and adoption

Conclusion and Recommendations

For retrofit applications with electrical constraints, LBTs are a compelling solution that can be critical for meeting decarbonization and electrification goals for residential and small commercial markets. Below are key findings and recommendations for supporting wider adoption of these technologies.

Manufacturers Installer Recommendations

Manufacturers provide clear instructions, commissioning protocols, and tighter alignment with the installation practices. Field demonstrations underscored the need for tighter alignment between original equipment manufacturers (OEMs) and installers to ensure reliable operation, maintainability, and transparency of smart energy management systems. For manufacturers, priority should be given to establishing formal firmware management protocols, including backward-compatible updates, clear version tracking, and automatic notification of pending updates through their applications. Systems must include defined fail-safe logic that restores relays to their last known state after any power or communication loss, and cloud dashboards should provide visibility into device status, connectivity, and software version history for authorized personnel.

LBT and appliance OEMS partner and develop the right controllability and sequence of operation structure. LBTs control circuits at the panel level. Whereas each appliance manufacturer is also controlling their devices via industry communication standards such as CTA2045/EcoPort and AHRI 1380. These OEMs need to collaborate further and develop the right controllability and sequence of operation approach for the successful adoption of LBTs. Currently, heat pump appliance manufacturers have raised concerns about third party LBT OEMs controlling their heat pump compressors.

LBTs are a new set of smart technologies, and there is not enough knowledge about their best installation practices and commissioning of these products. For the technology to be installed optimally, it is important that there is a post-install checklist and standardized commissioning procedures. This will help contractors confirm the right sequence of operation and priorities.

Installers should adopt standardized commissioning protocols that integrate both electrical and software validation. This includes verifying network performance under real site conditions, confirming reliable fallback connectivity (e.g., cellular hotspots), and documenting software versions, system limits, and applied configurations at turnover. Comprehensive installer training should extend beyond wiring and mechanical setup to encompass firmware verification, secure remote access, and basic cloud diagnostic procedures.

Utility Incentive Program Considerations:

Based on the pilot findings, the project team recommends the following when designing an incentive program for LBTs and/or cost-effective electrification:

LBTs for panel upsizing avoidance in electrification programs

Based on the recent electrification program findings, the customers can incur between $2,000 to $30,000 or more for electrical infrastructure upgrades (NV5 2022). Based on our study findings, the total project cost with LBTs ranged from $600 to $7,500. Each of these technologies have a service-upgrade-avoidance feature that allows the central circuit controller to look at the whole home circuit capacity, and in case the house reaches 80 percent of the panel capacity, then it pauses some circuits for the home to ride the peak. Due to this, load balancing the homes could electrify most of the end uses without adding additional load on the utility distribution and transmission system. We recommend that, for the electrification programs, utilities incentivize these technologies.

LBTs as home energy management systems

Every LBT manufacturer either has or is working on making their products bidirectional and grid interactive. With accelerating electrification needs, utilities are seeking scalable, cost-effective solutions that can avoid costly distribution upsizing, increase system flexibility, and enhance customer affordability. Most LBTs give customers circuit-level visibility of a whole home and control over electricity use inside the home. By shifting, pausing, of throttling loads in real time, they help avoid overloading neighborhood transformers and distribution lines, reducing strain on local infrastructure and supporting electrification. The future is pointing at dynamic signals and automated orchestration of loads. And LBTs with the right integration of appliance controls have the potential to help that transition. The project team recommends that the additional features of the technologies be studied and demonstrated further to identify the right program structure for these technologies. With the flexibility they provide, they can fit in energy efficiency, electrification, load management, and/or demand response programs.

No one size fits all solution, need incentives and program structure that aligns with unique technological features

Customers installing circuit splitters mostly did so for EV charging. The reasons for selecting smart panels and smart breakers were much more varied, and usually had multiple reasons for installing them.

It is important to understand that these technologies are providing a total system benefit (TSB) due to load management and peak shifting capabilities. The benefit is due to shifting the load to the off-peak period, which provides greenhouse gas emissions savings and reduces strain on the utility generation side. We recommend that in the next focus pilot, we evaluate the TSB of these projects. This will help identify the right program structure and measure package application for LBTs.

Policy and Market Recommendations

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

Code Recommendations

Based on the NEC load calculations for the homes, the project team learned that adding Level 2 EV chargers drives most customers over their panel threshold, but the load may never be realized at the meter. Several customers were learning or knew about time-of-use pricing and typically run EV charging during off-peak hours at night. The traditional NEC 220.83 electrical load calculations use nameplate ratings of individual devices with coincidence factors to calculate the total service load. These calculations are very conservative and provide a safety net to avoid overloading the electrical system. There is an alternative pathway available, NEC 220.87, which allows for the use of a home's actual maximum demand to calculate existing loads.

If the goal is to electrify one to two loads, contractors and designers should use a metering-based approach such as NEC 220.87 instead of traditional NEC load calculations.[25] However, the project team acknowledges that this might vary based on the customers' electrification goals. If the customer's goal is an aggressive multi-load electrification plan, it would be better to use the traditional, more conservative load calculation.

Permitting

LBTs are a new technology type and are becoming prevalent on the market. Due to the emerging nature of the LBTs, the permitting officers need inspection checklists to validate that the correct thresholds have been programmed into the LBT so it uses the built-in algorithm for load balancing and does not allow the home to exceed service capacity. It is critical that collateral materials and training are developed to specifically educate the permitting officers. In addition, tools and templates should be developed and made available to simplify the permitting process for electrification projects.

Workforce Development Recommendations

The pilot provided several lessons that should inform future workforce development efforts around LBTs. Market actor outreach and site demonstrations showed that installers and inspectors approach LBTs with different assumptions. Installers focused heavily on the physical installation, while many of the actual failure modes centered on software commissioning, networking requirements, and app-based configuration. Inspectors emphasized code visibility and labeling. Future workforce materials should explicitly address these communication dynamics and prepare installers to explain LBT behavior in a way that maintains homeowner confidence.

Training development further clarified where the gaps are. Electricians are comfortable with wiring and physical installation but receive far less exposure to the commissioning, networking, and firmware-management aspects that modern LBTs rely on. These digital competencies—installer-app setup, verification of service-limit settings, priority-list management, and troubleshooting connectivity—should be a central focus of ongoing training. Building inspectors and plan reviewers

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[25] NEC 220.87 is not universally accepted in all jurisdictions yet, though it appears to be a safe and effective method for calculating the safe capacity available on an existing residential electrical panel.

also emerged as key market actors who lack targeted guidance on this new product class. A parallel training track for code officials may accelerate safe adoption and reduce inspection-related delays.

From a technology-transfer perspective, utilities can maximize ratepayer benefit by embedding LBT workforce development into existing programs rather than treating it as a standalone effort. EVSE incentive programs are a clear fit: partnering with EVITP and encouraging (or requiring) certified installers would ensure that electricians deploying EV chargers are simultaneously trained on LBT strategies for avoiding panel upsizing. IOUs could also support creation of a qualified contractor list based on EVITP-aligned criteria, giving homeowners confidence in installer competency. Finally, utilities should consider funding broader rollout of LBT curriculum across JATCs statewide to build long-term workforce capacity as electrification accelerates.

Conclusion

Utilities nationwide are at a critical juncture of energy efficiency, electrification, load management, demand response, and building resiliency. It is important that we decarbonize the built environment using the current electrical infrastructure to its full capacity before having to build new electrical infrastructure. For optimal use of the reserved existing infrastructure, load management and automated controllability behind the meter are becoming more critical. Based on this pilot research, one to two homes in every five homes[26] has a constrained electrical service that may not easily accommodate additional electrification measures such as EV charging, a heat pump, or electric clothes dryer. The California Public Utilities Commission is now asking utilities to avoid upsizing main electrical service when smarter options exist, such as panel optimization and load management, before replacing the infrastructure with bigger wires.

The overall success of this pilot highlights the critical aspect of load balancing. Each household has a unique load profile; load profiles are changing with electrification and impacting California’s carbon footprint and greenhouse gas emissions. LBTs validated in the pilot confirm that they have capabilities for service-upgrade-avoidance and load management. The pilot participants were able to add a Level 2 EV charging and electrify HPWH and heat pump clothes dryers with existing solar and battery installations using LBTs. LBTs are a cost-effective alternative to traditional panel and service upsizing, averaging $600 to $7,500 compared to $25,000 in service upsizing.

Every LBT manufacturer is working on making their products bidirectional and grid interactive. These products are coming to the market at a critical time. With building and transportation electrification accelerating, utilities are seeking scalable, cost-effective solutions. LBTs have the potential to increase system flexibility and enhance customer affordability. By shifting, pausing, or throttling loads in real time, they help avoid overloading neighborhood transformers and distribution lines, reducing strain on local infrastructure and support load management. The future is pointing to dynamic signals and automated orchestration of loads, with the right integration of appliance controls, LBTs have the potential to help with that transition.

[26] Based on CPUC, EPRI, and TECH Clean California data sources.

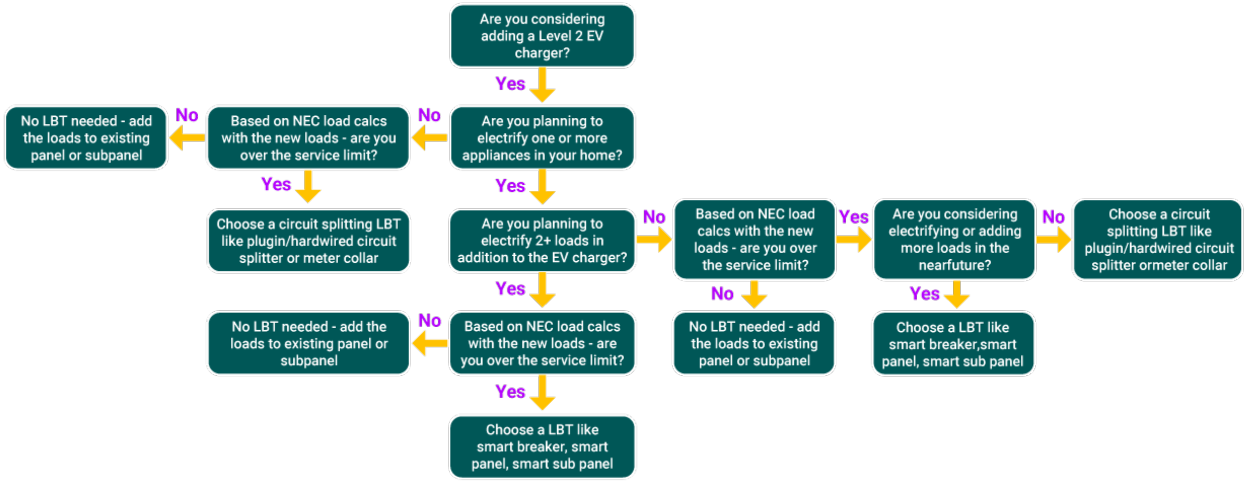

Figure 28: LBT selection flow chart.

Appendix A: Outreach Materials

Typical Outreach Flyer

Stipends for the purchase and installation of new electric equipment and controls to replace gas equipment.

CalNEXT is looking for residents to receive up to $14,000[1] for the purchase and installation of new electric appliances or equipment. To get started, take the enrollment survey—eligible respondents will receive a $35 gift card![2]

Who is eligible for the $35 gift card?

- Residents of single-family homes or townhomes with a garage and an EV charger who complete the enrollment survey.

Who is eligible for the stipend of up to $14,000?

- Residents of single-family homes or townhomes located in PG&E, SCE or SDG&E service territory, with a garage and at least one EV charger already installed.
- Those who complete a qualifying installation project that includes replacing at least one gas-fired appliance located in the garage—such as a water heater or clothes dryer—with a new high-efficiency electric model.

Participation Benefits

- ☑ Receive a stipend of up to $14,000 toward the purchase of new electric equipment and installation.
- ☑ Replace your old, inefficient gas-fired equipment with electrical appliances without upgrading the electric panel.
- ☑ Decarbonize your home while avoiding electrical upgrade costs.
- ☑ Provide your input on future rebates for this equipment throughout the state.

If you are interested in participating, please tap or scan the QR code to complete the survey.

We recommend using your mobile phone, as the survey will require you to take photos of equipment in your home.

[1]The stipend will be proportional to the project cost, and could range from $2,500 up to $14,000. [2]The first 100 eligible respondents get a $35 gift card for participating in the survey. | Read more about this pilot and how it works at **calnext.com/electrify**. This pilot is part of the CalNEXT emerging technologies program funded by the California electric investor-owned utilities.

CalNEXT Project Landing Page

(https://calnext.com/electrify/)

Home | How to Participate | About | Events | Resources | Approved Projects | Keep in Touch

Make the switch to electric and receive up to $14,000!

The CalNEXT **Electrification Enablement via Load Balancing Solutions Focus Pilot** is designed to help residents electrify their equipment without requiring costly upgrades to existing electrical panel and service. Residents can receive up to $14,000[1] for the purchase and installation of new electric appliances or equipment and controls. To get started, take the enrollment survey—eligible respondents will receive a $35 gift card!

Who is eligible for the $35 gift card?

- Residents of single-family homes or townhomes with a garage and an EV charger who complete the enrollment survey.

Who is eligible for the stipend of up to $14,000?

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- ☑ Replace your old, inefficient gas-fired equipment with electrical appliances without upgrading the electric panel.
- ☑ Decarbonize your home while avoiding electrical upgrade costs.
- ☑ Provide your input on future rebates for this equipment throughout the state.

If you are interested in participating, please email CalNEXT-LBT@trccompanies.com **to receive a private link to the survey.**

[1]The stipend will be proportional to the project cost, and could range from $2,500 up to $14,000.

CalNEXT Newsletter

Updates

California Homeowners to Get Paid to Switch to Electric Appliances

A new CalNEXT funded pilot program is offering cash stipends to qualifying California residents who replace gas appliances with electric equipment and controls. The CalNEXT team is recruiting residents of single-family homes and townhomes in California electric investor-owned utility service areas, who have a garage and at least one EV charger already installed. Selected pilot participants will receive a stipend to replace gas-fired equipment with new electric appliances and controls. Once installed, the pilot team will monitor the new electric equipment.

Learn More

Appendix B: Customer Survey Questions

Section A: CalNEXT Project Information Landing Page and Introduction

Thank you for your interest in the CalNEXT pilot program! The first 100 homeowners who qualify and complete this 15-minute online enrollment survey will receive a **$35 electronic gift card.**

Your participation in this research is voluntary. All personal information will be kept confidential and secure. Under no circumstances will the information you share with us be used to directly sell or market any products or services to you.

Toward the end of this survey, you will need to upload photos of some electrical equipment in your home. We recommend completing this enrollment survey on a **mobile device such as a smart phone or tablet.**

Click "Next" to begin the enrollment survey!

Section B: Screening Questions

B_Intro. First, please answer some questions about your primary residence referred to as "your home" for this survey.

B1. Which of the following best describes your home?

1. Single-family home
2. Townhouse, duplex, or triplex
3. Multifamily condo or apartment **[TERMINATE]**
4. Mobile home **[TERMINATE]**
5. Other **[TERMINATE]**

B2. Which of the following best describes the garage at your home?

1. Attached garage (The garage is in the same structure as my home.)
2. Detached garage (The garage is a separate structure from my home.)
3. My home does not have a garage **[TERMINATE]**

B3. How many electric vehicles (EVs), if any, are charged at your home?

1. 1
2. 2
3. 3 or more
4. None, I do not charge any EVs at my home. **[TERMINATE]**

B4. Which of the following EV chargers are installed at your home?

1. Level 1 charger: a standard 120 volt wall outlet that can charge an EV in 12 to 24 hours
2. Level 2 charger: a 240 volt charger that can charge an EV in 4 to 8 hours

3. Other, please specify: [OPEN END] [ASK FOR PHOTO IN SECTION D]
4. I do not have an EV charger installed at my home [TERMINATE]

B5. Where are the EV chargers installed at your home? Select all that apply.

[MULTIPLE RESPONSE]

1. Inside the garage
2. In the driveway
3. In a carport
4. At the street or curbside [TERMINATE IF ONLY SELECTED 4 OR 5]
5. Other [TERMINATE IF ONLY SELECTED 4 OR 5]

B6. Do you have a [PRODUCT NAME] installed in your home or garage? These devices are typically connected to an EV charger.

Example:

1. Yes, I have a [PRODUCT NAME] installed.
2. No, I do NOT have a [PRODUCT NAME]. [Skip to Section D]
3. Don't know [Skip to Section D]

Section C: Load-Balancing Technology Experience

C_Intro. Next, we would like to learn more about the [PRODUCT NAME] installed in your home.

C1. Which of the following describes why the contractor installed the [PRODUCT NAME] in your home? Select all that apply.

[MULTIPLE CHOICE]

1. My electric panel capacity was too small.
2. I wanted the ability to control which appliances are turned off during planned utility power outages.
3. I wanted to install solar panels.
4. I wanted to install a battery storage system.
5. I wanted to install an EV charger.
6. Other, please specify:
7. I don't know.

C2. When installing [PRODUCT NAME], what challenges, if any, did you experience? Select all that apply.

[MULTIPLE RESPONSE] [Optional]

1. Delays in receiving appropriate permits
2. Difficulty acquiring the parts or equipment needed for the upgrade
3. Difficulty finding available contractors
4. Difficulty understanding the permitting process
5. High upfront project cost
6. Other, please specify:
7. We did not experience any challenges during the installation process

C3a. Now that the product is installed, please rate your overall satisfaction with the [PRODUCT NAME].

1. Very satisfied
2. Satisfied
3. Neither satisfied nor dissatisfied
4. Dissatisfied
5. Very dissatisfied
6. Don't know

C3b. Please tell us about your overall experience with [PRODUCT NAME] that resulted in a rating of "[C2a RESPONSE]."

[OPTIONAL]

C4. Are you considering purchasing any of the following **electric** appliances or technologies for your home in the next 2-3 years? Select all that apply.

[MULTIPLE RESPONSE]

1. All-electric car, truck, or SUV
2. Heat pump HVAC system
3. Heat pump clothes dryer
4. HPWH
5. Induction stove
6. Other, please specify:
7. I am not currently considering purchasing any additional electric appliances or technologies.

Section D: Existing Electrical System and Appliances

Intro1_D. Next, we will be asking you about equipment currently in your home.

D1. Which of the following best describes any solar or battery storage systems installed at your home?

A battery storage system can provide back-up power to your home. In this case, please do NOT include an electric vehicle battery as battery storage.

1. Solar only (no battery)
2. Solar + battery
3. Battery storage (no solar)
4. I do not have any solar or back-up battery systems

D2. Please select all the **natural gas** appliances or equipment installed in your home. Select all that apply.

Do not include any electric-only appliances or equipment.

[MULTIPLE RESPONSE]

1. Clothes Dryer
2. Water Heater
3. Furnace
4. Stovetop, range, or oven
5. Fireplace
6. Other, please describe:
7. None, I do not have any natural gas appliances in my home.

[IF D2 = 1, 2, 3, 4, or 6]

D3. Which of your **natural gas** appliances or equipment, if any, are located **in your garage**? Select all that apply.

[MULTIPLE RESPONSE]

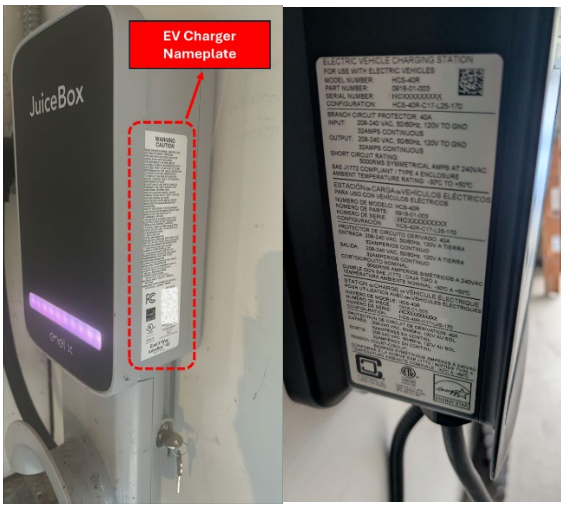
1. Clothes Dryer
2. Water Heater
3. Furnace
4. Stovetops/range/oven
5. Other, please describe:
6. None, I do not have any natural gas appliances in my garage.

Intro2_D. Next, we will be asking you to take photos of your home's electric panel and potentially your EV charger. If you are not currently at home, **please pause this enrollment survey and continue once you are home and able to take photos.**

[IF B4 = 3, OTHER]

D4. Please locate the EV charger installed in your garage, driveway, or carport. Search for the nameplate of your EV charger which is a rectangular white sticker located on the bottom, side, or back of the charger. Please take a clear photo of the nameplate and upload it below.

Nameplate location and example photo:



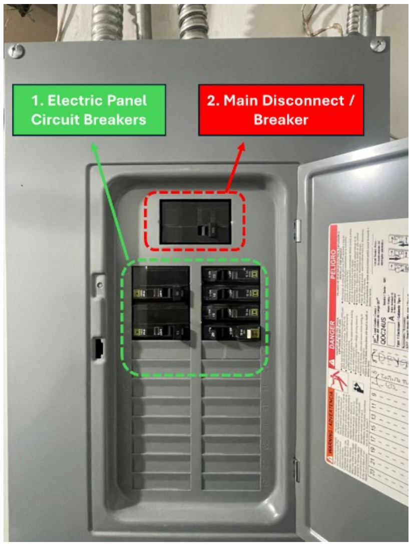
Please upload the photo of your EV charger nameplate:

D5. Please locate your home's **electric panel**, also called a breaker box.

1. Open the electric panel cover and take a clear photo of the **circuit breakers.** Please check that the numbers on the handles of the breakers are legible in the photo.

2. Additionally, please take a close-up photo of the **main disconnect breaker**, also called a service disconnect. Please check that the numbers on the handles of the breakers are legible in the photo.

Please click "next" to upload your photos.



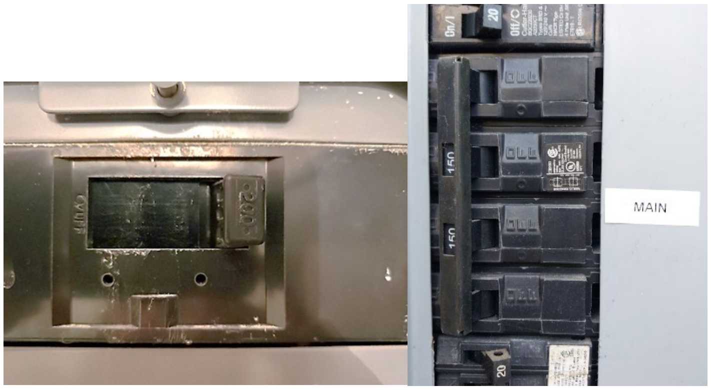
Where is my electric panel? The panel is typically located inside the home or outside the home near where your electric utility meter is mounted. Some homes may have multiple electric panels—please find the one closest to your electric utility meter.

D5a. Example photo of **circuit breakers**:

Please upload the photo you took of your **electric panel circuit breakers.**

D5b. If needed, upload an additional photo.

D5c. Example photos of **main disconnect breaker**:



What is a main disconnect? A main disconnect breaker is similar to other breakers in the panel and is often located in a separate space above the rest of the circuit breakers, but not always. The main disconnect breaker typically has a number on the handle that is greater than any of the other breakers on the panel—often a value between 100 and 200.

Please upload the photo you took of your **main disconnect breaker.**

D5d. If needed, upload an additional photo.

Section E: Demographics

Intro_E. Finally, we have a few additional questions about your home.

E1. What year was your home built?

1. Before 1950
2. 1951–1970
3. 1971–1990
4. 1991–2010
5. 2011 or newer
6. I don’t know

E2. What is the approximate square footage of your home?

1. Less than 500 ft^2
2. 500 to 999 ft^2
3. 1,000 to 1,499 ft^2
4. 1,500 to 1,999 ft^2
5. 2,000 to 2,499 ft^2
6. 2,500 to 2,999 ft^2
7. 3,000 ft^2 or more

E3. Including yourself, how many occupants currently live in your home for 6 months or more each year?

1. 1
2. 2
3. 3
4. 4
5. 5
6. 6 or more
7. Prefer not to say

E4. Please enter the zip code of your primary residence:

Section F: Pilot Program Details

Thank you! We have a few additional questions on your interest in providing additional information about your home.

F1. As part of the pilot, the research team is analyzing electric usage data to see how often panel upgrades are needed. The team has partnered with UtilityAPI, a utility data exchange platform, to securely access monthly electric utility usage data.

Would you be willing to share your home's electric usage data with the research team through the UtilityAPI platform for an **additional $35 electronic gift card**?

1. Yes
2. Maybe
3. No

F2. There is a CalNEXT pilot program which will provide up to $14,000 towards home installation and purchase costs of electric appliances for qualifying homes. Would you be interested in participating in this pilot if selected?

1. Yes, I am interested in participating.
2. Maybe, but I need more information before agreeing to participate.
3. No, I do not want to participate in the pilot.

[IF F2 = 1 or 2, Yes or Maybe]

F3a. Thank you for your interest in the CalNEXT pilot program! We will review the data you've provided in this enrollment survey and reach out to you if you are eligible to participate in the pilot. Please provide the information below to complete your interest in the CalNEXT pilot.

1. First name
2. Last name

3. Email

[IF F2 = 3, No]

F3b. Thank you for providing information about your home. Please provide your contact information below in case we have any follow-up questions regarding the answers you've provided.

1. First name
2. Last name
3. Email

Appendix C: Existing California and National Electric Code Review

The detailed methodology is outlined below:

Initial Scope Definition and Relevance Screening:

a. The project team screened 2022 California Building Standards Code (Title 24), comprising twelve parts, to identify parts containing guidance related to circuits, breakers, or panels for either EV charging or heavy appliances. Specifically, laundry, water heating, space heating/conditioning, pool/spa equipment, and electric cooking.
b. Based on the initial screening, Parts 1, 4, 5, 7, and 12 were excluded from further consideration at this preliminary stage due to their titles indicating irrelevance to the project scope.

Detailed Code Text Review (2022 Edition):

a. The project completed a thorough review of the remaining selected parts (2, 2.5, 3, 6, 8, 9, 10, and 11) of 2022 Title 24.
b. Parts 2, 8, 9, and 10 were eliminated upon closer review of their content, as they did not contain relevant guidance on the subject.
c. Part 2.5 was noted to refer to Part 3 but lacked any new amendments or specific panel/circuit requirements pertinent to the review, thus ceasing further consideration.
d. Part 3 was identified as highly relevant due to its sections outlining requirements for permissible circuit loading, including EV charging and heavy appliances. Specific attention was given to Section 220.23, which details general permissible loads.
e. CEC amendments within Part 3 that referenced requirements in Part 6 and Part 11 prompted a focused review of these two Parts. Relevant sections from these Parts, detailing load calculations, heavy appliances, or EV charging requirements, were recorded.

Prospective Code Review:

a. To ensure the review captured the most current and upcoming standards, the methodology extended to include the 2025 Title 24, which is set to go into effect January 2026, and compared it to the full text of the 2022 edition to get an accurate understanding of Part 3.
b. The 2023 NEC, which forms the basis for Part 3 of the 2025 California Electrical Code, was also thoroughly examined.
c. During this prospective review, Section 220.70 was identified as new introduction in the 2023 NEC, providing guidance on the use of EMS for electrical load calculation on feeders or services. This specific section was of particular interest as it directly addresses mechanisms for dynamic load management and potential load sharing.

Table 26 below links to 2022 California Building Standards code sections, the text from the code, and includes the Final Express Terms text for the 2025 California Building Standards code.

Table 26: California Building Standards code sections and Final Express Terms.

End Use	Relevant Code	Code Excerpt	Code Specifies Dedicated Circuit for the End Use (yes/no)
Readiness	Part 6	422.3(A) California Energy Code Requirements for HPWHs, electric cooktops, electric clothes dryers, and their readiness in single-family buildings [CEC].	No
Panelboard	Part 6	408.2(a) panelboards serving the individual dwelling unit shall be provided with circuit breaker spaces for HPWHs, heat pump space heaters, electric cooktops and electric clothes dryers as specified in California Energy Code Section 150.0 (n), (t), (u) and (v).	No
HVAC	Part 3	220.51 Fixed Electric Space Heating Fixed electric space-heating loads shall be calculated at 100 percent of the total connected load. However, in no case shall a feeder or service load current rating be less than the rating of the largest branch circuit supplied. Exception: Where reduced loading of the conductors results from units operating on duty-cycle, intermittently, or from all units not operating at the same time, the authority having jurisdiction may grant permission for feeder and service conductors to have an ampacity less than 100 percent, provided the conductors have an ampacity for the load so determined.	No

End Use	Relevant Code	Code Excerpt	Code Specifies Dedicated Circuit for the End Use (yes/no)
HVAC: Room AC	Part 3	440.62(A) Room Air Conditioner as a Single Motor Unit A room air conditioner shall be considered as a single motor unit in determining its branch-circuit requirements where all the following conditions are met: It is cord- and attachment-plug-connected. Its rating is not more than 40 A and 250 volts, single phase. Total rated-load current is shown on the room air-conditioner nameplate rather than individual motor currents. The rating of the branch-circuit short-circuit and ground-fault protective device does not exceed the ampacity of the branch-circuit conductors or the rating of the receptacle, whichever is less.	No
Water heating	Part 3	422.13: The branch-circuit overcurrent device and conductors for fixed storage-type water heaters that have a capacity of 450 L (120 gal) or less shall be sized not smaller than 125 percent of the rating of the water heater. (branch circuit guidelines in 422.10, and 210.23 for branch circuits serving multiple outlets and a water heater).	No
Washer-dryer	Part 3	220.54 Electric Clothes Dryers — Dwelling Unit(s) The load for household electric clothes dryers in a dwelling unit(s) shall be either 5000 watts (volt-amperes) or the nameplate rating, whichever is larger, for each dryer served. The use of the demand factors in Table 220.54 (100% for less than 5 dryers) shall be permitted. Where two or more single-phase dryers are supplied by a 3-phase, 4-wire feeder or service, the total load shall be calculated on the basis of twice the maximum number connected between any two phases. Kilovolt-amperes (kVA) shall be considered equivalent to kilowatts (kW) for loads calculated in this section.	No

End Use	Relevant Code	Code Excerpt	Code Specifies Dedicated Circuit for the End Use (yes/no)
Induction cooktop	Part 3	220.55 Electric Cooking Appliances in Dwelling Units and Household Cooking Appliances Used in Instructional Programs. The load for household electric ranges, wall-mounted ovens, counter-mounted cooking units, and other household cooking appliances individually rated in excess of 13/4 kW shall be permitted to be calculated in accordance with Table 220.55. Kilovolt-amperes (kVA) shall be considered equivalent to kilowatts (kW) for loads calculated under this section. Where two or more single-phase ranges are supplied by a 3-phase, 4-wire feeder or service, the total load shall be calculated on the basis of twice the maximum number connected between any two phases.	No
EV charging	Part 3	625.40 Electric Vehicle Branch Circuit Each outlet installed for the purpose of supplying EVSE greater than 16 amperes or 120 volts shall be supplied by an individual branch circuit. Exception: Branch circuits shall be permitted to feed multiple EVSEs as permitted by 625.42(A) or (B).	Yes—dedicated circuit for EV charging, can serve multiple EV chargers
Pool heater	Part 3	680.10(B): (B) Electrically Powered Swimming Pool Heat Pumps and Chillers Electrically powered swimming pool heat pumps and chillers using the circulating water system and providing heating, cooling, or both, shall be listed and rated for their intended use. The ampacity of the branch-circuit conductors and the rating or setting of overcurrent protective devices shall be sized to comply with the nameplate.	No

End Use	Relevant Code	Code Excerpt	Code Specifies Dedicated Circuit for the End Use (yes/no)
Hot tub	Part 3	680.10(B): (B) Electrically Powered Swimming Pool Heat Pumps and Chillers Electrically powered swimming pool heat pumps and chillers using the circulating water system and providing heating, cooling, or both, shall be listed and rated for their intended use. The ampacity of the branch-circuit conductors and the rating or setting of overcurrent protective devices shall be sized to comply with the nameplate.	No
Well pump	N/A	N/A	N/A
Sauna	N/A	N/A	N/A
Resistance welder	Part 3	630.31(A) Individual Welders The ampacity of conductors for individual welders shall comply with the following: The ampacity of the supply conductors for a welder that can be operated at different times at different values of primary current or duty cycle shall not be less than 70 percent of the rated primary current for seam and automatically fed welders, and 50 percent of the rated primary current for manually operated nonautomatic welders. The ampacity of the supply conductors for a welder wired for a specific operation for which the actual primary current and duty cycle are known and remain unchanged shall not be less than the product of the actual primary current and the multiplier specified in Table 630.31(A) for the duty cycle at which the welder will be operated.	No

Appendix D: Pilot Demonstration—Plug-In Circuit Splitter LBT

Site #1

Existing Conditions

Site 1 is a typical 4,100-square-foot single-family home located in Rohnert Park, as shown in Figure 31 below.

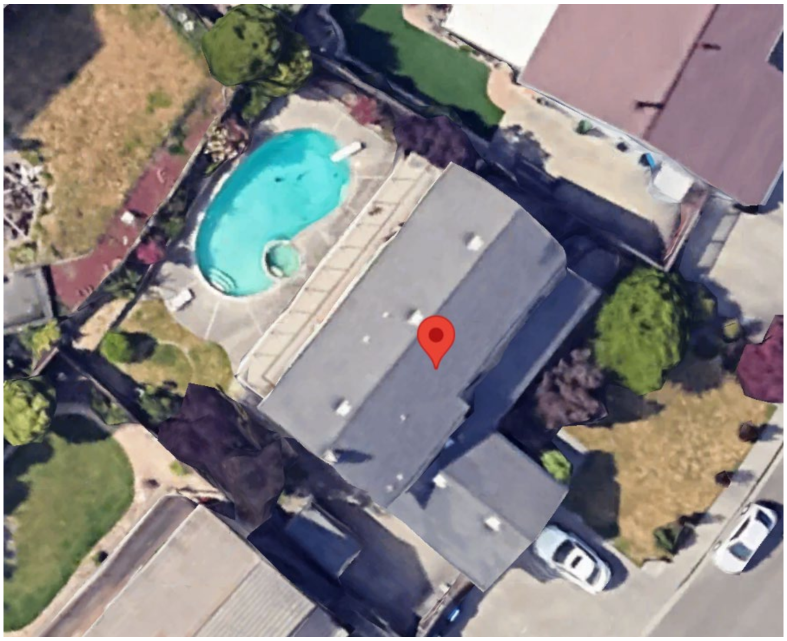


Figure 29: Google Earth view of site #1.

Electrification Plan

The plugin circuit splitter solution was a simple solution for the homeowner wanting to electrify their home. The plan for the homeowner was to electrify water heating with a HPWH, replace gas fired furnace with HP and install an EV charger. Since both the EV charger and HPWH are in the garage, it was determined a circuit splitter would be a cost-effective solution.

Figure 30: HPWH installed at site #1.

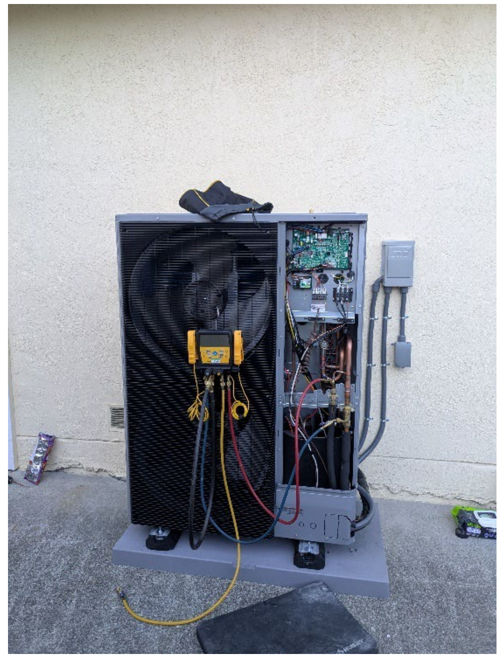


Figure 31: HVAC HP installed at site #1.

Figure 32: EV charger installed at site #1.

M&V and Test Plan

To test the plug-in circuit splitter LBT, the project team only looked at events when:

- The primary and secondary load ran in parallel.
- The secondary load was shed when the primary load drew over the threshold.

Installation Findings

The HPWH is set as the primary appliance (always on) and the EV charger is secondary on the circuit splitter. The HPWH typically draws over 10 amps when operating. As a result, the HPWH and EV charger did not run in parallel as the plug-in smart splitter dropped the secondary load (EV charger) when the primary was over the threshold (10 A). It is recommended that the homeowner looks for a larger capacity smart splitter, if they want parallel operation with large loads.

Results

The test day results are highlighted in the graph below. The circuit splitter data was shared by manufacturer. The device does not continuously log the data, but only when events are triggered.

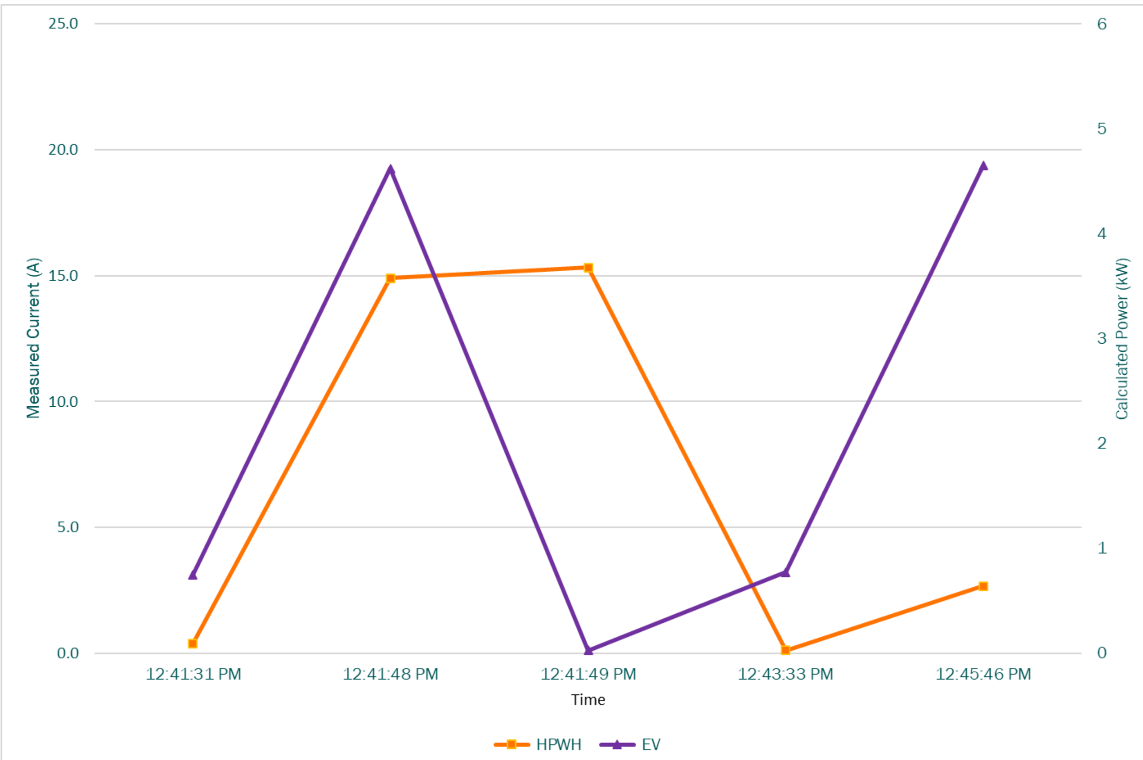


Figure 33: Plug-in circuit splitter maximum draw event—pilot demonstration site #1.

The data shows that when the HPWH is turned on and draws over 10 amps, the EV charger load drops within seconds. Once the HPWH is turned off, the system waits a couple minutes before ramping up the EV charger load. Thereby showcasing that the plug-in circuit splitter's load shedding capability when the primary load draws over the threshold value.

At this site, we were not able to test the parallel operation capability because the HWPH would always draw over 10 A when operating.

Appendix E: Pilot Demonstration—Smart Panel

Site #2

Existing Conditions

This site, referred to as The Lodge, is faculty housing at Bodega Marine Lab, as shown in Figure 36. The building contains six guest rooms—three with twin beds and three with queen beds—that share a common kitchen and laundry area.

Figure 34: Google Earth view of site #2.

ELECTRICAL INFRASTRUCTURE AND LOADS

The residence is served by a 208 V, three-phase, 200 A service delivered through a legacy Square D 42-circuit panel, which supplies power to all six units of the housing complex, as shown in Figure 37: Main electrical panel for site #2.. Prior to the electrification pilot, the site's electrical demand consisted primarily of general lighting, receptacles, and standard plug loads typical of a multi-unit residential building. Due to the region's mild, temperate climate, the facility did not use any central HVAC systems or large-scale space conditioning equipment. Instead, occupants occasionally relied on localized portable space heaters during colder periods, contributing minimally to the overall electrical load profile.

Figure 35: Main electrical panel for site #2.

Although the service panel is a three-phase design, no three-phase equipment was installed on-site, and all end-use loads were energized on single-phase branch circuits. The panel was electrically oversized relative to the building's baseline demand yet functionally constrained by the extensive subdivision of branch circuits needed for the six-unit layout. Numerous small, dedicated circuits distributed power across the property, producing a densely populated panel despite the comparatively modest overall load. At the time of initial assessment, the existing infrastructure provided sufficient capacity for the building's historic load profile but offered limited flexibility for the integration of additional high-power loads without reconfiguration or modernization of the distribution system.

GAS-FIRED APPLIANCES

The communal kitchen at site #2, shown in Figure 38: Typical existing gas range and oven unit in site #2., was originally equipped with two standard residential gas ranges, each consisting of a four-burner cooktop and an integrated oven. Typical residential gas ranges of this size feature one high-output burner (~12,000–18,000 BTU/h), two mid-range burners (~2,000–10,000 BTU/h), and one low-output simmer burner (~500–2,000 BTU/h). Oven bake burners on comparable units typically operate at approximately 16,000 BTU/h, while broiler burners are often rated between 12,000–16,500 BTU/h. When both the oven and cooktop are used simultaneously, a single range can draw an instantaneous peak input of approximately 40,000–45,000 BTU/h. These appliances require a 120 V, 60 Hz, 15 A branch circuit for ignition and control and operate on standard natural gas supply pressures.

Figure 36: Typical existing gas range and oven unit in site #2.

Electrification Plan

The installation phase involved deploying smart panel equipment and associated new electrical devices, with careful consideration given to electrical code compliance, panel constraints, and site-specific load profiles. Prior to any field installations, all devices, control systems, and integration pathways were fully assembled, powered, and evaluated under laboratory conditions to ensure system reliability and compatibility with the selected pilot sites.

During this pre-installation testing, each device was operated with simulated load scenarios to validate proper communication, switching behavior, and circuit monitoring capabilities. This process confirmed that the selected equipment was fully compatible with the 120/208 V single-phase service configurations used at the pilot sites (Figure 39).

Figure 37: Lodge electrical infrastructure lab pre-testing set-up.

Additionally, Service SUA/load shed functionality was verified in a controlled laboratory environment using appliances and other loads. These tests demonstrated the system's ability to shed and restore controlled loads effectively under high-demand scenarios without exceeding available service capacity. Following successful completion of lab validation, the equipment was packaged, labeled, and prepared for field installation.

ELECTRIFIED LOADS

As part of the electrification measures at site #2, two significant new electrical loads were installed: a Frigidaire 30-inch induction range with integrated air-fry capabilities and an Autel MaxiCharger Business Series Level 2 EV charger mounted on a dedicated pedestal. These installations required new conduit runs, properly sized conductors, and dedicated overcurrent protection to ensure safe integration into the site's managed smart panel infrastructure.

The Frigidaire induction range was selected for its energy efficiency, precision, and compatibility with the 120/208 V single-phase service used at the pilot sites (Figure 40). The appliance features a four-element induction cooktop and integrated convection oven, providing rapid and controlled heating while maintaining a cooler cooking surface compared to traditional gas or resistive electric ranges. To support the installation, conduit was routed from the smart panel to the stove location, where the range was connected to a dedicated 50 A breaker within the SPAN Panel system, consistent with manufacturer specifications. This configuration enables the induction range to be actively monitored and controlled by the smart panel, ensuring seamless integration into the broader managed load coordination strategy while also providing visibility into real-time circuit-level energy usage.

Figure 38: An inductive cooktop installed at site #2.

The second electrified appliance installed was the Autel MaxiCharger Business Series Level 2 EV charger, designed for multi-user, commercial-style deployments with network-enabled controls and integrated payment capability. The charger was installed on a concrete pad and mounted to a dedicated pedestal to provide secure and convenient access, as shown in Figure 41: A Level 2 EV Charger installed at site #2.. A newly routed conduit run connected the pedestal to the smart panel, with conductors sized for a 40 A breaker and configured to deliver a 32 A continuous charging current during pilot testing. The charging unit supports network connectivity, remote monitoring, and payment features, making it particularly well-suited for deployment at a multi-unit housing site where EV charging infrastructure may be shared among residents.

Figure 39: A Level 2 EV Charger installed at site #2.

The integration of these electrified loads required careful planning to ensure that conduit sizing, overcurrent protection, and panel capacity were aligned with both manufacturer specifications and electrical code requirements. By routing these devices through the smart panel, the project enabled real-time monitoring, circuit-level control, and coordination of load events. Together, the induction range and EV charger installations represent a significant expansion of the site's overall electrical demand.

SMART PANEL INSTALLATION AND CONFIGURATION

To support the addition of the new electrified loads at site #2, a smart panel was installed and configured to manage high-power loads as part of the electrification pilot. The existing 200 A three-phase main service panel supplies a newly installed 100 A three-phase subpanel, which was added as part of a contingency plan to simplify future reconfiguration should the smart panel hardware be removed following project completion. The subpanel is powered directly from the main service panel via a dedicated 100 A breaker and serves as the upstream source for the smart panel system, as shown in Figure 42.

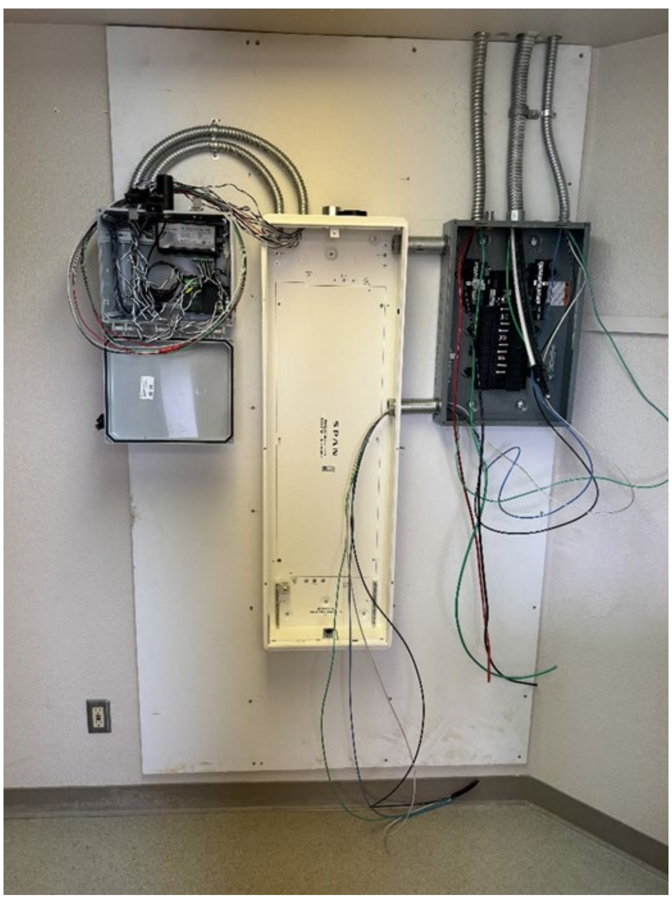


Figure 40: Mid-installation of smart panel infrastructure at site #2.

From this subpanel, the smart panel is powered using Phases A and C of the 120/208 V three-phase service, providing single-phase power to the managed branch circuits. The two, newly added electrified loads are controlled by the smart panel: the Frigidaire induction range on a dedicated 50 A breaker and the Autel MaxiCharger Business Series EV charger on a 40 A breaker, configured to deliver 32 A continuous charging current. In addition, the site's existing electric dryer, which was already installed prior to the project, was integrated into the smart panel system on a 30 A breaker to enable monitoring and coordinated control alongside the newly added loads (Figure 43).

Figure 41: Post-installation of smart panel infrastructure at site #2.

The smart panel-controlled circuits were placed on Phases A and C based on prior load measurements, which helped avoid phase imbalance during the pilot and kept total demand within researcher-defined limits. If the smart panel system is removed in the future, the three largest loads—the EV charger, induction range, and dryer—can be redistributed across Phases A, B, and C. This would restore a conventional, balanced configuration and maintain service reliability.

The dryer circuit was routed back through the main panel to align with the site's original wiring layout, while still being supplied downstream of the smart panel (Figure 44). This approach allowed the dryer to remain under smart panel control during the project while preserving compatibility with the site's long-term electrical configuration.

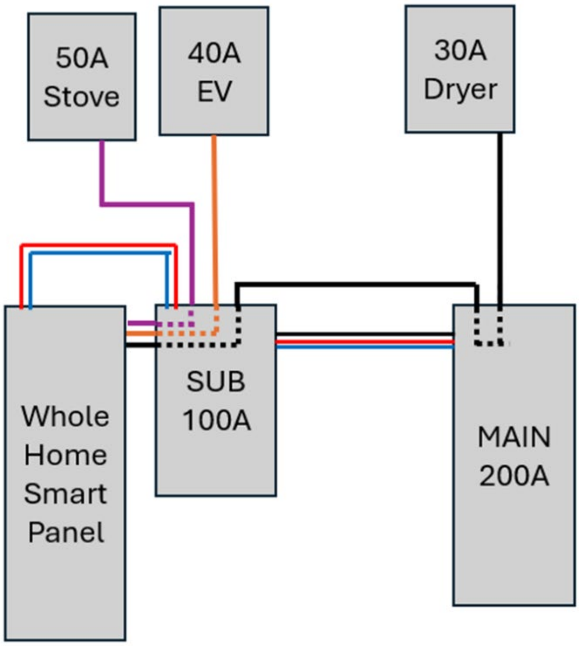


Figure 42: Electrical diagram of Site #2 infrastructure.

To protect the site's electrical infrastructure and ensure reliable service, the research team determined during pre-installation assessments that a 50 A per-phase limit on Phases A and C would be a conservative max amperage threshold based on the site's existing load profile. Upon commissioning, this limit was configured within the SPAN 40 system, enabling its SUA/load shedding functionality (Figure 45). Under this setup, if total combined demand on Phases A and C exceeds 50 A, the SPAN panel automatically sheds managed loads—such as the EV charger, induction range, or dryer—to avoid overloading the service and maintain safe operating conditions.

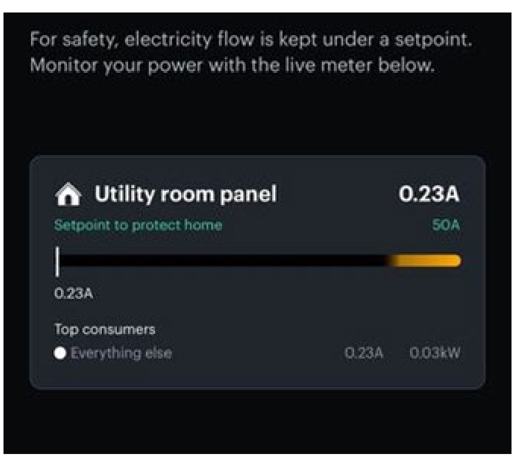


Figure 43: Smart Panel Power Up App screen shot.

Installation Findings

At the Lodge, installation and commissioning were straightforward. The smart panel was mounted in place, powered, and successfully connected to the existing Wi-Fi network through the manufacturer's mobile application. System registration and verification testing confirmed proper relay control, phase monitoring, and communication with the cloud platform. The unit was then configured with a 50 A threshold.

M&V and Test Plan

To evaluate the performance of the smart panel system, a dedicated M&V setup was installed alongside the panel. An E-Gauge EG4015 energy monitoring device was configured to capture circuit-level current, voltage, and power data for all managed loads connected to the smart panel 40 panel (Figure 46). High-accuracy current transformers (CTs) were installed on the EV charger, induction range, and electric dryer branch circuits, as well as on the main service feeders for Phases A and C supplying the smart panel. Voltage references were tied to Phases A and C to enable synchronized power calculations at one-second intervals.

Figure 44: Lodge M&V Mid-Installation.

Data from the E-Gauge is transmitted over a dedicated cellular gateway to a secure cloud platform, where it is stored using a tiered data retention structure: one-second resolution for the most recent hour, one-minute resolution for the last two months, and one-hour resolution for up to ten years. This allowed the research team to analyze short-duration load events in detail while also maintaining long-term visibility into usage trends and smart panel performance.

Within the smart panel-controlled environment, CTs on the dryer, induction range, and EV charger circuits monitor Phase A and Phase C currents, while voltage measurements on Phases A and C provide synchronized, high-resolution power calculations for each managed circuit. The E-Gauge data enabled the research team to independently verify the smart panel's service-upgrade-avoidance (SUA) operations, ensuring the configured 50 A phase limit is respected and providing a reliable record of each load-shedding event triggered to prevent overloads. The integration of the M&V system with the smart panel, including CT placements and voltage reference connections, is illustrated in the updated monitoring schematic (Figure 47).

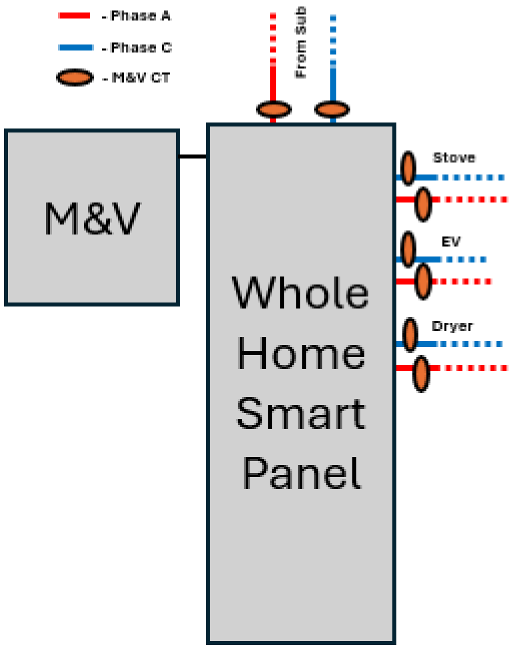


Figure 45: Lodge M&V CT location diagram.

Results

Since no load-shedding events occurred during the monitoring period, the research team returned to the Lodge to intentionally produce conditions that would trigger the smart panel's load-shedding response. The site was configured with a 50 A service limit, and manual overloads were created by operating all inductive cooktops simultaneously along with both the electric vehicle (EV) charger and the clothes dryer. During these induced conditions, peak currents reached approximately 53.2 A on Phase A and 53.8 A on Phase B, representing 6 percent to 8 percent overload beyond the configured limit. The smart panel responded as expected, prioritizing disconnection of the EV circuit before any other load. When testing the cooktop system, activation of all four burners and the oven again exceeded the 50 A threshold, prompting the panel's automated load-shedding feature to disconnect the stove circuit within seconds of the overload condition (Figure 48).

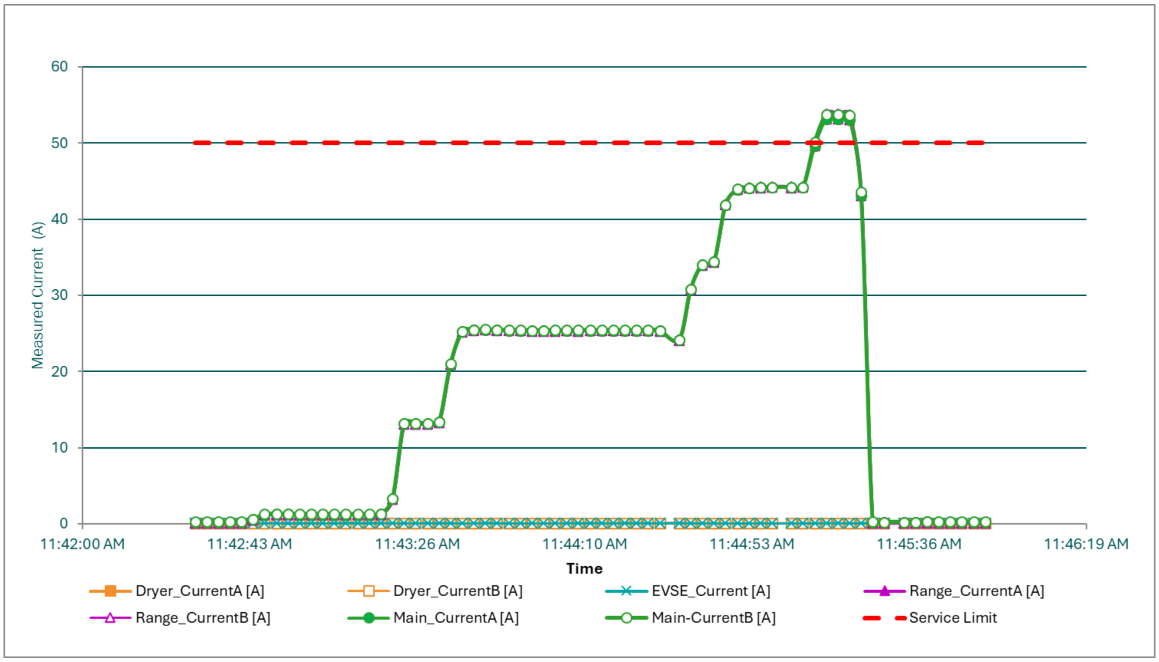


Figure 46: Overcurrent load shed testing of inductive stove—site #2, event #1.

The next manually induced overload condition involved operating the stove just below the service limit, followed by initiating EV charging. This test replicated a realistic household scenario in which one resident is cooking a meal using multiple burners while another arrives home and plugs in their electric vehicle. Under these combined loads, the system recorded peak currents of approximately 56 A on both Phase A and Phase B, corresponding to an overload of roughly 12 percent above the 50 A service threshold. As designed, the smart panel followed its internal load-shedding hierarchy, prioritizing the EV circuit for disconnection once the limit was exceeded. The EV charger was immediately disabled while the stove operation continued uninterrupted, and charging later resumed automatically once the cooking load decreased and the circuit was re-enabled (Figure 49).

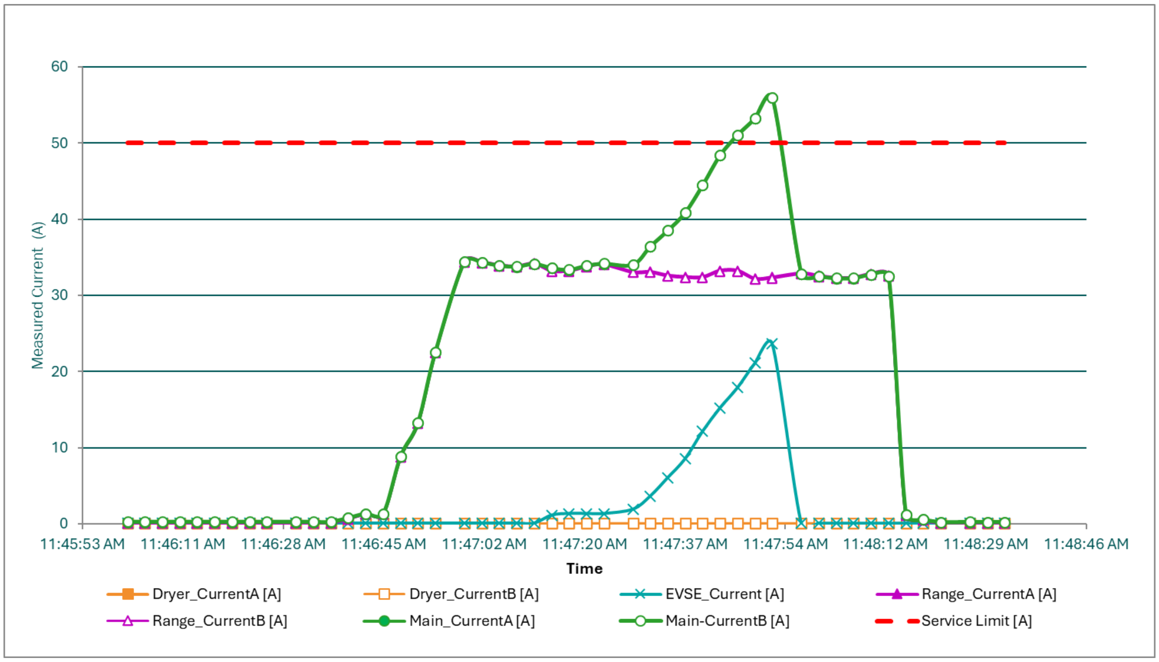


Figure 47: Overcurrent load shed testing of inductive stove and EV —site #2, event #2.

The next test aimed to determine whether the smart panel's software prioritized an EV that was already charging. The research team first connected the EV and allowed it to reach a steady-state charging condition before gradually increasing the stove load. This test represented a typical residential scenario in which an EV is charging when another high-power appliance, such as the stove, is activated. During the event, peak currents reached approximately 55.9 A on both Phase A and Phase B, resulting in an overload of about 11.8 percent above the 50 A service threshold. Consistent with previous results, the smart panel again prioritized the EV circuit for disconnection as the first load to be shed once the limit was exceeded (Figure 50).

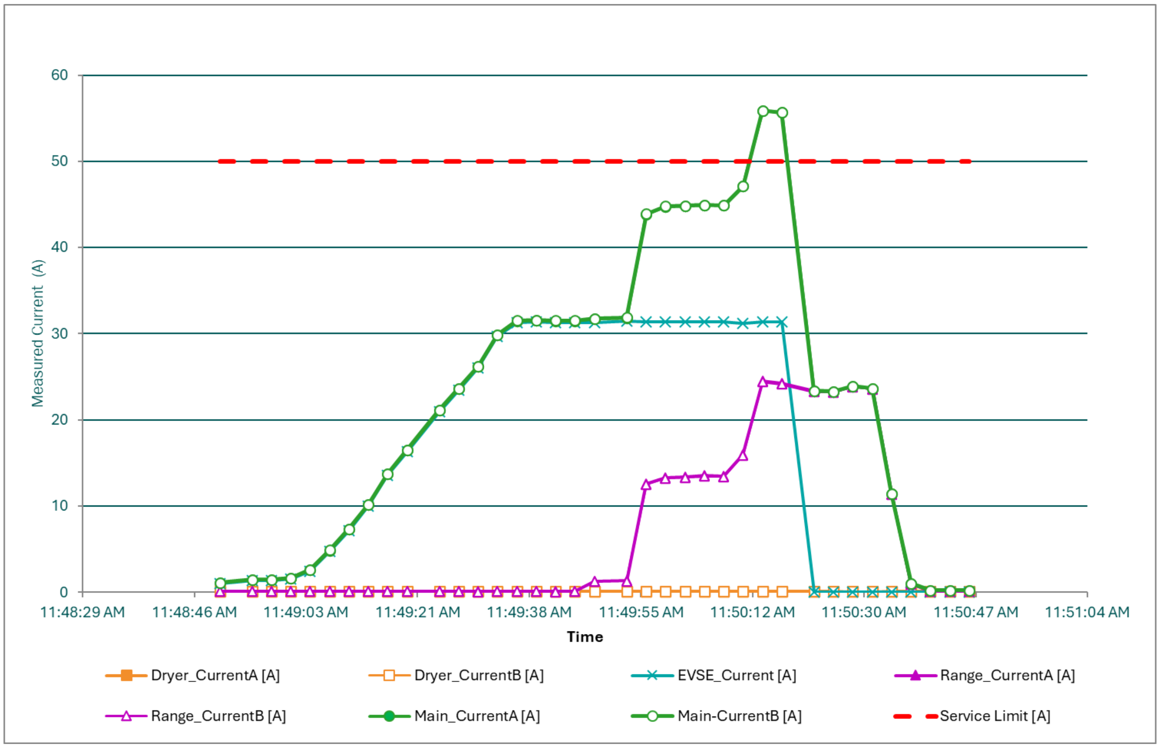


Figure 48: Overcurrent load shed testing of EV and stove—site #2, event #3.

Tests 4 and 5 were conducted consecutively while the dryer circuit—configured as an always-on load drawing approximately 20 A—remained active throughout. In Test 4, the EV charger was connected while the dryer was operating to observe the system's response under dual-load conditions. The system recorded peak currents of approximately 50.1 A on Phase A and 50.5 A on Phase B, representing less than 1 percent overload relative to the 50 A service limit. As expected, the smart panel maintained power to the dryer circuit and automatically disabled the EV circuit to prevent further overload (Figure 51).

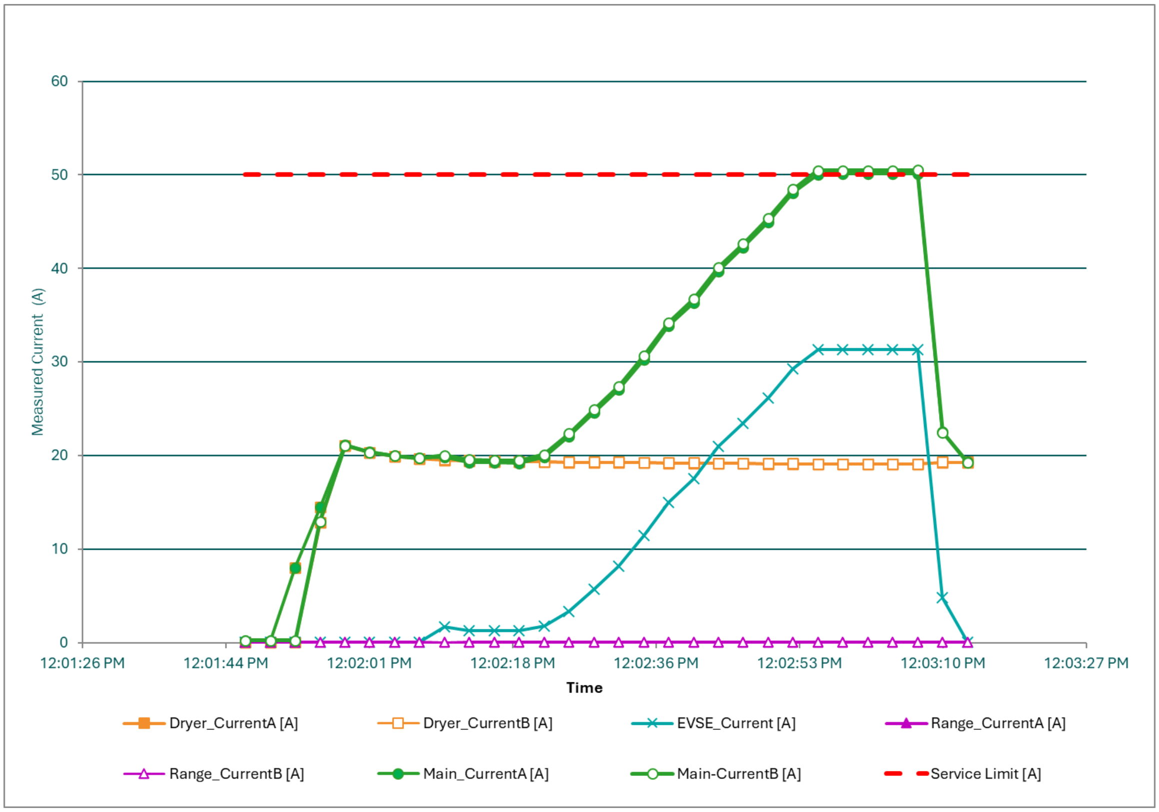


Figure 49: Overcurrent load shed testing of dryer and EV—site #2, event #4.

In Test 5, the same configuration was used, but the stove was energized in addition to the dryer to further stress the circuit. Peak current values increased to 52.4 A on Phase A and 52.7 A on Phase B, corresponding to an overload of approximately 5 percent. The smart panel again behaved as designed, shedding the EV load first to maintain system stability while allowing continuous operation of the active appliances (Figure 52).

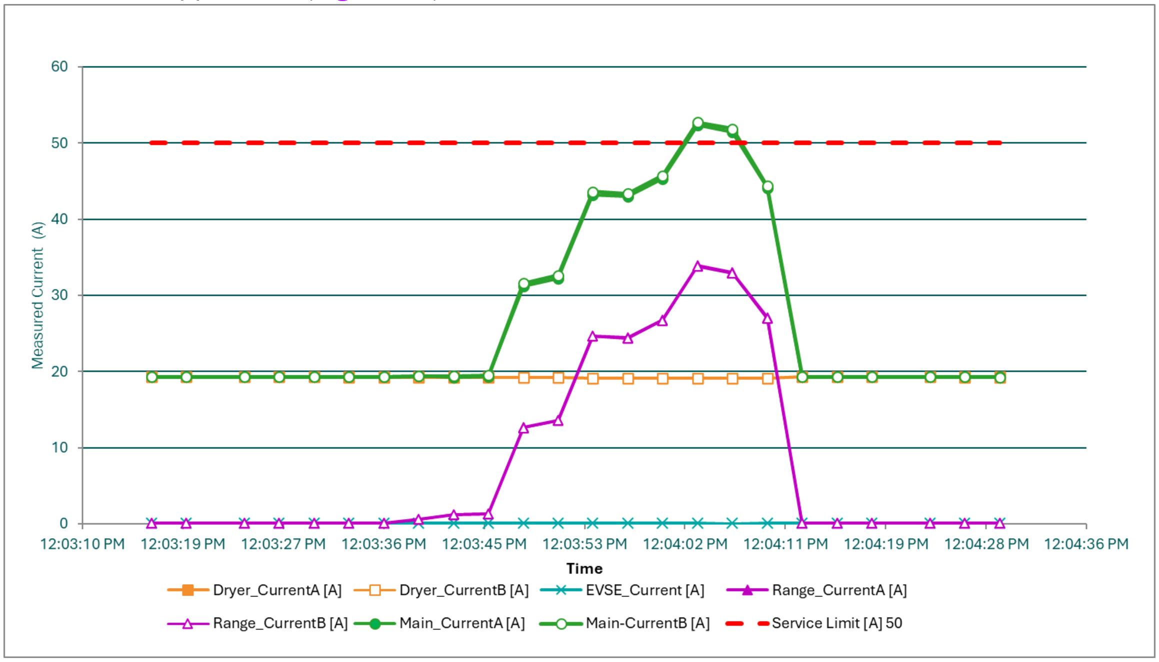


Figure 50: Overcurrent load shed testing of dryer and stove—site #2, event #5.

Site #3

Existing Conditions

Site #3, shown in Figure 53, is a typical 1,500-square-foot single-family home located in San Francisco.

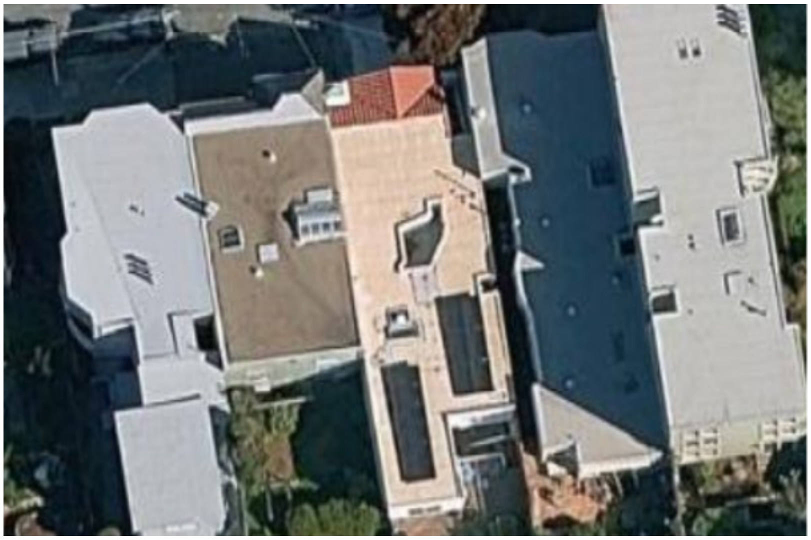


Figure 51: Google Earth view of site #3.

Electrification Plan

ELECTRICAL INFRASTRUCTURE AND LOADS

The residence is served by a 240 V, single-phase, 100 A service. The owner replaced the existing traditional 100 A panel with a new 200 A smart panel when they installed a new solar and battery energy storage system (Figure 54). However, the service is still rated for 100 A.

Figure 52: Main electrical panel for site #3.

The home has an existing Level 2 EV charger connected to the main panel. They are also planning to add a new subpanel for a hot tub. All the other electrical loads represent typical single-family home loads

GAS FIRED APPLIANCES

Site #3 had a gas fired water heater, furnace, standard cooktop range with oven, and a fireplace. The participant is interested in electrifying all the gas fired appliances in future. The existing water heater was A.O. Smith 40-gallon water heater with 40,000 Btu/h input rating (Figure 55).

Figure 53: Existing gas fired water heater at site #3.

ELECTRIFIED LOADS

As part of the electrification measures at site #3, one significant new electrical load was installed: a 65-gallon high efficiency HPWH. To support the installation, a conduit was routed from smart panel to the water heater location for a new 240 V outlet, where the water heater was connected to a dedicated breaker within the smart panel system, consistent with manufacturer specifications. This configuration enabled the water heater to be actively monitored and controlled by the smart panel, ensuring seamless integration into the broader managed load coordination strategy while also providing visibility into real-time circuit-level energy usage.

SMART PANEL INSTALLATION AND CONFIGURATION

The new electrified load at Site 3 was connected to the existing smart panel. The site's remaining loads, along with the EV charger, which was already installed prior to the project, are integrated into the smart panel system.

Figure 54: HPWH installed at site #3.

Installation Findings

Site#3 already had an LBT system installed prior to pilot. One installation findings was that the previous installer of the LBT set the panel size 200 A in the smart panel app, when the service was limit was 100 A. This could have resulted from the smart panel model being 200 A capacity, even though the service was rated at 100 A. We also found that the service-upgrade-avoidance feature to shed load was not enabled.

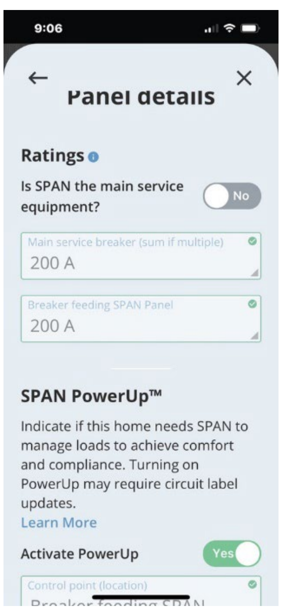


Figure 55: Incorrect service set in the app at site #3.

M&V and Test Plan

The M&V plan and test strategy for this home was largely constrained by the short time we had to monitor the home. The project team conducted a SPT which would concisely test LBT's load-balancing ability as well as LBT's ability to shed load when close to a set service panel threshold. Prior to the SPT test day, we confirmed access to the homeowner's LBT via manufacturer AP. We then asked homeowner to turn on all large loads in their home to identify each appliance load peak individually. We used the individual appliance peaks for two purposes:

- Characterize a worst case system load
- Determine the test appliance order in which three to four appliances would be turned on with the final appliance being the trigger that would put overall system over the previously lowered service panel threshold.

Table 27: SPT test load order—site #3.

Turn on order	Appliance	Load amps	Cumulative load test amps
Load 1	EV	13	13
Load 2	HPWH	22	35
Peak load trigger at 50 A			
Load trigger	Dryer	11	46

Results

The project team had some challenges the day of the SPT test. The homeowner let us know the day of test that his EV charger had a built-in dynamic charging feature that lowers the charging rate (amperage) if the total panel reaches the threshold. Therefore, we lowered service panel threshold to 50 A and used a Level 1 EV charger that the homeowner still happened to have. The level 1 EV charger would show under the remaining loads in the graph. We ran the SPT with the same appliance order – Level 1 EV charger followed by HPWH in electric resistance mode and electric dryer. The HPWH was turned on at 1:57 p.m. and all loads continued to operate till 2:02 p.m. when the HPWH was paused (see Figure 58 and Figure 59). At 2:03 p.m. the Level 1 EV charger was turned off and the HPWH resumed operation. It is worth noting that the total panel draw, as can be seen in Figure 59, did not reach the threshold limit (50 A) during the test. The project team is working with the manufacturer to confirm how the site's solar and battery energy storage system are integrated with the smart panel, and to determine if that impacts the total panel draw.

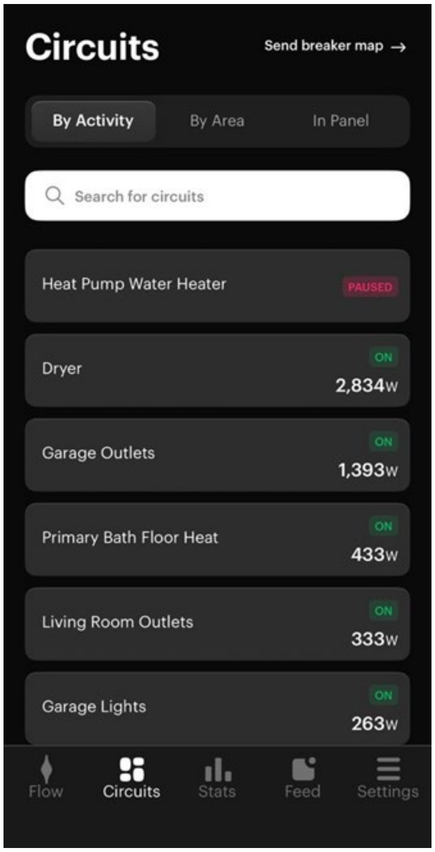


Figure 56: Smart Panel User App Display—site #3.

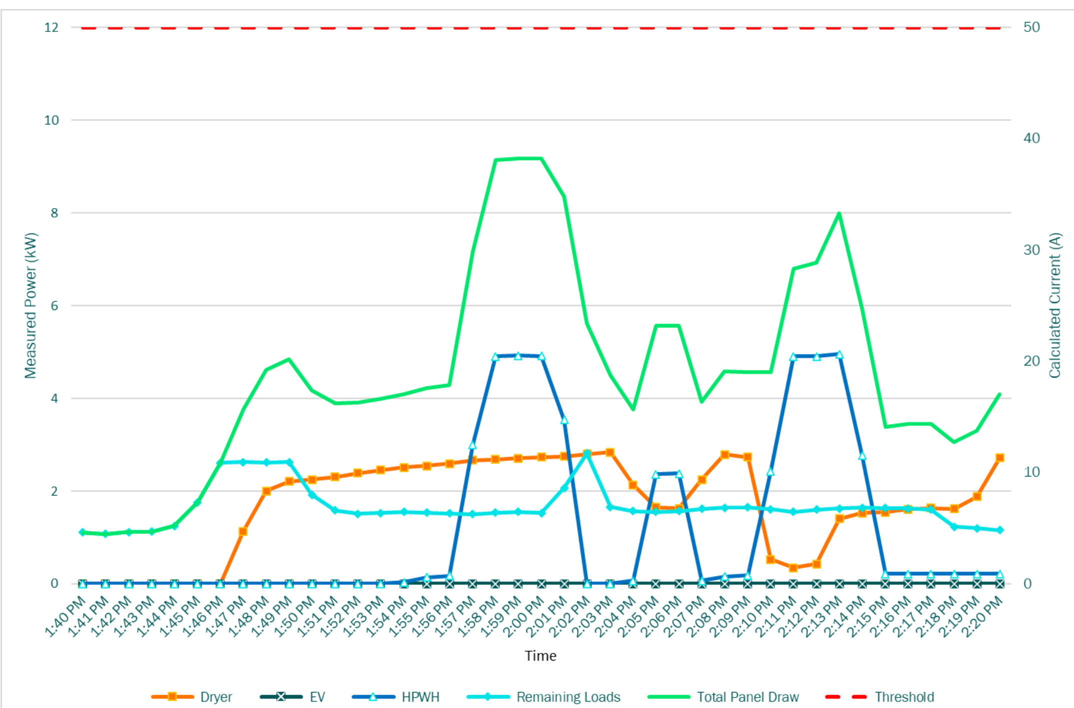


Figure 57: Smart panel SPT event—pilot demonstration site #3.

Site #4

Existing Conditions

Site #4 is a typical 1056 square foot single-family home located in Rocklin, as shown in Error! Reference source not found..

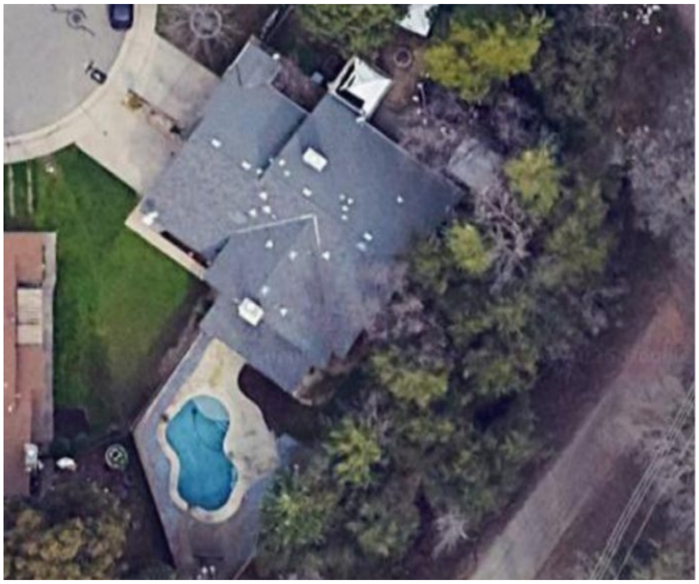


Figure 58: Google Earth view of site #4

Electrification Plan

ELECTRICAL INFRASTRUCTURE AND LOADS

The residence was served by a 240 V, single-phase, 125 A service. The electrical panel was obsolete and over 40 years old and had very limited open breaker slots (Figure). The home has no solar or battery energy storage system.

Figure 59: Main electrical panel for site #4.

The home has an existing Level 2 EV charger connected to the main panel. All the other electrical loads represent typical single-family home loads.

GAS FIRED APPLIANCES

Site #4 had a gas fired water heater, a furnace, and a clothes dryer. The existing water heater nameplate information was not available and is estimated at 40 gallons, as shown in Figure .

Figure 60: Existing gas fired water heater at site #4.

ELECTRIFIED LOADS

The LBT selected for this project was a smart panel system, although any smart solutions may have worked for this homeowner. We selected this system because the homeowners obsolete panel would be ideal candidate for a new smart panel and it would be a good representation of all LBT solutions. The electrification measure for this home was a 40-gallon high efficiency HPWH. To support the HPWH installation, a conduit was routed from the smart panel to the water heater to a new 240 V outlet, where the water heater was connected to a dedicated breaker within the smart panel system, consistent with manufacturer specifications. This configuration enabled the water heater to be actively monitored and controlled by the smart panel, ensuring seamless integration into the broader managed load coordination strategy while also providing visibility into real-time circuit-level energy usage.

SMART PANEL INSTALLATION AND CONFIGURATION

The new electrified load at site #4 was connected to the new smart panel. The site's remaining loads along with the EV charger, which was already installed prior to the project, was also integrated into the smart panel system.

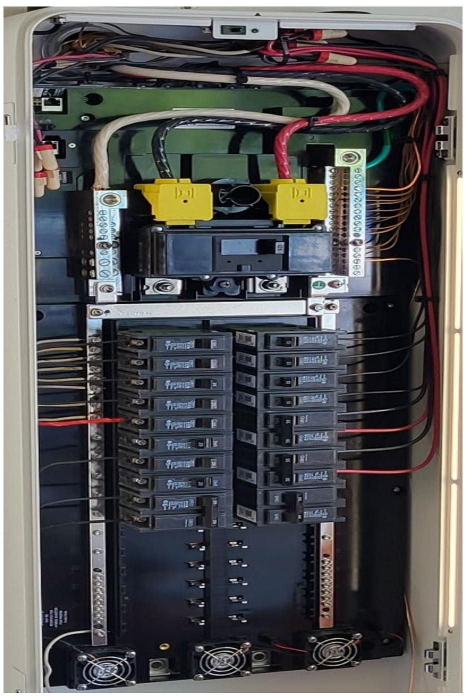


Figure 61: HPWH installed at site #4

Installation Findings

The installer of the LBT did not set up the service-upgrade-avoidance feature that would manage service panel threshold at the time of the installation. This highlights the importance of contractor training.

M&V and Test Plan

The M&V plan and test strategy for this home was largely constrained by the short time we had to monitor the home. The contractor spot checked the power draw for the major appliances/load to validate the manufacturer readings.

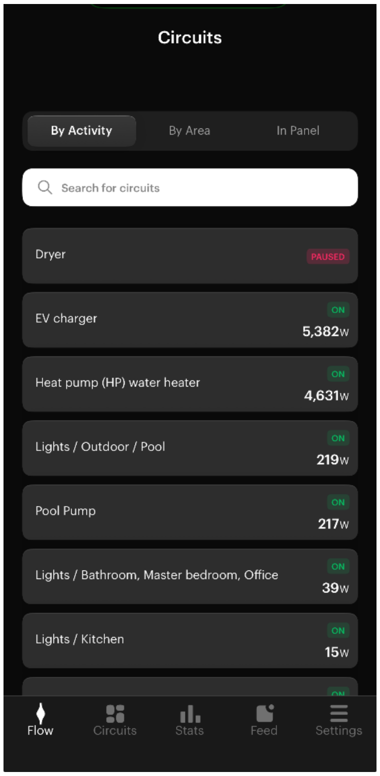
Table 28: SPT test load order—site #4.

Turn on order	Appliance	Load amps	Cumulative load test amps
Load 1	EV	21	21
Load 2	HPWH	19	41
Peak load trigger at 60 A			

Turn on order	Appliance	Load amps	Cumulative load test amps
Load trigger	Dryer	11	64

Results

After assuring we had remote access to the homeowner's LBT system, we coordinated with homeowner on a day and time to conduct this SPT test and informed him of the procedures of the test. We were primarily interested in how the LBT would shed load(s) as necessary to maintain the threshold. On the day of the test, we did experience some challenges as previously tested loads were drawing less current than what we had measured. We had to reduce the service threshold from 60 A to 50 A in order to trigger the event. Table 28 shows the order the appliances were turned and the max energy use of each appliance. The test began at 11:37 a.m. by turning on the EV charger, followed by the HPWH at 11:46 a.m. The dryer was turned on at 11:49 a.m. and one minute later, the system threshold was reached. This resulted in the dryer being turned off at 11:51 a.m. The test concluded 11:51 a.m., but we continued to monitor the system for a few minutes. Figure shows that the EV was shed at 11:55 a.m. when the total panel draw reached the threshold. The EV charger resumed operation when the total panel draw was maintained below the threshold and there was enough capacity to accommodate the EV charger without exceeding threshold.



Smart Panel User App Display—pilot demonstration site #4.

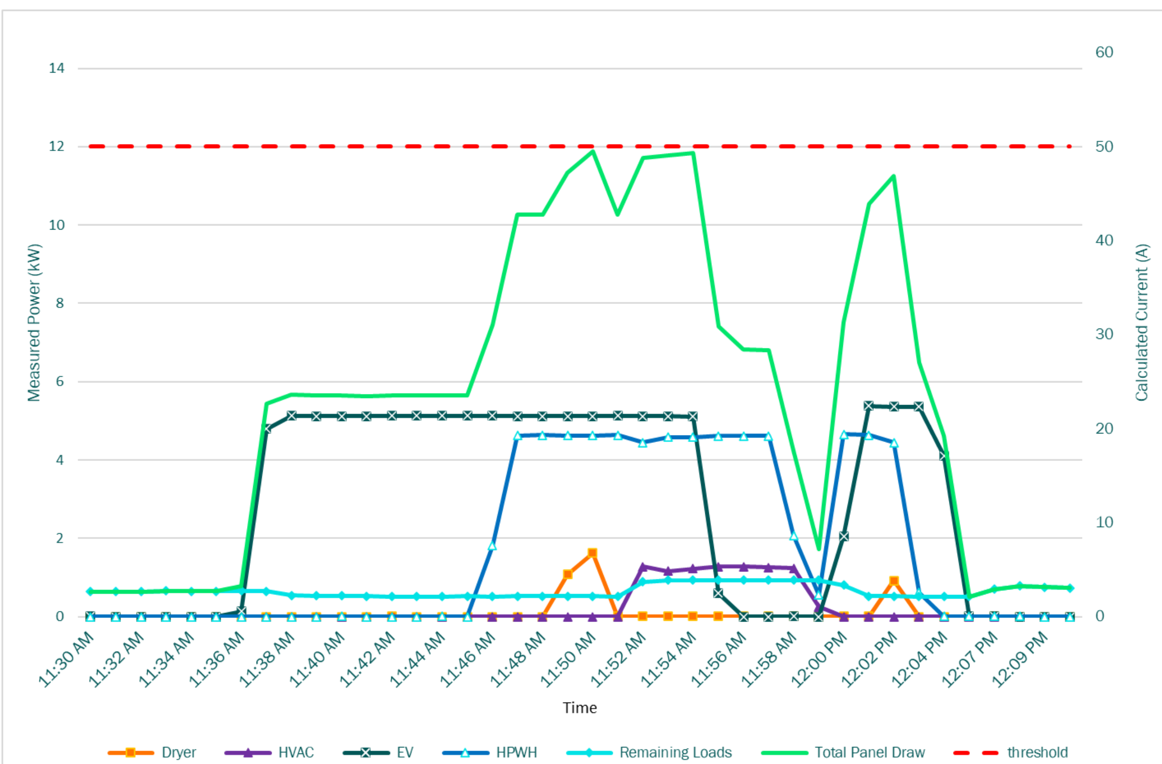


Figure 62: Smart panel SPT event—pilot demonstration site #4.

Appendix F: Pilot Demonstration – Smart Subpanel

Sites #5 and #6

Existing Conditions

Sites #5, Primrose, and #6, Heron, are two units of a duplex residence at the Bodega Marine Lab, as shown in Figure 65. Each unit is a fully furnished two-bedroom, two-bathroom apartment designed for family accommodation or long-term stays. The duplex provides all essential amenities and functions as a home-like environment for extended visits, making it a representative setting for residential electrification retrofits.

Figure 63: Arial view of sites #5 and #6.

ELECTRICAL INFRASTRUCTURE AND LOADS

Sites #5 and #6 are located within a two-unit residential duplex, with each unit configured as a three-bedroom, two-bathroom dwelling. Both units are currently energized through a single 100 A, single-phase, 208 V electrical service panel. This shared main distribution panel supplies power to both units and is in a small exterior-access utility room that also houses the gas-fired water heater. The shared nature of this electrical infrastructure presents a unique baseline condition compared to site #1, as all metering, overcurrent protection, and branch circuit distribution for both units originate from the same panel enclosure (Figure 66).

Figure 64: 100 A 208 V single phase electrical panel for sites #5 and #6.

Prior to the electrification pilot, the electrical demand across both duplex units consisted primarily of lighting, receptacles, and standard plug loads typical of single-family residences. Each unit includes a full kitchen which had a gas range and oven (covered in the Gas Appliances section) but does not include on-site laundry facilities. While there is no dedicated electric dryer load, participants may use the nearby laundry room, resulting in potentially lower baseline energy consumption compared to residences with on-site laundry.

Despite this, overall electrical usage patterns were expected to closely resemble typical single-family residential behavior. Occupants likely engage in common activities such as using small kitchen appliances, televisions, computers, and personal electronics. Given the temperate climate, there are no central HVAC systems, and primary heating needs are typically met through localized portable electric space heaters used intermittently during colder periods. Cooling demand is minimal, and air conditioning systems were not observed on-site.

Although the shared panel is sized at 100 A total, the circuit layout is densely populated, serving two independent households within the same enclosure. Branch circuit subdivision is significant, supporting kitchen loads, general lighting, receptacles, and bathroom circuits for both residences. This arrangement, while sufficient to support historical load profiles, limits panel capacity and presents potential constraints for integrating additional high-power appliances or managed load control systems without targeted infrastructure upgrades or a complete panel reconfiguration.

The baseline load assessments for these sites suggest an overall modest peak demand, largely consistent with typical plug-driven residential usage rather than large appliance or HVAC-intensive profiles. As with site #2, the electrification pilot introduced the opportunity to measure and analyze detailed circuit-level load behavior; however, site #5 and site #6 provided a valuable contrast by representing lower baseline energy usage scenarios within a shared electrical infrastructure.

GAS FIRED APPLIANCES

Sites #5 and #6 were each equipped with residential gas ranges prior to the electrification pilot. These appliances, similar to those at site #2, consisted of a four-burner cooktop with an integrated oven and served as the primary cooking appliances for both units.

An atypical feature of this site's configuration was the presence of a single shared gas-fired water heater located in the exterior-access utility room housing the main electrical panel. This single water heater served both units and supplied all four showers within the duplex. This setup differs from typical duplex designs, where each unit is commonly equipped with its own dedicated water heating system.

Additionally, there was no existing electric vehicle (EV) charging infrastructure on-site, and aside from standard kitchen appliances and typical plug loads, no other major electric appliances were observed in either unit prior to the pilot.

Electrification Plan

The second and third sites, referred to as site #5 (Primrose) and site #6 (Heron), are duplex-style faculty housing units at Bodega Marine Lab. Each unit contains three bedrooms and two bathrooms, and a private kitchen. The two units occupy opposite sides of a shared structure but are served by a common main service panel (Figure 67).

Figure 65: Arial image of sites #5 and #6 showing EV charger installation location.

ELECTRIFIED LOADS

As part of the electrification measures at site #5 and site #6, two significant new electrical loads were installed at each unit: a Frigidaire 30-inch induction range with integrated air-fry capabilities and an Autel MaxiCharger Home Series Level 2 EV charger. These installations required new conduit runs, properly sized conductors, and dedicated overcurrent protection to ensure safe integration into each unit's smart subpanel infrastructure, which manages and coordinates the connected loads independently per unit.

The Frigidaire induction range was selected for its energy efficiency and compatibility with the 120/208 V single-phase service used at the pilot sites (Figure 68). The appliance features a four-element induction cooktop and integrated convection oven, providing rapid and controlled heating while maintaining a cooler cooking surface compared to traditional gas or resistive electric ranges.

To support the installation, conduit was routed from each smart subpanel to the stove location, where the ranges were connected to dedicated 50 A breakers, consistent with manufacturer specifications. This configuration enables the induction ranges to be actively monitored and controlled downstream of the Lumin panels, ensuring seamless integration into the managed load coordination strategy while providing real-time circuit-level visibility into energy usage.

Figure 66: 50 A inductive cooktop installed at site #5.

The second major installation was the Autel MaxiCharger Home Series Level 2 EV charger, designed for residential applications and optimized for reliable single-user charging. At sites #5 and #6, the chargers were installed on the exterior walls closest to the duplex's shared parking area, ensuring convenient access for residents while minimizing conduit length and installation complexity (Figure 69). Newly routed conduit runs connected the chargers to each unit's smart subpanel, with conductors sized for a 40 A breaker and configured to deliver a 32 A continuous charging current during pilot testing.

Figure 67: Both 32 A Level 2 EV charger installed at sites #5 and #6.

The integration of these electrified loads required careful planning to ensure conduit sizing, overcurrent protection, and panel capacity were aligned with both manufacturer specifications and electrical code requirements. By routing the induction ranges and EV chargers through the Lumin Smart Panels, the project enabled real-time monitoring, automated circuit-level control, and dynamic coordination of load events. Together, these installations represent a significant expansion of the duplex units' overall electrical demand.

SMART SUBPANEL INSTALLATION AND CONFIGURATION

To enable active load monitoring and dynamic circuit-level control at sites #5 and #6, two smart subpanels were installed—one dedicated to each unit within the duplex (Figure 70). The two units share a single main service panel, but each unit's dedicated smart subpanel manages its own connected loads independently.

Figure 68: Smart subpanel installation at the duplex.

During installation, the smart subpanels were wired downstream of the shared main service panel and configured to manage critical high-power loads, including the induction ranges and EV chargers in each unit. Each smart subpanel was fitted with branch circuit CTs for load monitoring and control. A key distinction at this site is that the main service CTs for both smart subpanels are installed on the same set of incoming service conductors, resulting in both panels monitoring the total site load

(Figure 71). The configuration is designed to ensure the 100 A shared service limit is never exceeded.

Figure 69: Completed installation of both smart subpanels at sites #5 and #6.

Each smart subpanel operates autonomously, controlling its own unit’s critical circuits while communicating real-time usage data to the smart subpanel cloud platform for monitoring and management. This separation ensures that, despite the shared main panel, control of the induction ranges, EV chargers, and other monitored circuits remain fully isolated between the two units (Figure 72).

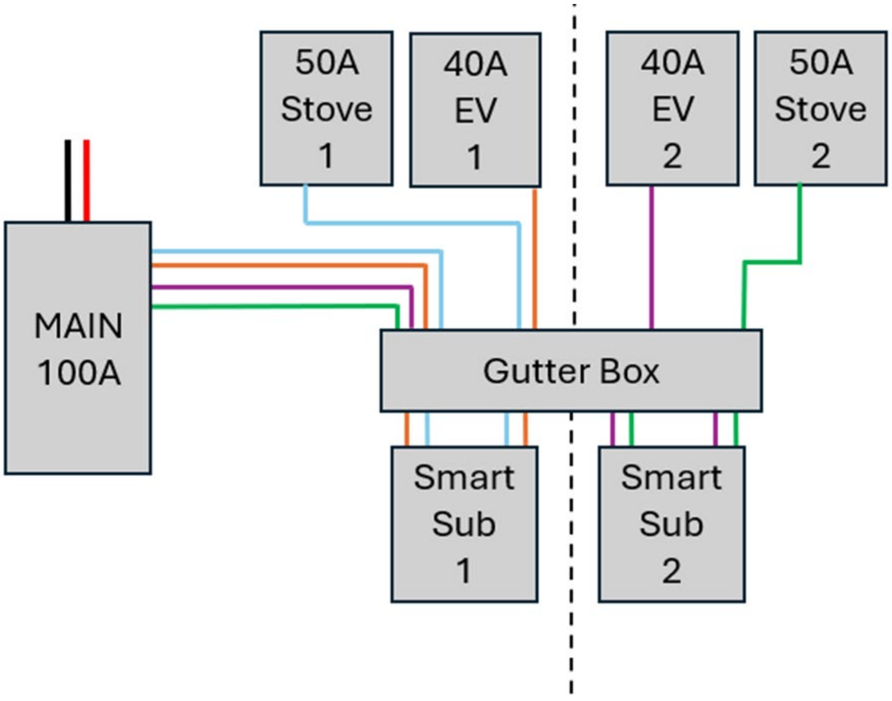


Figure 70: Electrical schematic showing the shared main service panel, dedicated smart subpanels for sites #5 and #6, and connected downstream loads.

To further enhance operational safety, a 100 A service limit was configured within each smart subpanel (Figure 73). This limit ensures that, regardless of simultaneous load events, the combined draw of both units remains within the available service capacity. In the event of potential overcurrent conditions, the smart subpanels can autonomously shed or delay noncritical loads to maintain compliance with site constraints.

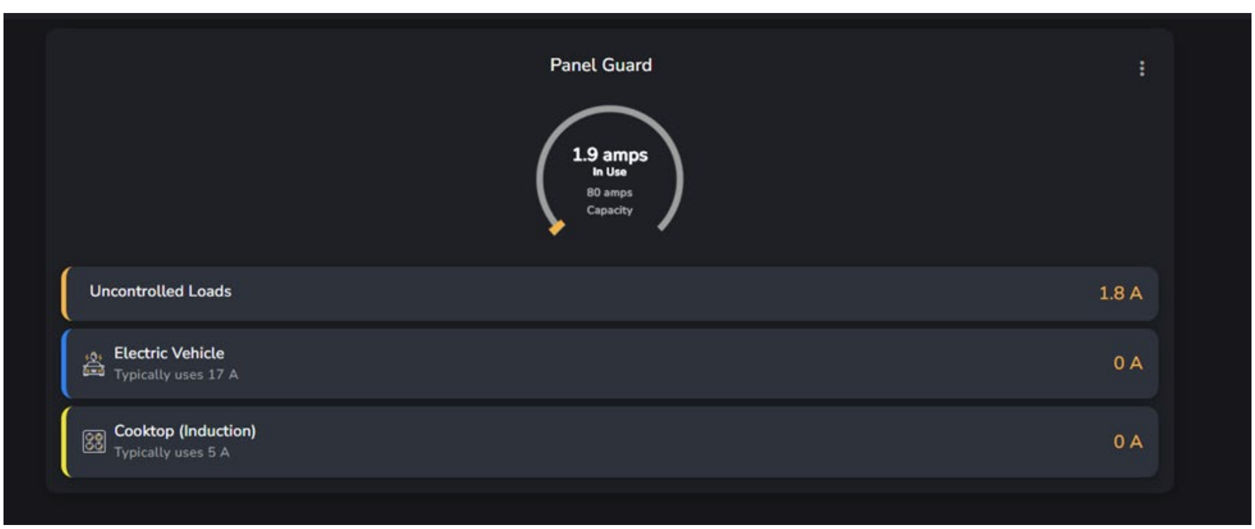


Figure 71: Screenshot from the Smart Subpanel app showing the configured 100 A shared service limit for the duplex.

This dual-smart subpanel deployment represents a unique configuration within the project, demonstrating how managed load coordination can be implemented in shared-service environments while still maintaining per-unit control and ensuring that maximum electrical load is not exceeded.

Installation Findings

At the duplex units, installation of the smart subpanels proceeded without mechanical or wiring issues. All electrical connections were inspected prior to energizing the systems, and both panels powered on as expected. Upon commissioning, the systems were configured with 100 A total service limits. Initial attempts to connect through the campus-managed Wi-Fi network revealed intermittent communication failures caused by firewall restrictions that limited application access. These connectivity issues were resolved by deploying a dedicated cellular hotspot, which restored reliable communication between the smart subpanels, the monitoring gauges, and the cloud-based control platform.

Subsequent testing also revealed that the smart subpanels occasionally booted with relays defaulting to an open state following power restoration during generator switchover events. This behavior was reported to the manufacturer and later corrected through a firmware update, ensuring that all relays reliably returned to their last known state after power interruptions. Since the update, both duplex systems have remained stable, and CLTC continues to monitor connectivity and performance.

M&V and Test Plan

The M&V systems at sites #5 and #6 were designed to provide high-resolution, circuit-level energy monitoring across both units within the duplex. While the configuration closely mirrors the site #1 implementation, the presence of a shared main service panel introduced a slight variation in monitoring strategy.

At the core of the system is an eGauge Pro monitoring device configured to collect energy data at 1-second granularity, aggregated into 1-minute intervals for 2 months and 1-hour intervals for long-term storage, up to 10 years. The eGauge connects via cellular modem to a secure cloud platform, where all data is stored and accessed for analysis and reporting (Figure 74).

Figure 72: M&V hardware installed at sites #5 and #6.

The M&V system monitored the main service panel inputs, capturing the combined energy consumption of all downstream circuits across both units. In addition, four dedicated branch-circuit CTs were installed to separately track the induction ranges and Level 2 EV chargers, enabling detailed visibility into the electrification loads introduced by the pilot program. These monitored branch circuits were wired downstream of the smart subpanels, meaning M&V captured the actual consumption commanded through each unit's smart subpanel-controlled relay while still providing visibility into overall site-level energy usage (Figure 75).

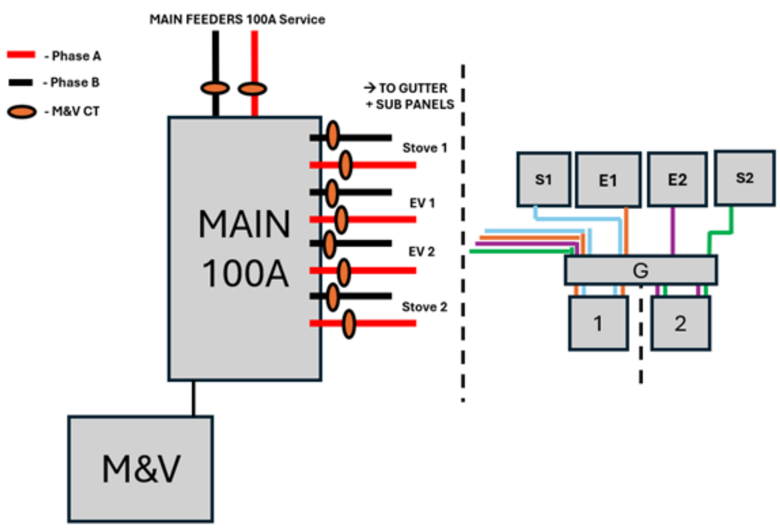


Figure 73: System diagram showing M&V current transformer placement on the shared main panel inputs and dedicated monitoring of EV chargers and induction ranges upstream of smart subpanel 1 and smart subpanel 2.

Beyond these circuit-level differences, the hardware and data collection scheme remained identical to the site #1 deployment. The eGauge platform monitored the smart subpanel-controlled environment, which enabled comprehensive measurement of both aggregate energy demand and individual electrification loads. This configuration ensured the pilot captured the full operational impact of EV charging and induction cooking upgrades while maintaining real-time visibility into duplex-level consumption patterns.

The research team continuously monitored data streams from all three -eGauge systems installed at the pilot sites (one for the smart panel at site #1 and one for each subpanel at sites #5 and #6). Each device captured energy data at one-second intervals, aggregated into one-minute views for long-term storage, while preserving access to full second-by-second records.

Data collection will continued for one month to establish baseline load profiles. Analysis characterized:

- Typical daily and weekly usage patterns, including timing of major appliances such as induction ranges and EV chargers.
- The relationship between appliance use and service loading, with emphasis on periods where demand approaches the service rating of each site.
- Distinctions between weekday and weekend usage, including identification of peak and minimum demand periods.

A primary objective was to detect any instances where site demand approached the configured service limit and triggered a smart panel load-shedding event. These events were identified in the eGauge data by observing currents rising toward the programmed threshold, followed by rapid reductions in load. Cross-verification was conducted through the smart panel and smart sub-panel applications to confirm that the panels initiated the shedding response. Metrics of interest included the frequency, timing, and duration of these events.

The pilot also evaluated occupant interaction with load shedding. Through follow-up engagement, the team assessed whether occupants experienced confusion or frustration, and whether their behavior adapted over time—for example, shifting EV charging or cooking patterns to avoid triggering load control.

If no natural load-shedding events were recorded within the month-long observation period, the research team will conduct controlled field tests. This will involve bringing an EV on site and deliberately operating high-demand appliances concurrently to exceed the programmed thresholds, thereby forcing a load-shed event. These staged tests will provide direct verification of system functionality under real-world operating conditions.

Results

The next set of tests was conducted at sites #5 and #6, located on the adjacent sides of the duplex building at the BML housing property. The sixth test, performed at the Heron unit, aimed to quantify the full power range of the stove. The load-limiting feature was intentionally disabled for this test, as the stove's maximum draw of approximately 50 A did not exceed the 80 A service limit configured at this site. Although no overload condition was triggered, this test provided useful reference data, illustrating the stove's total power consumption when all four burners and the oven were simultaneously preheating (Figure 76).

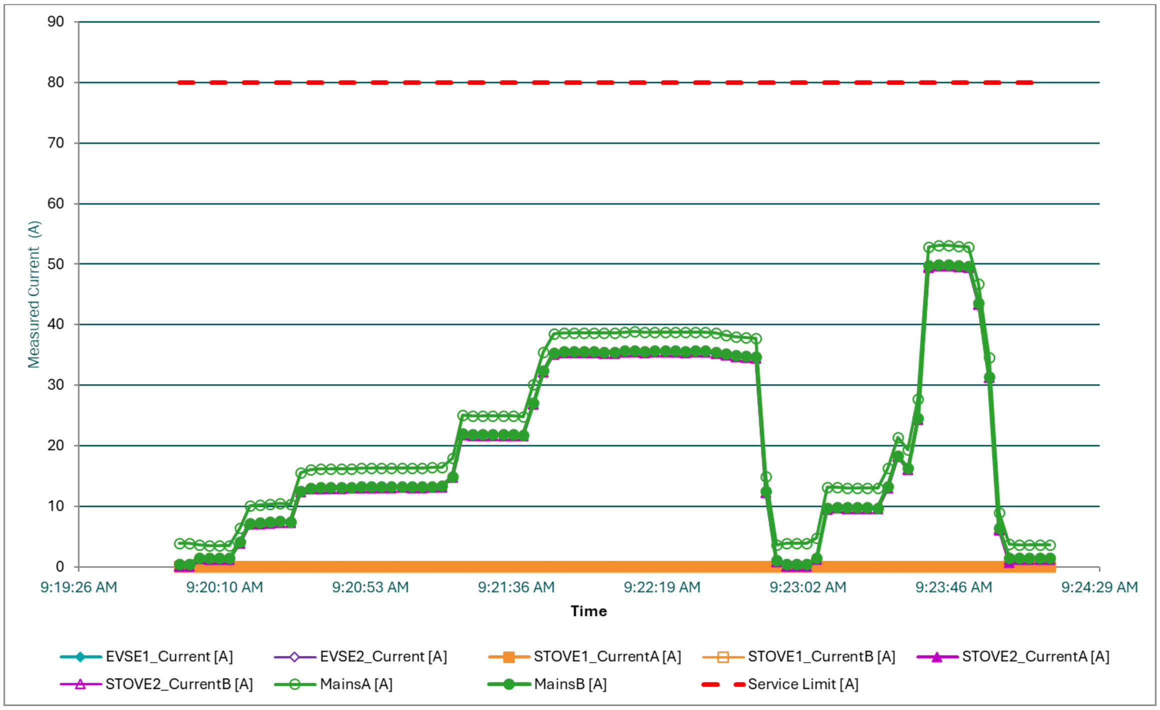


Figure 74: Overcurrent load shed testing of stove—site #5 event #1.

Test 7 and 8 aimed to reproduce the same operating conditions evaluated at the Lodge, but this time using the smart subpanel system rather than the smart panel. In Test 7, all stove burners and the oven were activated to full power, followed by connecting the EV charger. The system recorded peak currents of approximately 80.4 A, corresponding to a slight overload of about 0.5 percent above the 80 A service limit. As expected, the smart sub-panel automatically disabled the EV circuit, bringing total demand back below the service threshold while allowing cooking to continue uninterrupted (Figure 77).

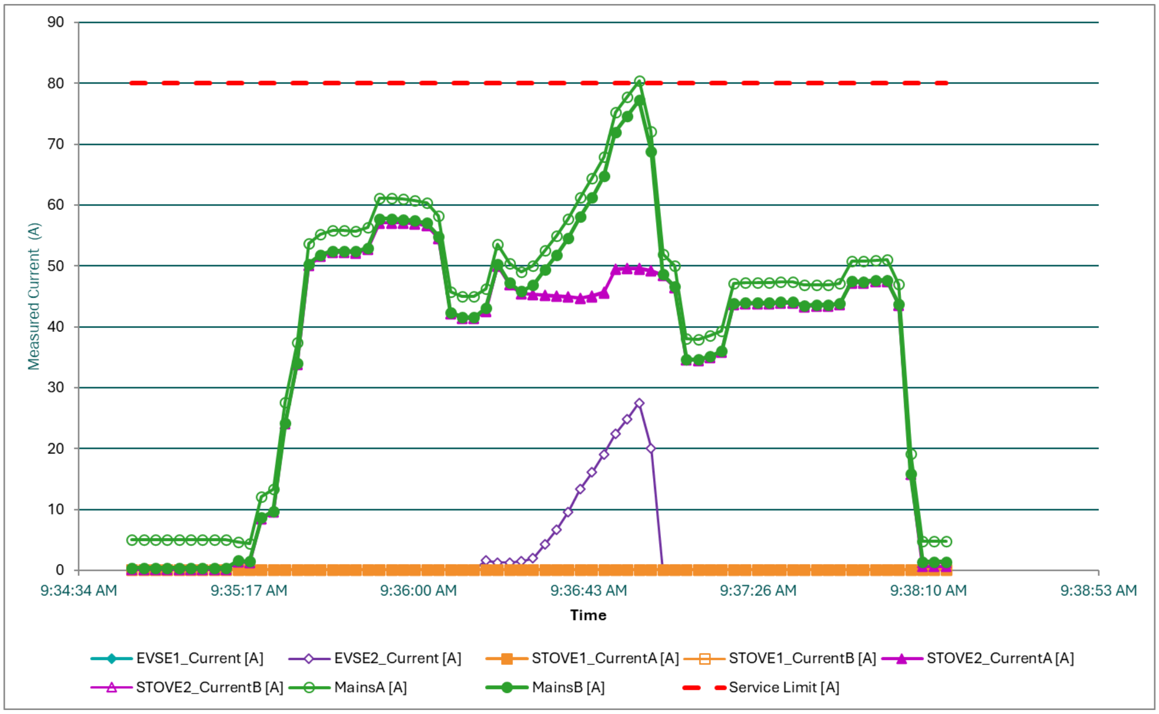


Figure 75: Overcurrent load shed testing of stove and EV—site #5 event #2.

In Test 8, the sequence was reversed—EV charging was initiated first, followed by activation of the stove. The system again reached approximately 80.5 A, producing an overload of roughly 0.6 percent, and responded in the same manner by disconnecting the EV circuit. Although the smart subpanel technology does not include an explicit circuit priority ranking like the smart panel installed at the Lodge, it was notable that the EV circuit was still consistently selected as the first load to shed, regardless of the order in which appliances were activated (Figure 78).

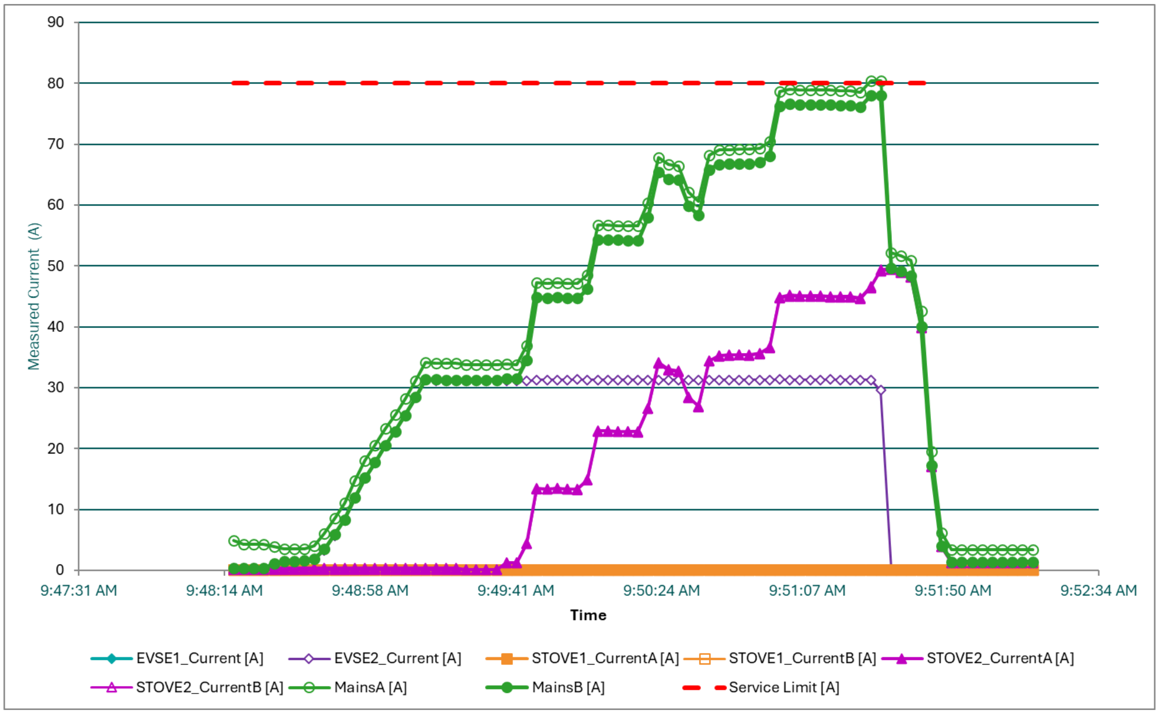


Figure 76: Overcurrent load shed testing of EV and stove—site #5 event #3.

Test 9 replicated the stove ramp test previously conducted at the Heron unit but was performed instead at the Primrose side of the duplex. The objective was to verify whether the stove in this unit exhibited a comparable load profile under full operation. As expected, the measured power characteristics closely mirrored those recorded in Test 6, confirming consistent appliance performance and circuit behavior across both units. No overload conditions were observed during this test (Figure 79).

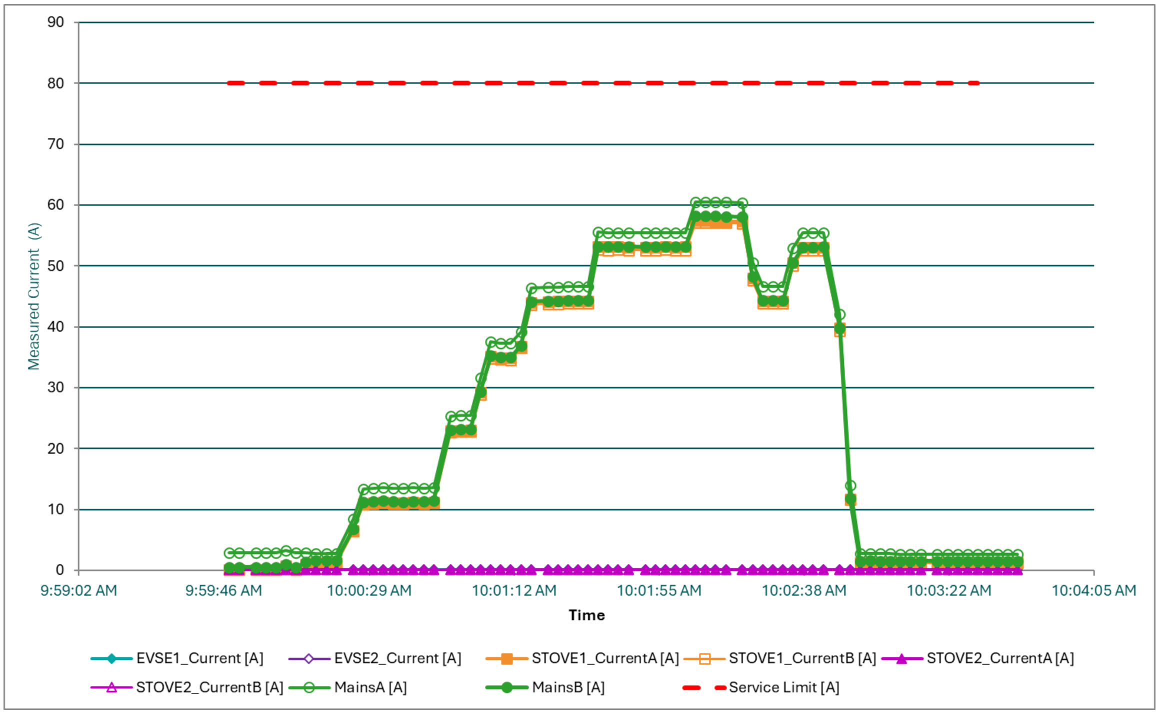


Figure 77: Overcurrent load shed testing of stove—site #6 event #1.

Tests 10 and 11 were performed at the Heron unit following the same procedures used in Tests 7 and 8. In Test 10, the stove was operated first, followed by initiation of EV charging, while Test 11 reversed this sequence—beginning with EV charging prior to stove ramp-up. In both cases, the system behavior was consistent with earlier observations: the EV circuit was automatically disabled once the combined load exceeded the service threshold, allowing the stove operation to continue without interruption (Figure 80) (Figure 81). Peak currents reached approximately 79.7 A in Test 10 (a slight 0.4 percent margin below the 80 A limit) and 80.7 A in Test 11 (about 0.9 percent overload). These results further confirmed the system's consistent response in prioritizing the EV circuit for load shedding under near-limit conditions.

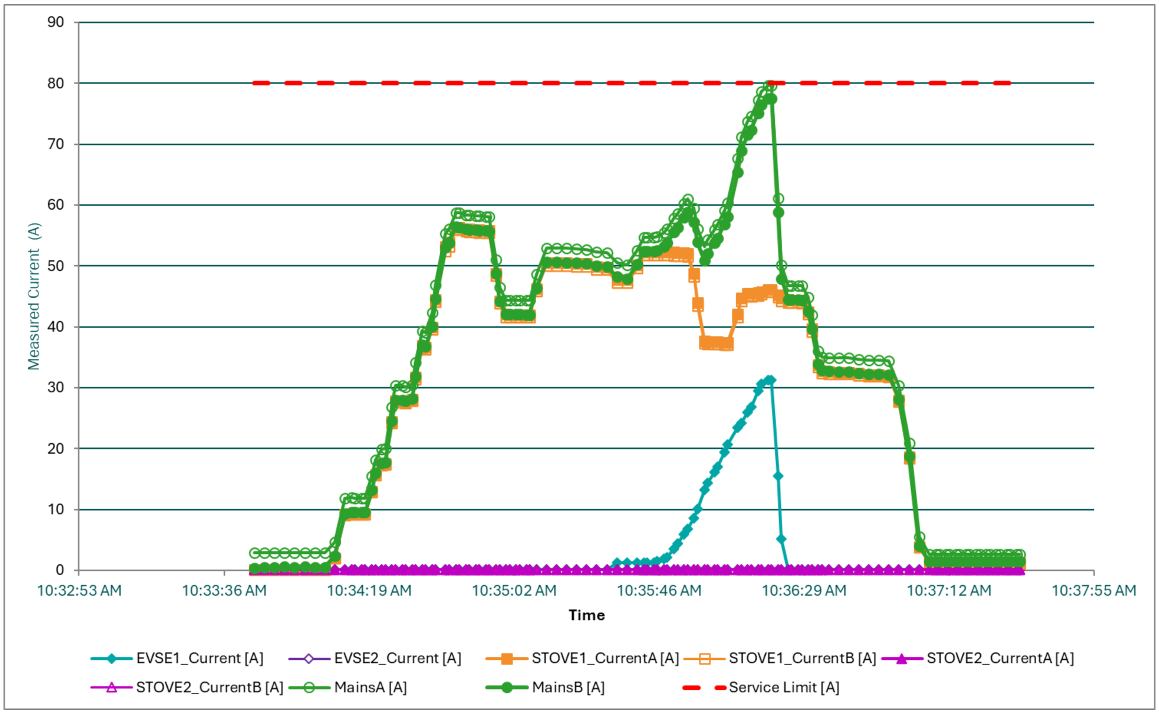


Figure 78: Overcurrent load shed testing of stove and EV—site #6 event #2.

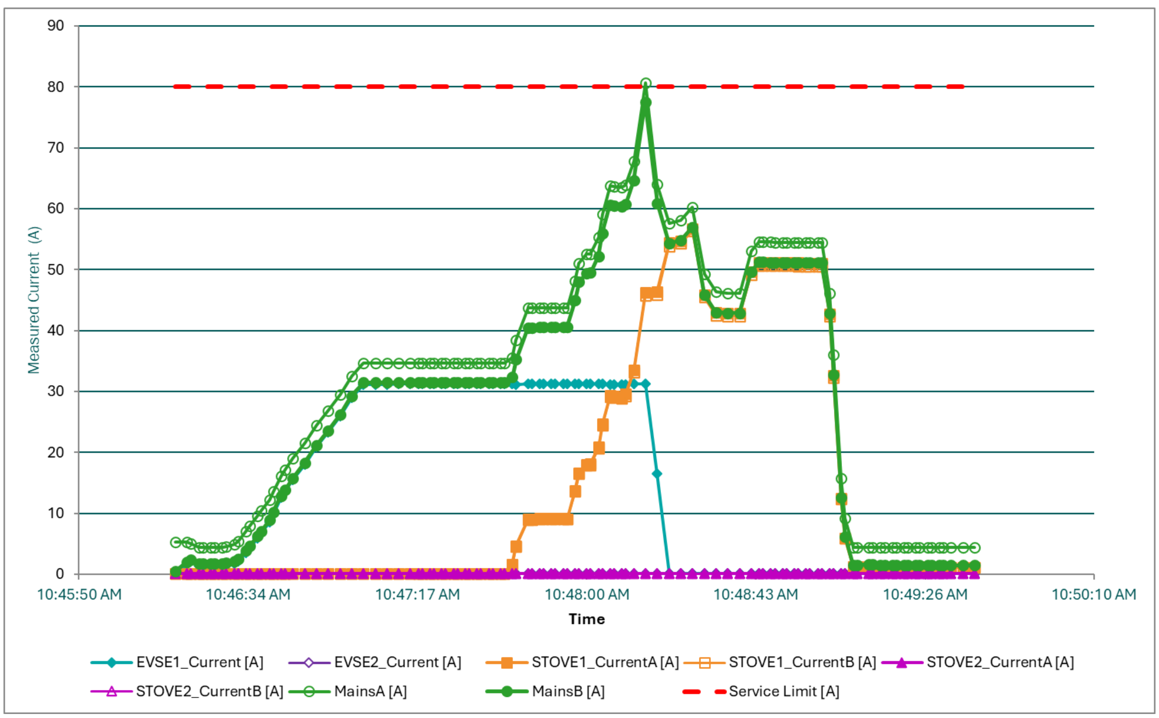


Figure 79: Overcurrent load shed testing of EV and stove—site #6 event #3.

Test 12 was designed to observe edge-case behavior in which both sides of the duplex simultaneously drew enough current to exceed the main service panel's capacity. Researchers gradually increased the power consumption of both stoves until an overload condition occurred, monitoring for override actions from either smart subpanel. The combined loads produced peak currents of approximately 96.7 A on Phase A and 93.6 A on Phase B, corresponding to overloads of 20.8 percent and 17.0 percent, respectively, relative to the 80 A service limit. The system responded within roughly 9 seconds, with each smart subpanel independently disabling its respective stove circuit.

While this outcome was less ideal from a user-experience standpoint, since both residents temporarily lost stove functionality, the panels successfully achieved the primary objective of the SUA control strategy—preventing a sustained service-level overload condition and maintaining overall electrical system protection (Figure 82).

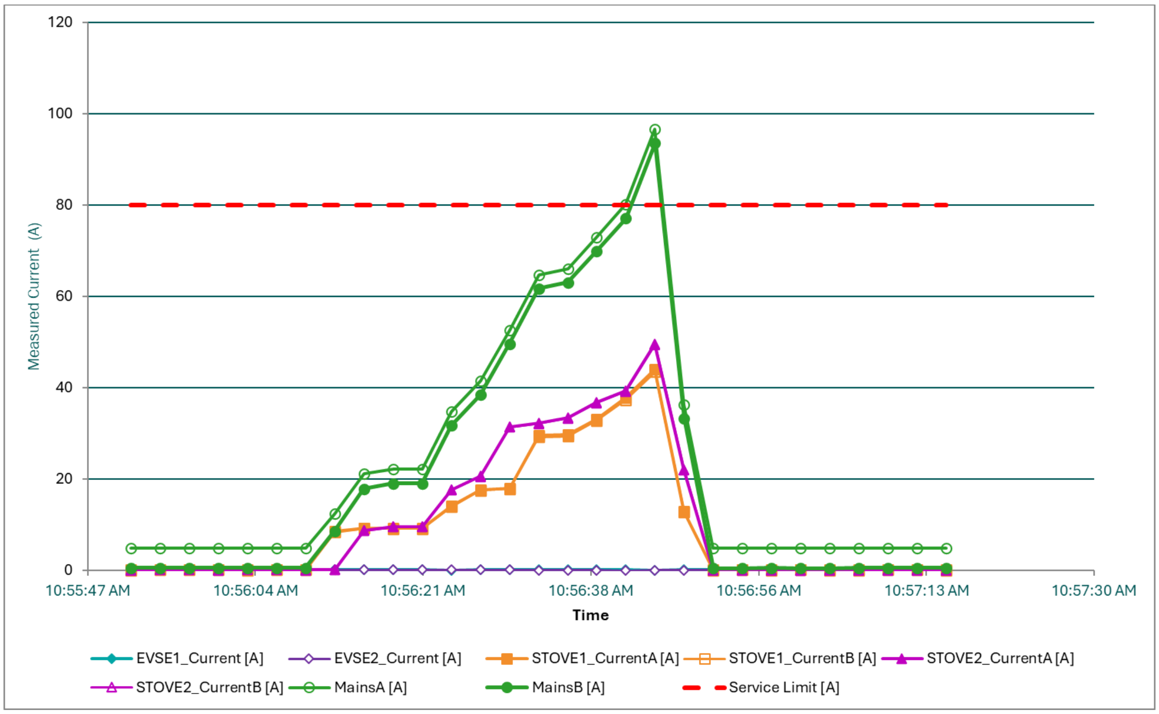


Figure 80: Overcurrent load shed testing of combined stove—sites #5 and #6 event #1.

Test 13 evaluated the system response when both EV chargers were operating simultaneously while one resident additionally used the stove. The combined EV charging drew approximately 64 A, and the subsequent activation of the stove caused the total current to exceed the configured 80 A service limit. During this event, peak currents reached approximately 83.8 A in Phase A and 81.0 A in Phase B, corresponding to overloads of about 4.7 percent and 1.2 percent, respectively. Because each smart subpanel operates independently, both panels detected the overload through their main current transformers and initiated load-shedding responses. In each case, the EV circuit was prioritized for disconnection, halting vehicle charging while allowing the stove to continue operating without interruption (Figure 83).

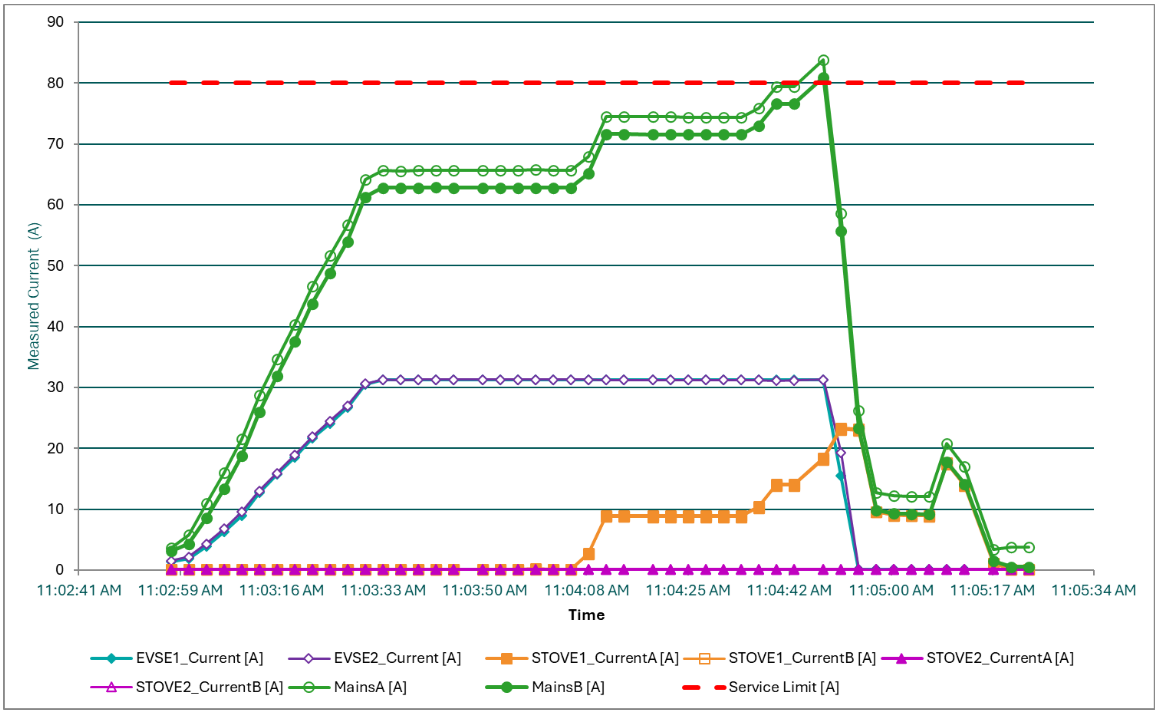


Figure 81: Overcurrent load shed testing of combined EVs and singular stove—sites #5 and #6 event #2.

Across all induced overload conditions, both the smart panel and smart subpanel systems consistently executed rapid, automatic responses that curtailed current within seconds of threshold exceedance. These response times were sufficient to prevent main-breaker tripping and ensured that total service amperage remained below damaging levels under every tested configuration (Table 29). This level of responsiveness demonstrates that the SUA functionality performed reliably, maintaining operation within safe electrical limits while preserving power to higher-priority household circuits.

To provide additional context, Figure 84 presents the 24-day average demand profiles for all individually monitored circuits. This allows direct comparison between total household demand and specific appliance contributions, highlighting the influence of high-power loads such as the induction ranges during meal preparation periods.

During the monitored period, no automatic load-shedding events were recorded. Analysis of the duplex data did, however, identify the highest observed demand: a short-duration instance in which one unit operated its electric oven while another uncontrolled load was active on the same phase, briefly pushing Phase B to 35.18 A. Although this spike did not reach the commissioned current threshold or trigger a control action, it represents the peak utilization observed in the dataset.

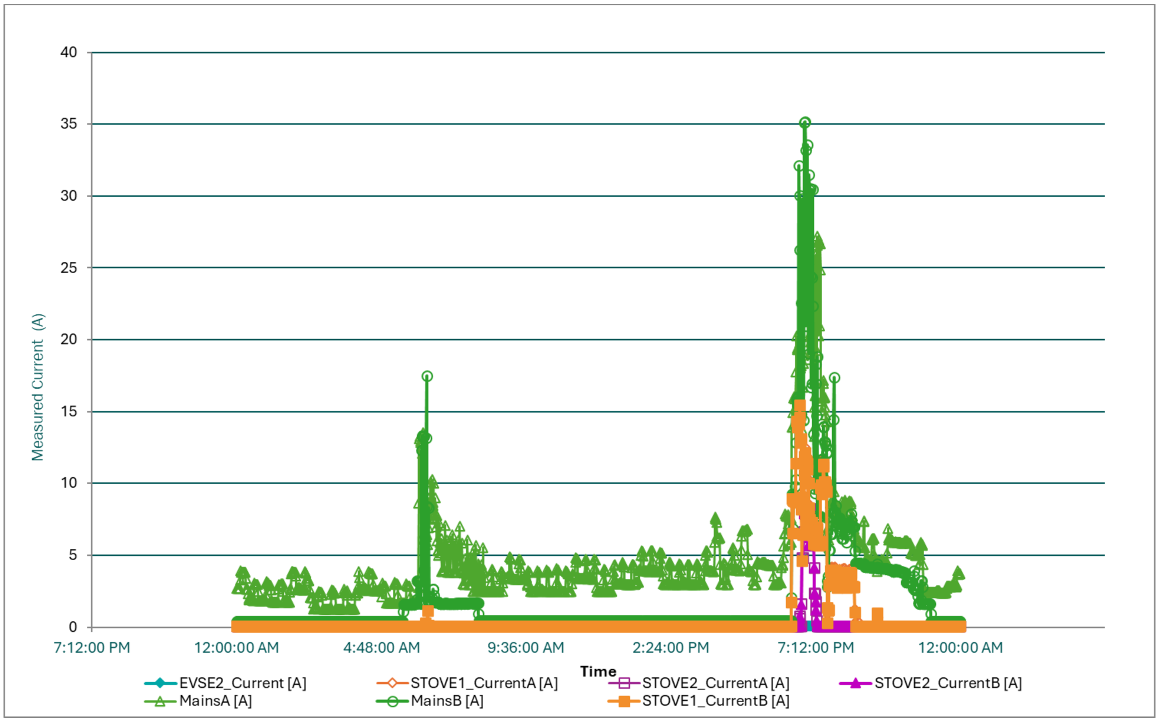


Figure 82: Peak current event experienced by the duplex.

Table 29: Performance under induced overload conditions.

Test ID	Loading Sequence	Overload Duration (s)	Peak Current A (Phase A)	Peak Overload A (%)	Peak Current B (Phase B)	Peak Overload B (%)	Circuit Disabled
1	STOVE RAMP	15	53.18	6.37	53.79	7.57	STOVE
2	STOVE MAX + EV	12	55.98	11.95	55.99	11.99	EV
3	EV + STOVE MAX	9	55.88	11.76	55.90	11.79	EV
4	DRYER + EV	18	50.09	0.18	50.49	0.98	EV
5	DRYER + STOVE	9	52.35	4.71	52.74	5.48	STOVE
6	STOVE RAMP	–	–	–	–	–	N/A

Test ID	Loading Sequence	Overload Duration (s)	Peak Current A (Phase A)	Peak Overload A (%)	Peak Current B (Phase B)	Peak Overload B (%)	Circuit Disabled
7	STOVE RAMP + EV	6	80.42	0.52	—	—	EV
8	EV + STOVE RAMP	9	80.45	0.56	—	—	EV
9	STOVE RAMP	—	—	—	—	—	N/A
10	STOVE RAMP + EV	9	79.70	−0.38	—	—	EV
11	EV + STOVE RAMP	6	80.69	0.86	—	—	EV
12	STOVE 1 + STOVE 2	9	96.67	20.84	93.62	17.03	STOVE 1 & STOVE 2
13	EV 1+ EV 2 + STOVE1	12	83.78	4.72	80.96	1.20	EV1 & EV2

Site #7

Existing Conditions

Site #7 is a typical 1,600 square foot single-family home located in Oakhurst, as shown in Figure 85.

Figure 83: Google Earth view of site #7.

ELECTRICAL INFRASTRUCTURE AND LOADS

The residence is served by a 240 V, single-phase, 100 A service. The electrical panel is over ten years old, as shown in Figure 86; the home also has a solar generation system.

Figure 84: Main electrical panel for site #7.

The home has an existing Level 2 EV charger connected to the main panel. All the other electrical loads represent typical single-family home loads.

GAS FIRED APPLIANCES

Site 7 only had a gas fired water heater. The water heater was an American Water Heater Company 30-gallon water heater with 33,000 Btu/h input rating (Figure 87).

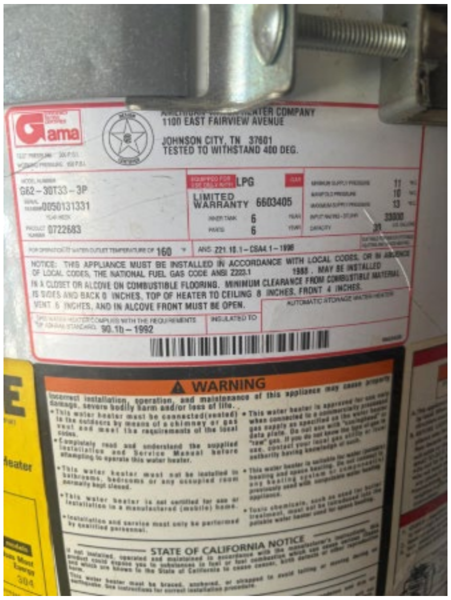


Figure 85: Existing gas fired water heater at site #7.

Electrification Plan

ELECTRIFIED LOADS

As part of the electrification measures at site #7, one significant new electrical load was installed: a 50-gallon high efficiency HPWH. To support the installation, a conduit was routed from the main electrical to the water heater location for a new 240 V outlet, where the water heater was connected to a dedicated breaker within the smart subpanel system, consistent with manufacturer specifications.

SMART SUBPANEL INSTALLATION AND CONFIGURATION

The site had an existing EV charger with a dedicated breaker installed in the main electrical panel. This EV charger was moved to a new smart subpanel. This configuration enabled the EV charger and the water heater to be actively monitored and controlled by the smart subpanel, ensuring seamless integration into the broader managed load coordination strategy while also providing visibility into real-time circuit-level energy usage.

Figure 86: HPWH installed at site #7.

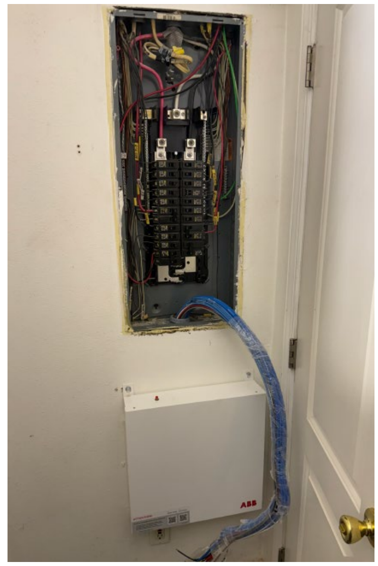


Figure 87: Subpanel at site #7.

Installation Findings

N/A

M&V and Test Plan

The M&V plan and test strategy for this home was largely constrained by the short time we had to monitor the home. The contractor spot checked the power draw for the major appliances/load to validate the manufacturer readings. See table below for the spot check results:

Table 30: Smart panel manufacturer data verification—site #7.

Appliance	Clamp Meter Measurement (A)	LBT Measurement (A)
Range	35	34.2
Hot Tub	24	24.95

After confirming the LBT's onsite data acquisition was accurate, we tested the LBT performance through an SPT **test**. Prior to the **SPT test** day, we confirmed access to the homeowner's LBT via manufacturer API, and then asked the homeowner to turn on all large loads in their home to identify each appliance load peak individually.

For this site, the HPWH was not connected to the smart subpanel for control. That HPWH load is still on the main panel and contributes to the total draw.

Table: 31SPT test load order-1—site #7.

Turn on order	Appliance	Load amps	Cumulative load test amps
Load 1	EV	34	34
Load 2	Hot Tub	8	42
Peak Load trigger at 50 amps			
Load Trigger	Stove	14.5	56.5

Results

The homeowner let us know the day of test that their EV charger was installed with a circuit splitter sharing the circuit with the electric dryer. A separate circuit for the EV charger was not added yet.

The measurements recorded prior to the test day were with the circuit splitter, and we were not able to validate if the measured current on the shared circuit was for EV charger or dryer. We asked the homeowner to re-run the loads at max to re-evaluate the testing load order. We monitored the EV charger draw through the circuit splitter interface, and it was much lower than expected. Therefore, we set the new SPT load order.

Table 32: SPT test load order-2—site #7.

Turn on order	Appliance	Load amps	Cumulative Load Test amps
Load 1	Hot Tub	5-19	5-19
Load 2	Dryer	24	29-48
Peak Load trigger at 50 amps			
Load Trigger	Stove	14.5	43.5-62.5

After assuring we had remote access to homeowner's LBT system, we coordinated with the homeowner on a day and time to conduct the SPT test and informed them of the procedures of the test. We were primarily interested in how the LBT would shed load(s) as necessary to maintain the threshold.

During this SPT test, the homeowner turned on the hot tub, dryer, and cooktop. The total panel draw was maintained below the service threshold until the hot tub heater turned on at 12:48 p.m., resulting in the total panel draw exceeding the service threshold. As a result, the smart subpanel shed the hot tub circuit. After a few minutes, the smart subpanel restored the hot tub circuit, However, the cooktop came on at the same time, drawing the total panel draw over the threshold, resulting in the hot tub circuit being shed again. The smart subpanel continued to monitor the system to ensure there is enough capacity remaining so the shed load can resume without reaching the system threshold. At 12:54 p.m., the smart subpanel sensed that the system was no longer close to the threshold and had enough capacity to accommodate the hot tub load and resumed hot tub operation.

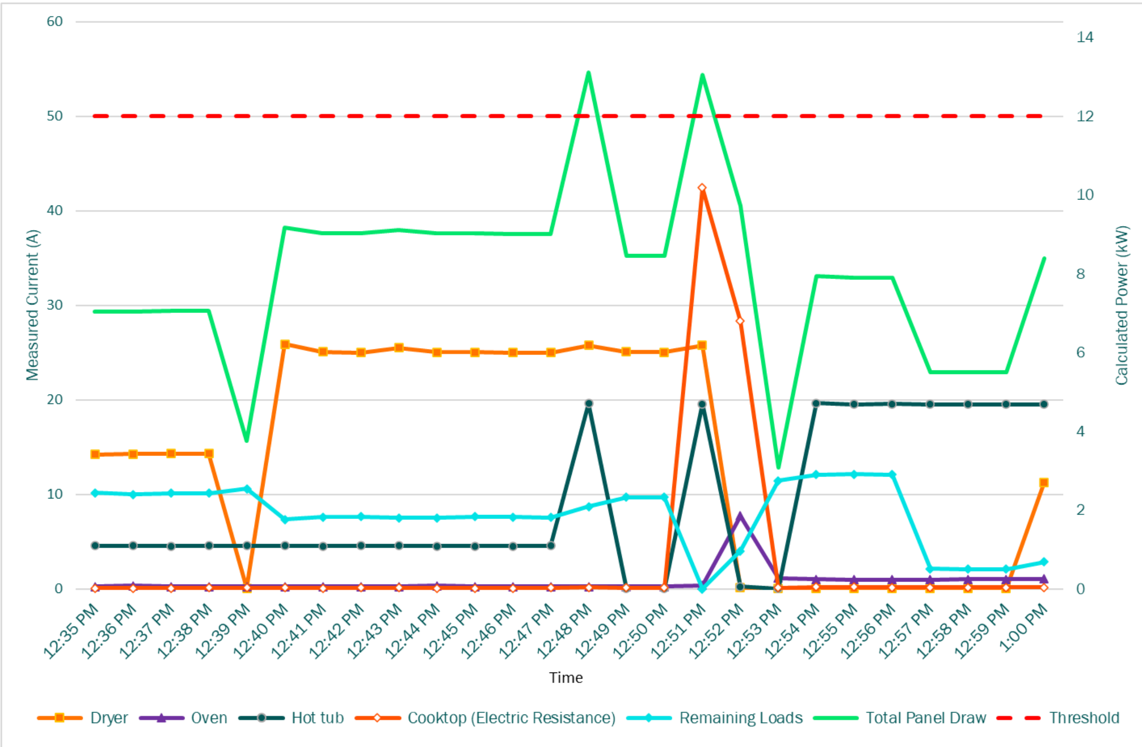


Figure 88: Smart subpanel SPT event—pilot demonstration site #7.

Appendix G: Pilot Demonstration—Smart Breaker

Site #8

Existing Conditions

Site #8 is a 2,700 square foot single-family home located in Carmel Valley, as shown in Figure 91.

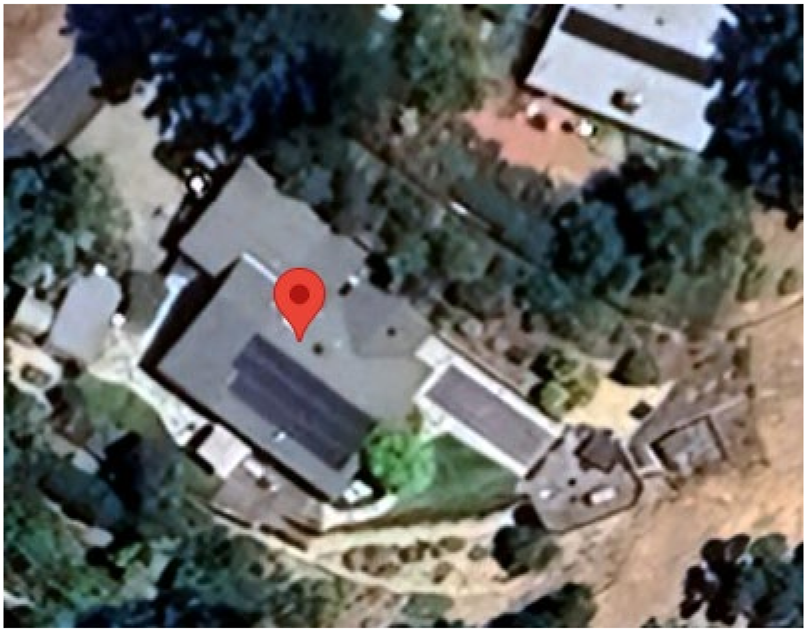


Figure 89: Google Earth view of site #8.

ELECTRICAL INFRASTRUCTURE AND LOADS

The residence is served by a 240 V, single-phase, 200 A service. The residence has a main panel that feeds into a 200 A subpanel which is the scope of the retrofit (Figure 92). The site also has an existing solar and battery energy storage system, which can be isolated from the subpanel.

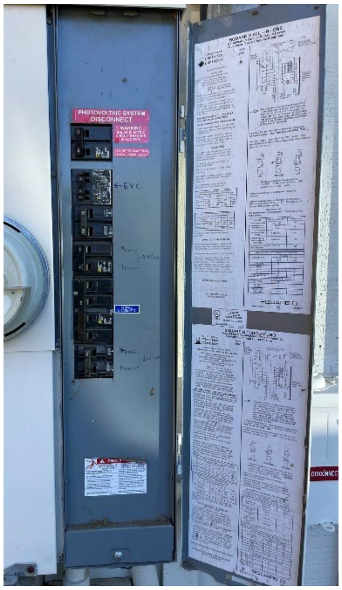


Figure 90: Main electrical panel for site #8.

The home has an existing Level 2 EV charger connected to the main panel. They are also planning to add a new subpanel for a hot tub. All the other electrical loads represent typical single-family home loads.

GAS FIRED APPLIANCES

Site #8 had a gas fired space heating and domestic hot water heater, furnace, standard cooktop range with oven, and a fireplace. The participant was interested in electrifying all the gas fired appliances in future. The existing water heater was a Pheonix 119-gallon commercial water heater with 119,000 Btu/h input rating (Figure 93).

Figure 91: Existing gas fired water heater at site #8.

Electrification Plan

ELECTRIFIED LOADS

As part of the electrification measures at site #8, one significant new electrical load was installed: a new air-to-water heat pump system for HVAC and domestic hot water, featuring an outdoor unit, an indoor unit, and a steel buffer tank (20 gal). To support the installation, a conduit was routed from the electrical subpanel to the heat pump location, where the heat pump was connected to a dedicated breaker within the subpanel, consistent with manufacturer specifications. Homeowner also electrified outdoor space heaters and added a second EV charger.

SMART BREAKER INSTALLATION AND CONFIGURATION

It was the customer's choice to install smart breakers at this site. The smart breaker power modules were installed in the subpanel and connected to the two EV chargers, new space heating and Domestic water HPWH, space heaters, and hot tub.

Figure 92: Space and DHW HPWH installed at site #8.

Figure 93: Space and DHW HPWH installed at site #8.

Figure 94: Smart Breakers installed at site #8.

Installation Findings

Installation had issues primarily due to contractor being new to LBT installation. Wrong subpanel was installed, loads were mislabeled after handoff, current transformers were installed in wrong direction, and no contractor to homeowner transfer at system set up. At the end of installation homeowner was wishing he would have chosen installer that had experience but at the time was not as available.

M&V and Test Plan

The M&V plan and test strategy for this home was largely constrained by the short time we had to monitor the home.

After confirming the LBT's onsite data acquisition was accurate, we proceeded to test the LBT's performance through a **SPT test**. Prior to the **SPT test** day, we confirmed access to homeowner LBT via manufacturer AP.I We then asked homeowner to turn on all large loads in their home to identify each appliance load peak individually.

Table 33: SPT test load order—site #8.

Turn on order	Appliance	Load amps	Cumulative Load Test amps
Load 1	EV	51.25	51.25
Load 2	Hot Tub	19.6	70.85
Peak load trigger at 90 A			
Load Trigger	AC	38.75	109.6

Results

Prior to SPT test day, the system service panel threshold had been set to 90 A. This LBT system was part of a 200 A service panel. We had selected four loads to assist in reaching a 90 A service panel threshold. The trigger load was the existing AC system that was not monitored by smart breaker LBT. At 6:20 pm the EV charger was turned on, followed by the hot tub with heaters on and pool pump at 6:25 pm. The trigger load at 6:47 p.m. was the AC which resulted in the EV charger being shed, as shown in Figure 97. The current version of this LBT system sheds the largest load and in this case, it was the EV charger. This LBT system does not automatically turn back on after a certain period. An upcoming software update will have the load that is shed be able to turn back on once loads are under service threshold. Also, the homeowner will be able to select which loads are non-critical and those loads will be selected to be shed.

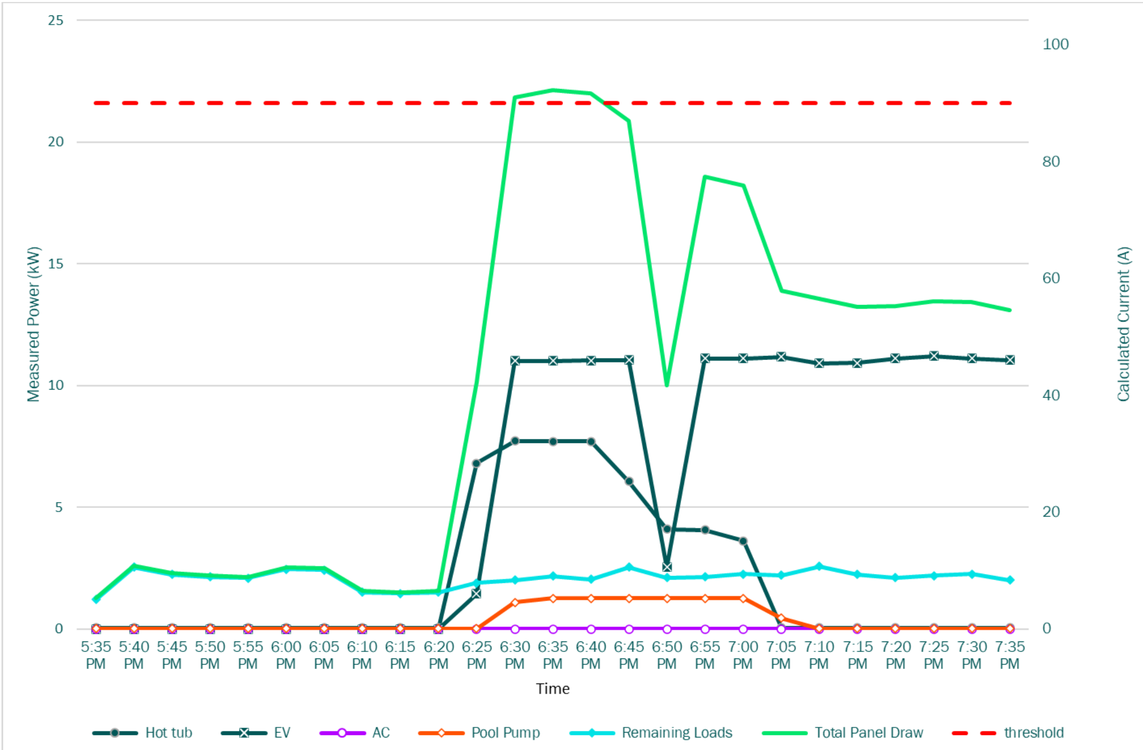


Figure 95: Smart breaker SPT event—pilot demonstration site #8.

Site #9

Existing Conditions

Site #9 is a typical 3,500 square foot single-family home located in Oakland (Figure 98).

Figure 96: Google Earth view of site #9.

ELECTRICAL INFRASTRUCTURE AND LOADS

The residence is served by a 240 V, single-phase, 100 A service. The main electrical panel is over thirty years old and has limited open/spare breaker slots. The main electrical panel feeds into two subpanels. The home also has a solar and battery energy storage system (Figure 99).

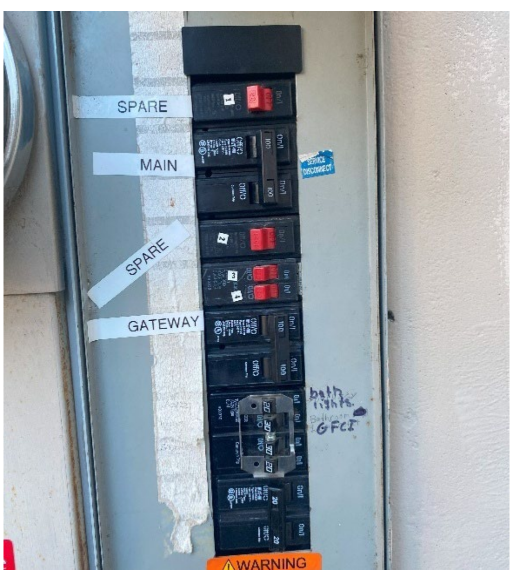


Figure 97: Main electrical panel for site #9.

The home has an existing Level 2 EV charger connected to one of the subpanels. All the other electrical loads represent typical single-family home loads.

GAS FIRED APPLIANCES

Site #9 had a gas-fired water heater furnace (Figure 100), clothes dryer (Figure 101), and standard cooktop range with oven (Figure 102). The participant is interested in electrifying all the gas fired appliances in future. The existing water heater is a Kenmore 40-gallon water heater with 40,000 Btu/h input rating.

Figure 98: Existing gas fired water heater at site #9.

Figure 99: Existing gas fired dryer at site #9.

Figure 100: Existing gas fired cooking range at site #9.

Electrification Plan

ELECTRIFIED LOADS

As part of the electrification measures at site #9, two significant new electrical loads were installed: a new heat pump clothes dryer and new heat pump water heater. To support the installation, new conduits were routed from the electrical panel to the dryer and HPWH location for new 240 V outlets, where the dryer and HPWH were connected to a dedicated breaker within the panel, consistent with manufacturer specifications.

SMART BREAKER INSTALLATION AND CONFIGURATION

The homeowner selected this LBT after researching other LBT solutions and had come to the conclusion that to reach electrification goals in his 100-year-old home, he would need add an LBT, as a service upsizing is too costly. After customer contacted the LBT manufacturer, the manufacturer connected customer to this pilot.

The homeowner had a very old subpanel where a majority of his breakers were located. We included replacing with a new subpanel that had more space and was not obsolete. The new smart breaker power modules for HPWH and HP dryer were installed in the new subpanel. The power module will also monitor the total panel draw which include the draw from the EV charger which is installed on a different subpanel.

Figure 101: HPWH installed at site #9.

Figure 102: HP clothes dryer installed at site #8.

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Figure 103: Smart Breakers installed at site #9

M&V and Test Plan

The M&V plan and test strategy for this home was largely constrained by the short time we had to monitor the home. The contractor spot checked the power draw for the major appliances/load to validate the manufacturer readings. See Table 34 below for the spot check results:

Table 34: Smart panel manufacturer data verification—site #9.

Appliance	Clamp Meter Measurement (A)	LBT Measurement (A)
Main Line 1	3.3	3.4
Main Line 2	2.2	2.0

After confirming the LBT's onsite data acquisition was accurate, we proceeded to test LBT performance through a SPT test. Prior to the SPT test day we confirmed access to the homeowner's LBT via manufacturer API. We then asked the homeowner to turn on all large loads in their home to identify each appliance load peak individually. Table 35 shows the test load order.

Table 35: SPT test load order—site #9.

Peak Test Order	Loads	Load amps	Cumulative load amps
Load 1	HPWH	21.6	32
Load 2	EV	32	53.6
Home Peak Avoidance Test amps: 70 A			
Peak Load Trigger	HVAC	21.25	74.85

Installation Findings

The core findings from this installation primarily centered on the **contractor's knowledge and understanding of the system.**

While the contractor was required to complete manufacturer training prior to installation, the challenges encountered were related to the technical recommendations provided to the homeowner, rather than the physical installation itself, which was performed correctly.

Key Issues and Observations

- **Suboptimal System Recommendation:** The installation costs were unnecessarily high due to the contractor's limited knowledge of the system's proper application.
  - The homeowner requested the replacement of an obsolete subpanel.
  - The contractor selected a more expensive and larger subpanel than required, assuming it was necessary due to a misunderstanding of the system's specifications. A less costly alternative would have sufficed.
- **Incorrect Device Ordering and Misapplication:** An example of this misunderstanding involved the procurement of a specific Ethernet-connected device.
  - This device was intended to connect to a separate subpanel containing the homeowner's electric vehicle (EV) charger.
  - The device requires a hardwired Ethernet connection, which was not available at the installation site, making the ordered component unusable for the intended purpose.

The system was physically installed correctly. However, a deficiency in the contractor's practical system application knowledge led to **inflated costs** and **incorrect component selection**, specifically regarding the subpanel and the Ethernet-dependent device

Results

At the point when this test was taken, the homeowner only had one load connected to the LBT. The HPWH was turned on at 10:40 a.m. followed by the EV charger. The EV charger was not controlled or monitored by the LBT at the time but was still impacting the service load and energy use and can be seen in "remaining loads." The EV charger and HVAC were both turned on between 10:45 a.m. and 10:50 a.m. with HVAC being the trigger load. At 11:00 p.m., a SPT was triggered and the HPWH was shed at 1:05 a.m. This LBT system, in its current version, sheds the largest load, and in this case, it was the HPWH. This LBT system does not automatically turn back on after a certain period. An upcoming software update will have the load that is shed will turn back on once loads are under service threshold. Also, the homeowner will be able to select which loads are non-critical and those loads will be selected to be shed.

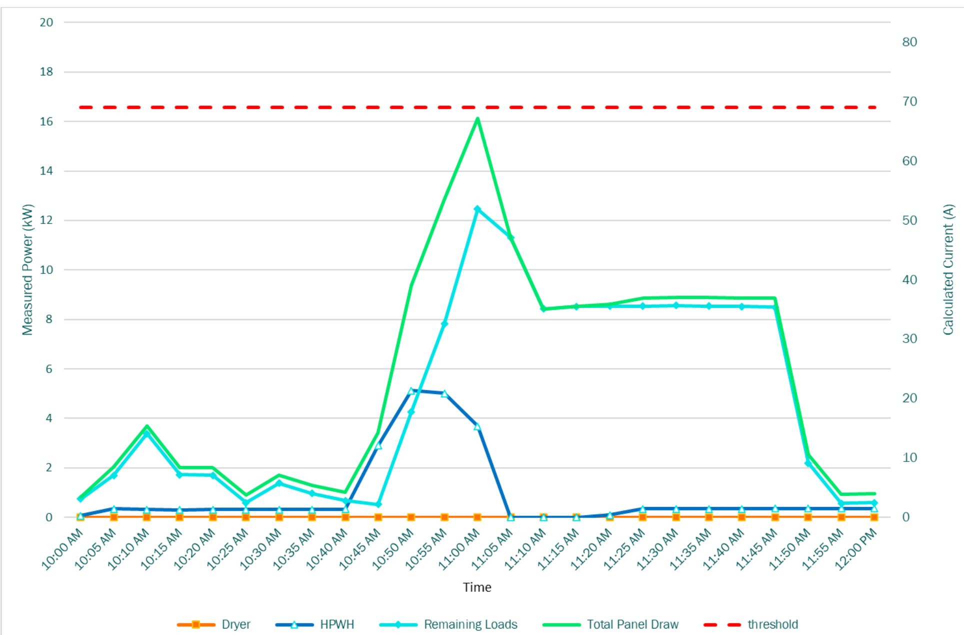


Figure 104: Smart breaker SPT event—pilot demonstration site #9.

Site #10

Existing Conditions

Site #10 is a typical 1,500 square foot single-family home located in Jurupa Valley, as shown in Figure 107.

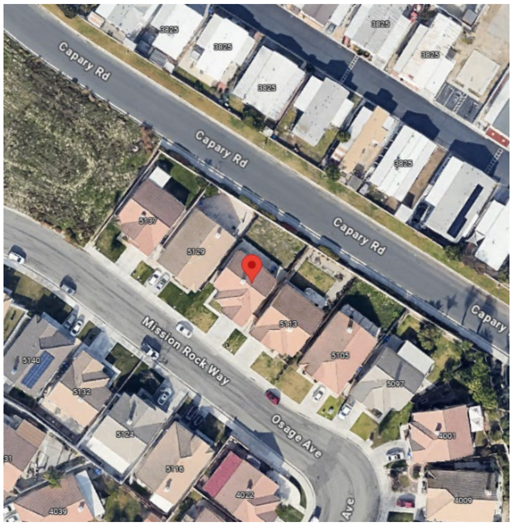


Figure 105: Google Earth view of site #10.

ELECTRICAL INFRASTRUCTURE AND LOADS

The residence is served by a 240 V, single-phase, 200 A service with several open breaker slots on the main panel. The electrical panel was recently replaced when the owner installed a solar and battery energy storage system.

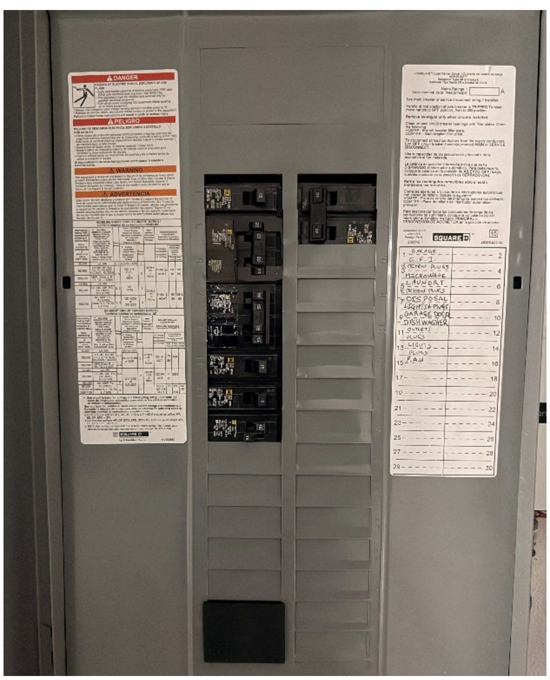


Figure 106: Main electrical panel for site #10.

The home has an existing Level 2 EV charger connected to the main panel.

GAS FIRED APPLIANCES

Site #10 had a gas fired water heater, furnace, standard cooktop range with oven, and a clothes dryer. The participant is interested in electrifying all the gas fired appliances in future. The existing water heater was an American Water Heater Company 40-gallon water heater with 34,000 Btu/h input rating.

Figure 107: Existing gas fired water heater at site #10.

Electrification Plan

ELECTRIFIED LOADS

As part of the electrification measures at site #10, one significant new electrical load was installed: a 40-gallon high efficiency HPWH. To support the installation, a conduit was routed from the main electrical to the water heater location for a new 240 V outlet, where the water heater was connected to a dedicated breaker within the main panel system, consistent with manufacturer specifications.

SMART PANEL INSTALLATION AND CONFIGURATION

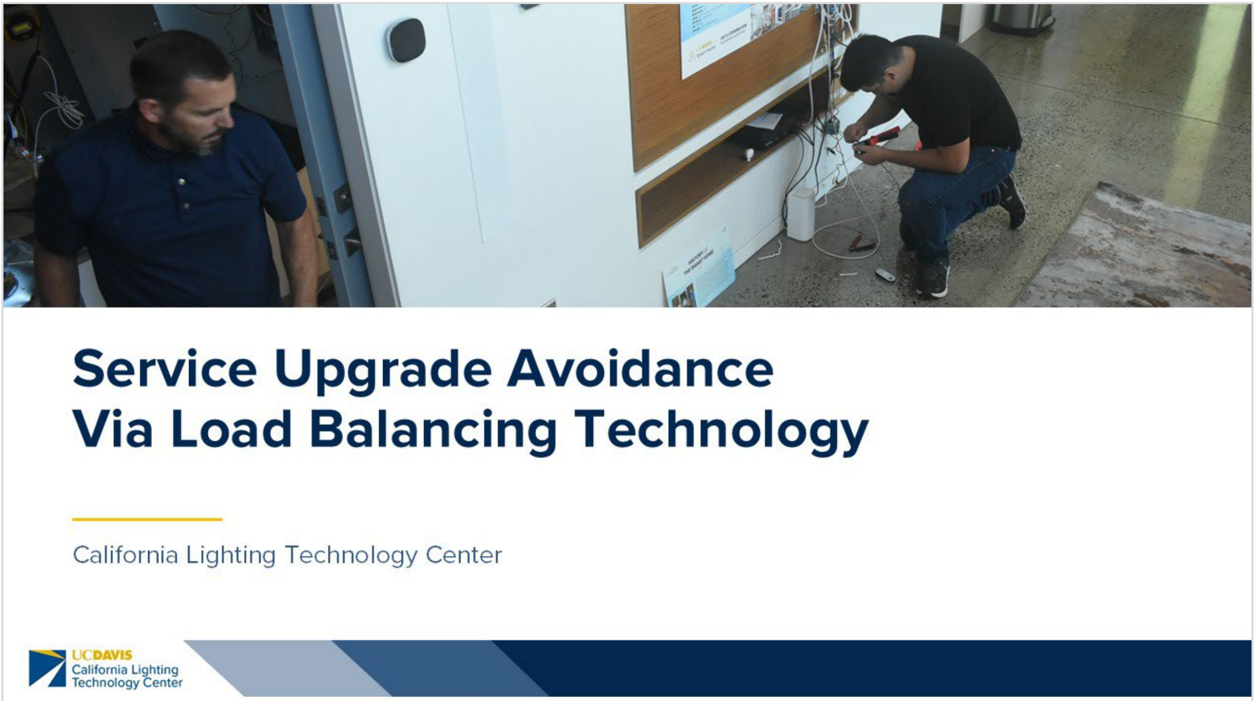
The site had an existing EV charger with a dedicated breaker installed in the main electrical panel. This EV charger was moved to a new subpanel with a relay and energy monitor for the whole home. This configuration enabled the EV charger to be actively monitored and controlled by the smart breaker, ensuring seamless integration into the broader managed load coordination strategy while also providing visibility into real-time circuit-level energy usage.

The other loads along with the new water heater were in the existing electrical panel and were not controlled or monitored.

M&V and Test Plan

The LBT system and the HPWH were installed at this site but not commissioned by the time this report was submitted. Hence no test plan or results are available.

Appendix H: Training Material Developed for EVITP



Why Load Balancing Technologies?

- LBTs can enable **service upgrade avoidance (SUA)** and prevent costly service and infrastructure upgrades
- Enable smart control of loads during grid isolation events to prolong off grid operation of a building
- Allow homeowners to view real time energy usage
- Provides a method of demand response with utilities

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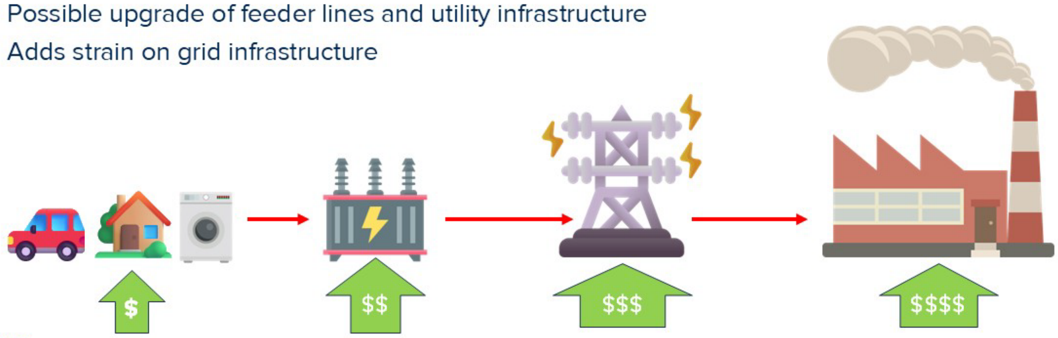
Service Upgrades

- Upgrades and replacements of equipment needed to increase the service threshold to a building
- Service upgrades can range from $2,000 - $20,000
  - Minimum requirements panel upgrade
  - Possible upgrade of feeder lines and utility infrastructure
  - Adds strain on grid infrastructure



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What is "Load Balancing Technology?" (LBT)

- LBT prevents the total load of a building from exceeding the service threshold
- LBTs monitor power from the grid and/or generation sources and can monitor power to individual circuits
- LBTs can shed loads or manage loads automatically
- LBTs provide load visibility to users to help inform time of use decisions

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Load Balancing Technologies

- Smart panels
- Smart sub panels
- Smart breakers
- Circuit splitters
- Meter collars

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Smart Panels (SPs)

- Full panel replacement
- A smart main panel with individual circuit monitoring and control
- Able to prioritize specific circuits for load shed
- Can meter the total load to the building
- Several SPs can act as grid isolation devices (GIDs)
- Can help manage and control local generation and storage systems

Smart Sub Panels (SSPs)

- Sub panel that monitors and controls individual circuits
- May be used to control dedicated circuits to high power loads (EV chargers, appliances, pool pumps, etc.) which can be shed if the total building load approaches the maximum load to the service
- Like SPs, SSPs can provide circuit prioritization for load shed

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Smart Breakers (SBs)

- Smart control and monitor individual breakers
- Requires information from other devices to provide appropriate load shedding control, requires additional hardware
- Used as an endpoint for a LBT control scheme
- Smart breaker can have their own metering

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Circuit Splitters

- Allows switching of a circuit’s power to multiple devices
- Example: a switch that allows only the washer and dryer or an EV charger
- Prevents appliances from being used at the same time

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Meter Collar

Attaches to the service meter to the building to provide real time information about the total load to the service

Allows powering of large loads through meter bypassing panel (e.g. EV chargers)

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UL-3141

- Covers systems that **monitor** and **limit/control current or power** to enforce safe limits, rather than relying only on passive protection like overcurrent devices
- The standard is intended to **align with NEC requirements** (e.g. NEC 705.13 in the 2020 version, or 750.30 in 2023) that mandate that energy management systems limit current/loading

UL CERTIFIED

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Features in UL-3141

- Current/Power Limiting: The system must limit power or current so that the busbars, service, feeder or conductors are never overloaded beyond defined limits
- Overload Safety/Fallback Protection: Imposes safety criteria such that if the system fails, it must still prevent overloads via passive or redundant protection
- Interface with DER/Inverters/Loads: The system may control loads or sources(inverters, EV chargers, storage, etc.), and may coordinate among them to prevent exceeding limits
- Autonomous or Command Operation: The system may be fully autonomous or respond to external commands or load schedule (from the utility or a controller) while ensuring limits are maintained

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Load Balancing Technology (LBT) Installs

- Physical and electrical install
- Software Commissioning
- Load Calculations
- Commissioning
- Homeowner education

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Physical and Electrical Install

- LBT Manufacturers provide online installer training
- Require Software commissioning through web applications
- Install of SP and SSPs are similar to panel installs
- SPs have standard breakers with the addition of controllable relays inline with the breakers

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Commissioning

- Installer training and certification for SP and SSP's is available through the manufacturers
- Commissioning is done through web applications for most LBTs
  - Ensure latest software version for LBT device as well as software applications to avoid security/functionality issues
- During commissioning the maximum load from load calcs should beset as the Service limit
- If available coordinate with the customer to prioritize circuits for load shed during high load events
- If Scene control is available set applicable scenes for grid isolation and overload events

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Load Calculations

- Determine out if a LBT is required with standard load calcs for the area of the install
  - If the Load to the building exceeds the maximum load to the panel LBTs maybe installed to prevent the load from exceeding the maximum load
  - Applicable deratings should be applied in load calculations
  - LBTs allow for total loads in the building to exceed the service threshold, but the service threshold will be used as the control limit
  - SPs and SSPs have a derating factor (usually around 80% of the set limit) where the systems will began shedding loads to avoid the service threshold

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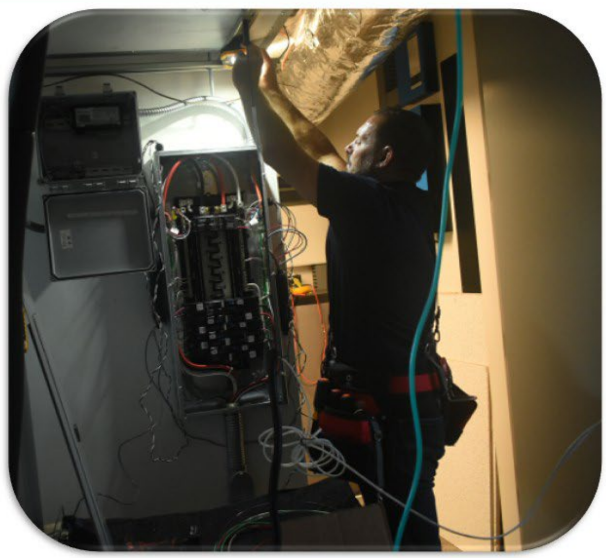
Prioritizing Circuits

- Most of the LBT Panels manage current overload by prioritizing specific circuits while classifying some circuits as expendable
  - Essential circuits: will attempt to keep these circuits powered at all times
  - Important circuits: lower priority circuits and will be cut if necessary
  - Expendable circuits: circuits to lose power first if near an over current state or during a blackout



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Service Upgrade vs LBT Install

Cost Comparison

- ~**$2,000** to >**$20,000** to upgrade electrical service to a home depending on things like underground or overhead wiring

Upgrade	Material Cost	Installation Cost	Total	$/Amp Controlled
Smart Breaker	$988	$150 - $300	$1,138 - $1,288	$30.28 / A
Smart Sub Panel	$2,200	$400 - $1,750	$2,600 - $3,950	$52.00 / A
Smart Panel	$2,550	$2,000 - $3,000	$4,550 - $5,550	$45.50 / A

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Code Compliance

LBT's are a new product category, with a lack of institution knowledge

- Field inspectors reported relying on code and listings when assessing smart panels
- Inspectors are relying on manufacturer installation manuals due to code lag
- Products are required to pass UL testing

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Questions?
Contact us
Sign up for our newsletter
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Caution!!
Panel is Energized

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