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End-Use Load Flexibility: Connected Water Heater Study

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List of Abbreviations/Acronyms

DR: Demand response
DERMS: Distributed Energy Resource Management System
ERWH: Electric resistance water heater
HPWH: Heat pump water heater
IOT: Internet of things
LTE: Long-term evolution
OEM: Original equipment manufacturer
SGD: Smart grid device
UCM: Universal communications module
WH: Water heater

Glossary

Critical Peak Event: A DR request wherein a smart grid device or group of devices is requested to reduce energy consumption more than a Shed request. The reduction may affect the comfort of the owner.
Capacity, Storage Capacity, or Energy Take: The amount of electrical energy that the smart grid device can consume before being fully heated
CTA-2045: An open technical standard for device-level energy management
Curtailment/Curtailment Event/Event: Any point at which an SGD or fleet of SGDs is being instructed to reduce energy draw
Demand Response (DR): The ability of a flexible load asset to respond to a curtailment or heightened energy use event, generally in response to greater or lesser demand on the electrical grid
Distributed Energy Resource Management System (DERMS): A software system that controls or manages the energy use of distributed energy resources (DERs) through over-the-air event signaling
EcoPort: A standard communications method for SGDs to connect with third-party hardware to receive grid signals and relay device-level telemetry
EcoPort Module: The physical device used to connect the smart grid device to the grid and send demand-response signals
Flexible Load Management: The coordinated dispatch of large aggregations of flexible loads or smart grid devices to provide utilities or grid managers with the ability to alter demand on the electrical grid
Grid Emergency: A basic DR request wherein a smart grid device or group of devices is requested to reduce energy consumption to 0 unless there is risk of freezing
Heightened/Heightening Event: Any point at which an SGD or fleet of SGDs is being instructed to increase energy draw, if there is sufficient storage capacity
Load Up: A basic DR request that instructs the SGD or fleet of SGDs to operate until the maximum stored energy state is reached
Long-term evolution (LTE): A standard for wireless broadband communication developed to enhance mobile network performance beyond 3G technologies. It is often marketed as 4G LTE.
Normal: An operating state wherein no demand response event is in effect. The smart grid device may be in an Idle Normal state (no or insignificant power draw), or a Running Normal state (actively drawing power).
Shed: A Basic DR request wherein a smart grid device or group of devices is requested to reduce energy consumption. The reduction should not affect the comfort of the owner.
Smart Grid Device (SGD): A device that is connected to, or capable of connecting to the electrical grid in some manner, and receiving signals to heighten or curtail its energy use
Universal Communications Module (UCM): The device used to connect a smart grid device to the grid and receive and send demand-response signals

Executive Summary

The following report summarizes the findings of an “End-Use Load Flex Study for Testing QR Code and Participant Self-Install UCM,” hereafter referred to as the “Connected Water Heater Study” or simply “the study,” which was conducted by SkyCentrics for the Northwest Energy Efficiency Alliance (NEEA) from June 2024 to October 2025. The purpose of the study was to understand the barriers, goals, and opportunities involved in connecting CTA-2045 EcoPort-enabled residential storage water heaters and completing a series of load flexibility events.

The study focused on learning how well CTA-2045 EcoPort modules could be installed, connected, operated, and kept online over time. These modules enable smart grid devices (SGDs) to receive signals from a distributed energy resource management system (DERMS) platform with the goal of modifying their energy demand and helping to shape electrical load. The study began with several core research questions:

1. When an EcoPort module is connected to a water heater, what is the granularity of the location that can be identified remotely?
2. What motivates installers to learn about and promote connected water heater technology, and how willing are they to do so?
3. What is the success rate of a residential customer installing the mobile application and enrolling in the study?
4. How does the customer respond to their water heater being controlled? What are some value-exchange messages that resonate with the customer?
5. How does the handoff from contractor to utility (or aggregator) occur, from both the utility’s and the customer’s perspective?
6. What is the customer’s retention rate as they move from installation to enrollment and ultimately to utility control?

As the study progressed, research questions were added. These are included in the Methodology section under **Additional Research Questions**.

The study also evaluated how effectively the DERMS platform could dispatch events to the connected fleet of water heaters, test various dispatch strategies to maximize event performance and mitigate a large spike in energy usage after the completion of an event (“snapback”), and test whether the EcoPort modules remained connected for the duration of the study.

The study was made possible through the NEEA End-Use Load Flex Special Project, and was conducted in the states of Washington and Oregon within the territories of eight participating utilities: Tacoma Power, Seattle City Light, Puget Sound Energy, Snohomish Public Utility (the “Puget Sound Region”), Portland General Electric, Pacific Power, Clark Public Utilities (the “Portland Metro Region”), and Emerald People’s Utility District. These eight are collectively referenced as the “Participating Utilities”).

Study Findings

Customer/Installer Experience

Survey responses

For the initial customer survey (at time of EcoPort install), customers rated ease of app use and installation as Good. Nearly half required installer assistance with EcoPort installation and two in five needed help with study sign-up.

Customer Survey 2 (45 days post-installation) yielded a strong customer likelihood to recommend the program and minimal perceived reduction in hot water availability.

Customer Survey 3 (90 days post-installation) saw a degree of drop-off in likelihood to recommend the program—though still fairly strong—and similar minimal perceived reduction in hot water availability.

Installer Survey—most claimed they had assisted customers with EcoPort module installation, a process they rated as easy. Over one-quarter of installers helped customers with the sign-up process for this study and rated ease of app use as Good. All said they would be likely to recommend the program.

Calls to customer support line

Only 15 customer calls were received by the support line, with most of these related to installation of the EcoPort module, questions about completing study enrollment through the application, and the study timeline and incentive process. No calls were received about cold-water events.

The few calls from installers largely related to EcoPort module installation and enrollment app navigation.

Marketing materials and potential motivations

Simplification of the language in customer marketing materials to emphasize maintaining low electricity costs and community benefits—steering clear of verbiage related to electrical usage alignment and integration of renewables into the grid—yielded a notable increase in customer recruitment.

In addition to accomplishing the overarching objective of reducing electricity consumption, use of the EcoPort module provides several other benefits to customers, including ability to remotely change usage modes; access to household usage analytics; hot water leak detection; early equipment failure detection; water heating scheduling for time-of-use rate plan customers; and access to utility program incentives for load-shifting participation.

EcoPort modules

EcoPort module connectivity

Cellular-connected EcoPort modules generally exhibited reliable and effective performance throughout the study. The quality of the connections facilitated collection of granular data, which allowed nimble shifts in dispatch strategies and revelations of performance issues for water heaters.

Self-installed EcoPort modules

Forty-six of ~150 water heaters ordered by utility customers ordered an EcoPort module with their HPWHs, of which 31 modules were installed and achieved cellular connection. A challenge emerged during study enrollment; only 20 of the 31 customers completed the terms and conditions in the enrollment application, compared to 90 of 100 for those conducted with a professional installer.

“Smart Actions”

Implementation of Smart Actions during study

Preliminary performance results during the study revealed some limitations in the initial load shape. To address these limitations, the study team introduced additional demand response event call features to the Load Up and Shed event patterns dispatched to the enrolled fleet of water heaters. These refinements, executed through 10 revisions to the initial test method, are described and explained in Appx B and served to increase the effectiveness of events, improve customer experience, and remedy operational difficulties from earlier in the study.

Issue unveiled: Continued heating into a Shed event. Remedy: Implementation of “Smart Start.”

The early months of the study demonstrated that a portion of the fleet continued heating beyond completion of the Load Up event and into the start of the Shed event, given some WHs had not yet reached 0 watts.

This manufacturer-implemented behavior undermined the intended effect of a Load Up and Shed cycle. Given its effect on the load shifting strategy, the study added a new feature, “Smart Start,” that ensured all water heaters fully curtailed at the very start of the event.

Subsequent revisions to the test method introduced a “Critical Peak” event and eventually a “Grid Emergency” event, most effective at preventing unintended heating when a curtailment event starts. Its implementation restored the intended performance of a Load Up and Shed cycle; however, this intervention yielded only modest improvements in looking at the entire fleet of WHs.

Issue unveiled: Snapback. Remedy: “Smart Feathering.”

Early in the study, the conclusion of a curtailment event was driving a subsequent sharp, short-duration spike in power consumption (the “snapback”). For cases in which many SGDs might receive identical event schedules, the synchronized post-event recovery spikes could strain large-scale infrastructure or decrease benefits of the curtailment event.

After some experimentation, "Smart Feathering" was introduced to serve as an enhanced snapback management strategy. This approached ranked devices by their risk of cold-water events, then staggered their release times from the event accordingly. However, inaccurate (or missing) values for instant capacity undermined the ability to compare values across WHs or to identify which units were at higher risk for cold-water events.

Issue unveiled: Inaccurate (or missing) values for instant capacity. Remedy: "Smart capacity translation."

Next, Smart Capacity Translation was implemented to establish the "true zero" capacity value of the SGDs in the study and to normalize reported capacity values across the fleet. It informs the other smart actions by providing a more accurate representation of each unit's capacity.

While capacity value should reach 0 when the SGD has reached setpoint, more than half of the evaluated units reported instant capacity values above 0 at the end of their heating cycle. This is a significant issue in that incorrectly reported high capacity values appear at higher risk of a cold-water event than they actually were, which could end their curtailment prematurely based on their rankings during a smart feathering event.

Implementation of a capacity translation logic set was designed to correct for this (see report section **Smart Capacity Translation)**.

Demand response operation state compliance

During the study, each device's operational state was evaluated at each heartbeat (individual transmission of power, capacity, and operational state from the EcoPort module to the cloud) during each curtailment or heightening event. Each timestamp was categorized into one of three classifications, with the associated compliance rates for the study: Compliant (79%), Non-compliant (13%), or Opted-out (8%).

Opt-outs

Data analysis identified four main categories of water heater opt-outs: 1) Customer-initiated 24-hour, 2) Vacation mode, 3) OEM safeguard, and 4) New installation (see section **Opt-outs**). Among these, opt-outs in the first category were by far the most common among the 265 recorded opt-out events for the study.

82% of the opt-out time, by hours, was due to suspected Type 3 opt-outs (see section **Opt-outs**), which are triggered by code on the water heater itself. By working with OEMs to identify the cause of Type 3 opt-outs—triggered on the water heater—or identifying whether EcoPort can override such triggers, more significant load shift from connected water heaters can be achieved.

Estimated load shifted from CTA-2045 events

Results across all study events yielded a sizable reduction (49%) in energy consumption relative to baseline. While this reduction is notable, its level could have been greater during curtailment events with higher device-level compliance.

Given heat pump water heaters exhibited a greater likelihood to opt out (10%) and miss events (17%) compared with ERWHs (0.8% and 12%, respectively), HPWHs have the opportunity for larger potential benefits from perfect event participation than do ERWHs.

The study period ended with 6,902 morning device events and 7,071 evening device events. Morning events shifted an average of 227 watt-hours per device, while evening events shifted an average of 418 watt-hours per device as compared to baseline.

This per-unit energy shift was significantly higher among enrolled devices since non-participating devices considerably reduced the fleetwide average. During curtailment events, 63% of all running minutes were attributed to the 21% of units in normal or opted-out operational states, while only 37% of running minutes were attributed to the 79% of devices in curtailed mode. This distribution implies that a fully compliant fleet could likely shift 800–1,000 watt-hours per water heater per day, compared to the study's observed average of 645 watt-hours per day.

No significant difference existed between the percentage of load shift between morning and evening load events when compared with baseline energy use. This analysis indicated that morning and evening curtailment events appear to be approximately equivalent in their ability to shift load away from the curtailed period (not accounting for local price of energy or grid stress).

Energy curtailment performance also improved over time as additional smart features were deployed and the study cohort grew. Over the final five months of the study, the fleet achieved a 54% reduction relative to baseline, compared with an average 39% reduction during the preceding seven months. This suggests that the enhanced control strategies and more sophisticated Load-Up and Shed protocols implemented during the study contributed to improved curtailment effectiveness.

Curtailment event duration

To assess whether a shorter Shed event could improve load shifting performance, a two-week event schedule was implemented in which the evening curtailment event was reduced to 4:00–7:00 PM, rather than the standard 4:00–9:00 PM window used for most evening events in the study. This modification did not yield improved results. During the shortened three-hour window, energy use decreased by only 30.94% (223 watt-hours per unit per event) relative to the previous two-week baseline for the same hours.

Not only was the curtailment period 40% shorter than the standard five-hour events, it also produced a smaller effect size. The five-hour curtailment events achieved an average 46.37% reduction in energy use across the full curtailment window. Normalized to a 100-unit fleet, the 5-hour events shifted approximately 423 watt-hours per unit per event, whereas the 3-hour Shed shifted only 223 watt-hours per unit per event.

A two-week trial that shortened evening Shed events from five hours to three hours yielded limited effectiveness. The trial shifted only 223 watt-hours per unit per event compared to 423 watt-hours per unit per event for the normal five-hour evening curtailment events.

Electric resistance vs. heat pump water heaters

As expected, electric resistance units exhibited sharper, more pronounced peaks during load shifting events, whereas heat pump units showed more moderate pre-curtailment Load Up periods and post-event recovery periods.

On days without load shifting events, however, the aggregate daily load shapes of the two technologies were broadly similar (see section Estimated Energy Shift: **Electric resistance vs. heat pump water heaters**). Electric resistance heaters consumed an average of 4.84 kWh/day, whereas HPWHs consumed an average 3.97 kWh/day.

Conversely, on event days the difference in load shape between the two technologies becomes pronounced. Although the overall power consumption ratio between ERWHs and HPWHs remains relatively consistent, the shape of their load profiles diverges significantly.

The data also indicate that HPWHs were more effective at reducing power consumption during curtailment events, particularly in the evening. During the critical 4:00–8:00 PM window on event days, ERWHs consumed an average of 693 Wh per unit, whereas HPWHs consumed only 407 Wh per unit. This difference highlights the greater inherent flexibility of HPWHs and their ability to sustain deeper curtailment during peak demand times.

Introduction

This report summarizes the findings of an "End-Use Load Flex Study for Testing QR Code and Participant Self-Install UCM," hereafter referred to as the "Connected Water Heater Study" or simply "the study," which was conducted by SkyCentrics for the Northwest Energy Efficiency Alliance (NEEA) from June 2024 to October 2025.

The purpose of the study was to understand the barriers, goals, and opportunities involved in connecting CTA-2045 EcoPort-enabled residential storage water heaters and completing a series of load flexibility events.

Background

In 2024, NEEA launched the End-Use Load Flexibility Project to explore Market Transformation opportunities to enhance the region's capacity to manage electric loads. The near-term goal is to expedite the integration of features that enable end-use load flexibility and gain insight into related opportunities. Since 2023 and 2025, Washington and Oregon, respectively, have required that electric storage water heaters with a capacity of 40–120 gallons sold in their states come with an EcoPort®, which enables direct communication with the water heater via the ANSI/CTA-2045 standard. NEEA leveraged its Market Transformation experience with heat pump water heaters to test the load flexibility benefits of connected residential water heaters, understand customer barriers to participating in utility load flexibility programs, and gain insights into optimizing the dispatch strategies to maintain customer comfort.

Objectives

The study focused on learning how well CTA-2045 EcoPort modules could be installed, connected, operated, and kept online over time. These modules enable smart grid devices (SGDs) to receive signals from a distributed energy resource management system (DERMS) platform with the goal of modifying their energy demand and helping to shape electrical load.

Figure 1: EcoPort Module

The study began with several core research questions:

1. When an EcoPort module is connected to a water heater, what is the granularity of the location that can be identified remotely?
2. What motivates installers to learn about and promote connected water heater technology, and how willing are they to do so?
3. What is the success rate of a residential customer installing the mobile application and enrolling in the study?

4. How does the customer respond to their water heater being controlled? What are some value-exchange messages that resonate with the customer?
5. How does the handoff from contractor to utility (or aggregator) occur, from both the utility's and the customer's perspective?
6. What is the customer's retention rate as they move from installation to enrollment and ultimately to utility control?

As the study progressed, additional research questions developed:

1. How does the shiftability of an electric-resistance water heater differ from that of a heat pump (hybrid) water heater?
2. What variations in performance, conformance, and compliance are seen across different manufacturers and across product lines within a manufacturer?
3. How can a DERMS increase the value of a shiftable fleet by "fine tuning" the sequence of event signals sent to the connected water heaters?
4. What is the customer's ability to successfully install the EcoPort module without installer assistance, and does this lead to a significant number of "stranded assets"?

These latter questions are explained in further detail in the section **Additional Research Questions.**

Overview

The information to answer the above questions was collected from several sources, including data transmitted from the enrolled water heaters, participant surveys, and installer surveys.

The study included two categories of participants: customers (those who were having a new water heater installed and adding the EcoPort modules) and installers (those who performed the installation and introduced the study to customers).

The study comprised 31 water heater models across four OEMs, revealing a wide range of conformance and compliance. Some models did not comply with basic CTA-2045 reporting standards, such as providing real-time power and capacity values. Other models consistently complied throughout the study.

Throughout the study, each water heater continuously reported its operational state, instantaneous power draw, and storage capacity. These data were continuously transmitted via the LTE network via the EcoPort module and were aggregated to analyze device activity patterns during "event periods" and non-event "baselining" periods.

Preliminary performance results during the study revealed some limitations in the initial load shape. To address these limitations, the study team introduced additional demand response event call features to the Load Up and Shed event patterns dispatched to the enrolled fleet of water heaters. These refinements are described and explained in **APPENDIX B: Full List of Event Schedules and Reasoning for**

Schedule Alterations and served to increase the effectiveness of events, improve customer experience, and remedy operational difficulties from earlier in the study.

Methodology

The study was designed to pair EcoPort module installations with the installation of new storage water heaters, typically replacing failed water heaters in existing homes. When arriving on-site for a new water heater installation, the installer introduced the customer to the study and affixed a QR code sticker on the water heater, providing the customer access to additional information upon scanning. The installer presented key value propositions to the customer including the opportunity to earn up to $75 in incentives ($25 per completed survey), the ability to support grid stability, and the opportunity to help optimize energy usage on the electrical grid.

If the customer expressed interest in the study, the installer provided the customer an EcoPort module, an informational flyer, and a one-page instruction sheet outlining how to install the EcoPort module and enroll in the study. By scanning the QR code on either the water heater sticker or the flyer, the customer would follow a link to install the EcoPort module on their water heater, download the mobile app, and complete study enrollment. Installers were instructed to assist the customer with the installation of the EcoPort module only if the customer was unable to complete the process on their own.

Study Participants

The study included two categories of participants: customers (those who were having a new water heater installed and adding the EcoPort modules) and installers (those who performed the installation and introduced the study to customers).

Customers

Customers participating in the study were owners of single-family homes located within the service territory of one of the participating utilities. Study participation was opt-in and customers were offered up to $75 in incentives for participation. There was no screening for household size, income level, or any other factors performed as a part of the study.

Installers

Installer companies were recruited based on their experience with installing water heaters and the size of their distribution network within the study territory. The study began with a single installation company in the Portland, OR metropolitan area and later expanded to include two additional installation companies operating in Oregon and Washington.

While the ultimate goal was for customers to self-install their EcoPort module and enroll into the study, installers were often the first point of contact. They introduced customers to the study, explained the EcoPort technology, provided the EcoPort module to the customer, and guided customers through the enrollment process as needed. To support their role, installers were offered incentives for each customer they successfully enrolled.

Tested Elements

CTA-2045 Hardware

The study used alternating current (AC) CTA-2045 LTE SkyCentrics EcoPort modules to connect each participating water heater. These devices communicate over the 4G LTE IoT network and are compatible with any water heater equipped with an AC CTA-2045 EcoPort socket. A central goal of the study was to ascertain the reliability of this technology and the long-term stability of its cellular connection. The study also sought to understand how easily an untrained customer (not a professional installer) could locate the CTA-2045 EcoPort socket on their water heater, successfully install the EcoPort module into that socket, and achieve a connection between the DERMS platform and their water heater.

Water Heaters

Another key research objective was to better understand the conformance and compliance of water heaters with the CTA-2045 standard from a range of manufacturers. This study's work builds on the analysis by Dr. Robert Bass and Dana Paresa, who introduced and defined these concepts for CTA-2045-B-enabled heat pump water heaters (Paresa and Bass, 2024). In their framework, compliance refers to whether the water heater's communication strategy is in alignment with the CTA-2045-B standard. Conformance, by contrast, is not a standards-based metric; it reflects how effectively a water heater's actual performance supports grid-peak mitigation when participating in demand-response events—namely, how well it reduces power consumption during curtailment events and increases power consumption during Load Up events.

Study Supporting Elements

Application Development

SkyCentrics developed a mobile application to assist both customers and installers throughout the study. The mobile application includes the following capabilities: enrollment, incentive disbursement, customer-installer pairing, and eligibility confirmation. The application was released on both the Apple App Store and Google Play Store and was compatible with all major iPhone and Android devices.

To streamline the enrollment process, the application does not require utility account information or manual entry of water heater make or model. The application relied on a familiar experience to provide information, accept terms and conditions, and upload photos. The installer and customer interfaces are housed within the same application, with separate login panels for each user type. The application features a step-by-step installation guide and registration workflow to ensure a smooth enrollment experience. The installation and study registration flow is as follows:

Customer Enrollment Flow (Using the Application; see Figure 2)

1. Create an account in the application. This step requires an email verification process to confirm the email is valid and able to receive surveys and incentive disbursements.
2. Enter the customer's home ZIP code to confirm study eligibility (this prevents accidental sign-ups from customers outside the utility service territory)
3. If the ZIP code is in an eligible area, scan the QR code on the front of the module. This step confirms that the device is approved for the study and ensures the serial number has not already been enrolled (this is a safeguard against duplicate or fraudulent entries with unlicensed QR codes).
4. Take a picture of the customer's home electrical meter (to confirm utility).
5. Take a picture of the water heater's nameplate (rating plate) to which the EcoPort module has been connected.
6. Complete the Study Onboarding Survey (Survey 1), which officially enrolls the customer in the study and triggers their first study participation incentive.
7. If the installer is present for the EcoPort installation, scan the QR code embedded in the installer's application to confirm which installer should receive the incentive for that installation.

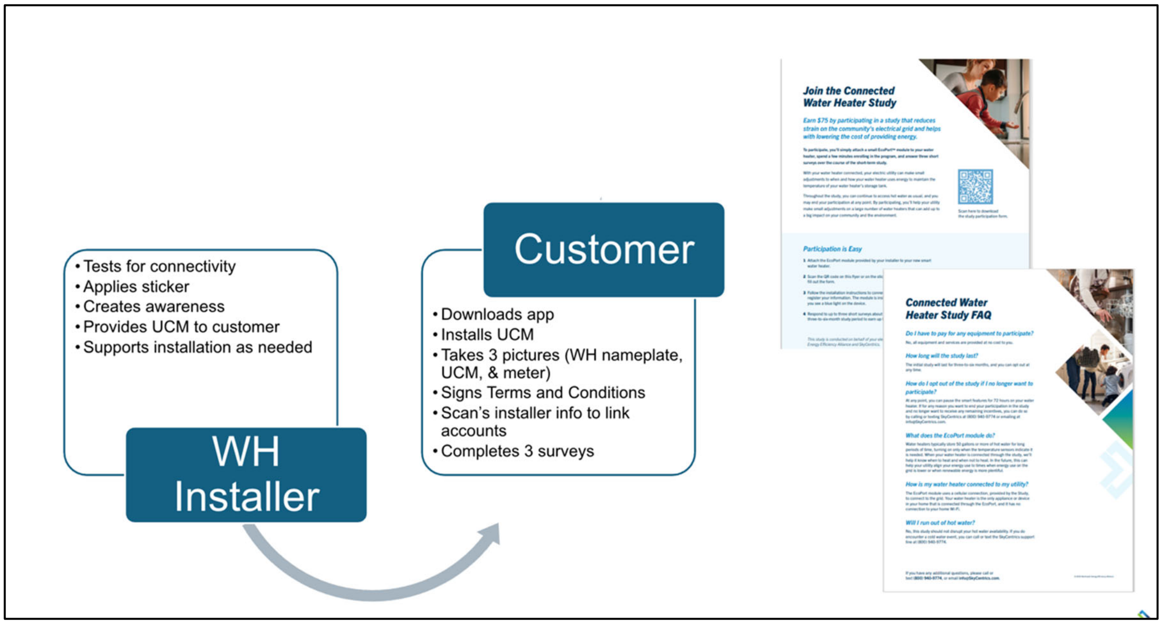

Figure 2: Study enrollment flow

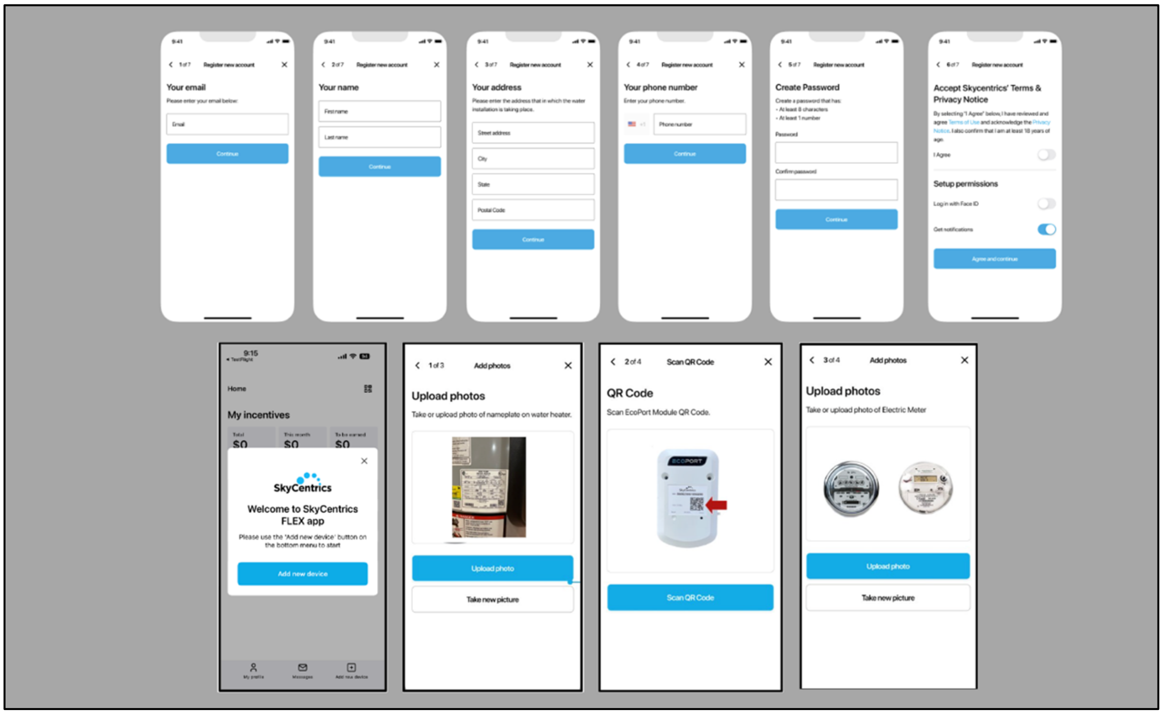

Figure 3: App registration process—Customer

Installer Connection Flow

The installer portion of the app was developed primarily to support tracking incentives. For each installation, the installer provided the customer with their unique QR code to scan, creating a direct link between customer and installer and automatically assigning incentive credit for the installation. The installer interface also included dashboards showing total completed installations and incentives earned. In addition, the app provided EcoPort module installation guides and offered direct access to study support personnel to assist with questions or troubleshooting

Customer and Installer Study Support

Customer support services were available throughout the study for both customers and installers. A dedicated 1-800 phone number operated Monday through Friday from 8:00 AM – 5:00 PM Pacific time, which aligned with the study territory's time zone. The support line provided assistance with EcoPort module installation and answered questions about the study's duration, purpose, and incentives. Customers or installers could also report cold-water events (instances where hot water was expected but not delivered). In the event of a complex issue or question that was not answerable by the customer support service, the study staff were available to address them.

Installer training and outreach

Installers were trained for the study through a series of training sessions. These training sessions were conducted on-site or through a virtual meeting using Microsoft Teams or Zoom (with installers gathered at a single physical location and the trainer in a remote location). Study staff delivered a presentation covering the benefits of grid connectivity, the steps for affixing the sticker to the water heater, how to introduce the study to potential customers, the steps for installing the EcoPort module, and completing study enrollment. This ensured installers were fully prepared to assist customers during installation. Additionally, a member of study staff was on-site at the installer meeting room to demonstrate the installation of the EcoPort modules, give hands-on walkthroughs of the app installation and study enrollment process, as well as answer questions regarding grid connectivity, customer engagement strategies, and incentive structure.

After this training was complete, installers received their study materials, including stickers that contained a QR code pointing to study information, study flyers, and instruction sheets—one version intended for customers and another serving as a step-by-step reference for installers. Staff distributed EcoPort modules to each installer to stock their delivery trucks.

Self-Installations

During the study, an additional utility expressed interest in evaluating customers" ability to self-install EcoPort modules. This study expansion began April 9, 2025, in the territory of a single electric utility. Unlike the installer-led process used previously, study participation began when customers responded to an email outreach campaign by their utility promoting deeply discounted hybrid heat pump water heaters. The email campaign also included information about the study, highlighted the opportunity to earn up to $75 for survey completion, and gave customers the option to select a free EcoPort module with their water heater. The distributor then shipped an EcoPort module, an instruction manual, and a study flyer packaged together with the new water heater.

From that point forward, the enrollment process for the study mirrored the original study workflow, with two exceptions: No QR code sticker was placed on the water heater; instead the app download link was provided directly on the installation guide and no installer QR code was scanned to assign incentives since the installer was not part of the recruitment process. The utility did complete some follow-up calls with customers who had not installed their EcoPort module.

Methodology: Quantifying Installation Experience

To quantify the customer experience of installing their EcoPort module and enrolling in the study, the study issued three surveys and incented customers to complete each one. The initial survey consisted of six questions, including Likert-scale questions ascertaining ease of EcoPort module installation and study signup process. Additional yes/no questions asked about whether the customer required assistance from the installer (if present) to connect the EcoPort module to their water heater or to complete study enrollment. Finally, free response questions were included, which allowed customers to provide detailed feedback on their installation and enrollment experience.

Design: Connectivity

One important research goal of the study was to determine the long-term connectivity performance of the EcoPort modules. Previous studies using EcoPort modules connected to customers" home Wi-Fi networks have shown high rates of connectivity drop-off (Hunt et al., 2021, 3), (Chiu and Demand Side Analytics 2021, 31). They also required labor-intensive installations and study sign-up processes that needed significant hands-on support from study organizers (Urigwe et al. 2024). This study sought to evaluate whether EcoPort modules leveraging cellular LTE technology could maintain higher and more stable connectivity over time compared to Wi-Fi based modules, and if low-contact methods such as guided self-installation or fully remote "mail-in" installation are viable alternatives.

Design: Demand-Response Load Shifting

A central goal of the study was to evaluate the effectiveness of demand response signaling delivered to a fleet of water heaters connected via cellular EcoPort modules—an approach not previously tested at this scale in a field environment. Before this was assessed, each device transmitted data for a two-week baseline period during which normal household hot water usage was recorded. No demand response events were run during this period. After completing the baseline data collection, water heaters were categorized into groups based on household hot water usage.

Grouping was determined by balancing both total water heater runtime with "runtime intensity," defined as the ratio of the highest instantaneous capacity observed during the baselining period to the water heater's reported total capacity. After a two-week baseline measuring period (noted as "PLUS 2 weeks"), all water heaters were assigned to one of four groups based on household hot water usage: "Normal," "Heavy," "Very Heavy," or "Noncompliant." Water heaters classified as "noncompliant" exhibited poor CTA-2045 compliance—failing to reliably report power, capacity, or operational state correctly—and were therefore excluded from load shifting events.

Each water heater received twice-daily events of "Load Up" and "Shed" transmitted to their water heater via the EcoPort module. These events directed the water heaters to either increase their power usage (Load Up) or curtail their power usage (Shed) for a specified duration. Events were run only on weekdays (excluding weekends and holidays). Events were generally run once in the morning and once in the evening to align with typical Pacific Northwest peak energy demand periods (Northwest Power and Conservation Council 2026). The study sought to determine whether CTA-2045 curtailment events effectively decrease energy consumption during these peak periods and, if so, to quantify the size of the effect.

Throughout the study, each water heater continuously reported its operational state (running, idle, heightened, curtailed, or acting without directive), instantaneous power draw, and storage capacity (the remaining watt-hours needed to reach the water heater temperature setpoint). These data were continuously transmitted via the LTE network and aggregated to analyze device activity patterns during "event periods" and non-event "baselining" periods.

The study period spanned from the installation of the first EcoPort module on a customer water heater (08/18/24) through the final day on which CTA-2045-B events were sent to the enrolled fleet (10/31/25).

Methodology: Quantifying Load Shifting

"Instantaneous Power" is a metric defined by the ANSI/CTA-2045-B standard ("CTA-2045") (Consumer Technology Association 2021). It measures the real-time power draw of the Smart Grid Device (SGD); in this study, that is the water heater. This value can either be directly measured by using a current transformer (CT) installed on the device or calculated using the original equipment manufacturer's (OEM's) pre-programmed power consumption values for that specific SGD. Heat pump water heaters (also called "hybrid") typically operate at multiple power levels: a heat pump-only mode consuming between 300–450 watts of instantaneous power, and an electric resistance element mode consuming between 2,250–5,000 watts for 230-volt models (Ecotope 2011).

The EcoPort module enables precise estimation of total power consumption for each unit by reporting instantaneous power at intervals ranging from sub-minute to five minutes. Internally, the module polls the water heater every 20 seconds. If it detects a change in instantaneous storage capacity or power consumption, it immediately publishes an information packet—including capacity, power consumption, and operational state—to the cloud. If no change is detected, the module transmits an information packet every five minutes. Therefore, under normal conditions and excluding rare cellular signal interruptions, the maximum interval between information packets was five minutes.

An SGD's power consumption was estimated by calculating the energy used between successive information packets, with an upper limit imposed to prevent outliers caused by poor connection. For example, if a water heater reported instantaneous power consumption of 400 W in the 00:00 packet and then 0 W in the successive packet at 00:02, the recorded power consumption would be 13.33 watt-hours. A limit of 15 minutes was placed on this "forward-fill" method, to avoid a scenario in which a device went offline while the water heater was consuming power and did not report a timestamp for hours.

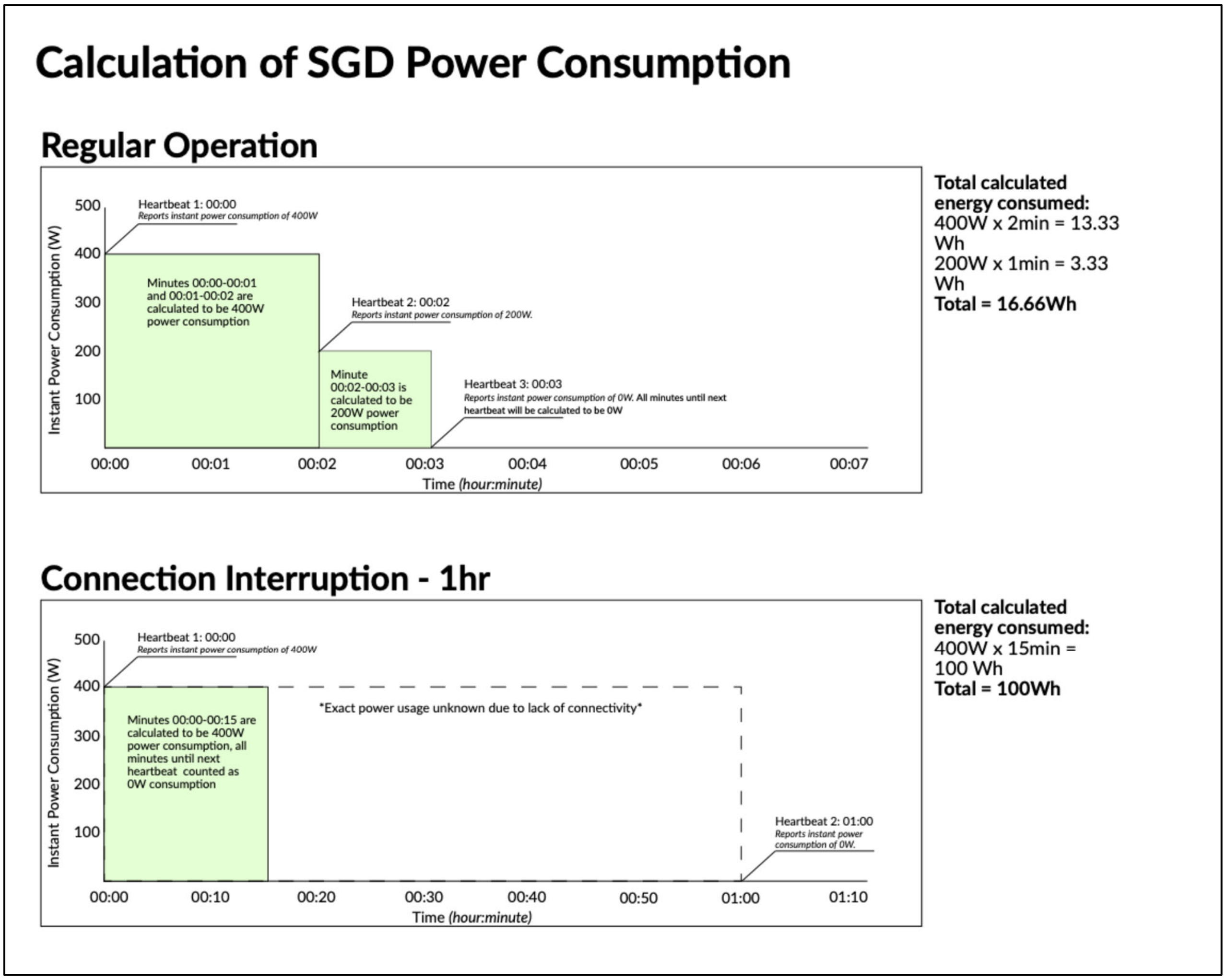

Figure 4: Calculation of SGD power consumption (regular operation vs. connection interruption)

Consumption Compared to Baseline

The method for estimating the baseline power consumption of a fleet was intentionally straightforward. Throughout the study, load shifting events were run on either a “two weeks on, two weeks off” basis, or a “one week on, one week off” schedule. Baseline estimation was performed by calculating the power consumption of the group of water heaters that received the curtailment event, then comparing that power consumption to the same group’s power use during the same hours either seven days prior (if on the “one week on, one week off” schedule) or 14 days prior (if on the “two weeks on, two weeks off” schedule). This methodology ensured that comparisons were made across the same time of day, the same day of the week, and same cohort of water heaters. However, it did not account for changes in hot water usage driven by weather or holidays. Weather-related differences were minimized by selecting baseline periods as close as possible to the controlled periods, with a maximum offset of two weeks.

The final “Estimate of Shifted Energy” was calculated as the difference between the power consumption of the entire controlled fleet during a curtailment period and the baseline power consumption of those same units during the corresponding hours either one or two weeks prior. This energy calculation included devices that were online but did not respond to the curtailment signal, reflecting realistic operational conditions. However, event periods during which a device spent a significant portion of time offline due to connectivity issues were excluded, as the corresponding baseline period would not provide an accurate comparison if the number of “device hours” differed between the event and baseline windows.

Operational State Tracking

As an additional measure for evaluating the fleet’s responsiveness to CTA events, operational state tracking was included in the Estimated Load Shifted analysis. This metric tracks, for each minute of every event, the operational state of each device that received a CTA-2045 event and calculates the proportion of the fleet in each operational state. Incorporating operational state data provides insight into the effectiveness of end-to-end event signaling between the cloud dispatcher, the EcoPort module, and the SGD.

An “idle” state indicates that the SGD is not actively consuming power to heat water, whereas an “active” state indicates that the SGD is heating water, outside of the minimum baseline power draw required for background processes. The operational states tracked in this analysis are as follows:

Table 1: CTA-2045 Operational State Codes

Operational State Code	Mode
0/1	Idle/running normal
2/4	Running/idle curtailed
3/6	Running/idle heightened
11/12	Idle/running opted out
Other (5, 7, 8, 9, 10, 13)	All other states (error codes, etc.)

In an ideal curtailment event scenario, most water heaters would operate in State 4 (idle curtailed), with the occasional instances of State 2 (running curtailed) when an imminent cold-water event required the water heater to activate despite the curtailment event—prioritizing customer comfort.

Occasionally, devices may operate in State 11/12 (idle/running opted out), since some homeowners could place their water heater into either "CTA opt-out mode" (typically used during times of higher-than-expected household hot water usage, for example, when guests are staying at the customer's house) or "vacation mode" (typically used when nobody is home for an extended period). Distinguishing between these two states relies on interpreting both total capacity values and power-consumption patterns. An SGD is determined to be in "opted out" mode when it reports normal capacity and significant power consumption. Conversely, an SGD device reporting zero capacity for an extended period, coupled with minimum power consumption, indicates a water heater has been placed in vacation mode. In both cases, the potential for load shifting is effectively nonexistent.

During curtailment events, the water heater should not appear in operational States 0 or 1, or "Other." Operational States of 0 or 1 indicate that the EcoPort module either did not receive the curtailment signal from the cloud or that the water heater failed to respond to the signal. High representation in these states would therefore suggest communication or compliance issues within the signaling chain.

Additional Research Questions

Throughout the study, additional research questions were added to the original list. These questions, along with the rationale for their inclusion, are as follows:

1. **How does the shiftability of an electric-resistance water heater differ from that of a heat pump (hybrid) water heater?** This study represents a first-of-its-kind mixed fleet of electric- resistance and heat pump (hybrid) water heaters. Understanding the relative shiftability and total power consumption of each technology type may yield important insights for identifying load shifting opportunities at scale.
2. **What variations in performance, conformance, and compliance are seen across different manufacturers and across product lines within a manufacturer?** This study included a diverse fleet of 31 models across four manufacturers, providing valuable "in-the-field" data on device behavior and CTA-2045 implementation differences.
3. **How can a DERMS increase the value of a shiftable fleet by "fine tuning" the sequence of event signals sent to the connected water heaters?** Early in the study, several compliance issues were identified through daily load-shift analyses. To improve the load-shift capability of the fleet, the study partner implemented a series of adjustments to standard control sequences, collectively referred to as "smart actions." These adjustments were intended to improve the baseline demand response behavior of the fleet of connected water heaters.

4. **What is the customer's ability to successfully install the EcoPort module without installer assistance, and does this lead to a significant number of "stranded assets"?** While the original study design included only water heaters installations with a professional present, and providing the module to the customer for installation, the study expanded to include self-installed water heaters with self-installed EcoPort modules.

Findings

Participant Experience: Survey Response and Customer Support

Survey 1 – Completed at Time of Installation Enrollment

Survey 1 focused on assessing the ease of EcoPort module installation, the usability of the mobile application for study enrollment, and whether participants required assistance during either the module installation or onboarding processes.

Response Rate

There were 102 total recorded responses to Survey 1 out 110 completed installations, yielding a response rate of 92.7%. Since the survey was the final step of the in-app study enrollment process, eight customers abandoned the app before completing enrollment. However, these eight customers were still included in load-shifting testing because they had provided all necessary information—including utility, water heater model, and EcoPort module serial number—and had signed the study terms and conditions. Any customer who did not sign the study terms and conditions was excluded from all load shifting events.

Customer Responses

- Ease of app use: 4.2 / 5.0
- Ease of installation and connection: 4.4 / 5.0
- Required assistance from installer with EcoPort module installation: 46.5%
- Required assistance from installer with study sign-up process: 40.6%

Survey 1: Survey Response Excerpts

- “Very helpful to have the contractor walk me through the process, even though it was fairly simple.”
- “Install point was not where the picture showed it being”
- “I needed to scan the QR code in the installer’s phone rather than the one on the module - this was confusing”
- “The module doesn't sit perfectly level on my water heater's CTA adapter plate so I needed to add a small cardboard shim before tightening the screws down. Without that shim it looked a bit odd. None, it was super easy.”

Survey 2 – 45 Days Post-Installation

Survey 2 gauged user satisfaction 45 days after EcoPort module installation, focusing on perceived changes in hot water availability and general impressions of the study.

Response Rate

Survey 2 yielded a lower response rate (62.7%, or 69/110) than Survey 1. All enrolled customers (n = 110) were invited to complete the second survey regardless of whether they had responded to Survey 1. Survey 2 was delivered both through the study app and via the email address associated with each customer's account. Responses from each platform were treated identically.

Customer Responses

- Likelihood to recommend the program: 4.3 / 5.0
- Perceived reduction in hot water availability: 2.9% (2/69)

Survey Response Excerpts

- "I have not noticed any change to our hot water."
- "[S]hare more usage details with the end user."
- "I've noticed lower electric bills but have not had any moments of no hot water supply. The hot water has been available when I needed it and has not run out while using."
- "No recommendations as it has been smooth sailing from my perspective."
- "My installer was a little confused about installing the monitoring hardware on a non-hybrid water heater. Better instructions?"

Survey 3 – 90 Days Post-Installation

Survey 3 assessed user satisfaction 90 days after installation, repeating the same questions used in Survey 2 to identify any changes that occurred over the intervening 45-day period.

Response Rate

Survey 3 exhibited a response rate lower than that for Survey 2 (43.6% [48/110], compared to 62.7%). All enrolled customers (n = 110) were invited to complete the third survey, regardless of whether they had responded to Survey 1 or Survey 2. The distribution method was identical to that used for Survey 2.

Customer responses

- Likelihood to recommend the program: 3.8 / 5.0
- Perceived reduction in hot water availability: 4.2% (2/48)

Survey Response Excerpts

- "Arrange for direct deposit rather than printing checks"
- "I would appreciate seeing the results and impact of the program on my unit's interaction with the grid like run time, scheduling, and/or alignment with cleaner generation resources"
- "A final synopsis message?"
- "Don't allow the study to commence in conjunction with large home renovations."

Installer Surveys

Installers were also invited to complete surveys regarding their experience with the study. Surveys were delivered through both email and in-app notifications. However, unlike the study participants, installers were neither required nor incentivized to complete these surveys, which unsurprisingly resulted in low response rates. The first survey was requested after the first installation, and a total of seven installers responded to the first survey out of 14 confirmed installers, yielding a response rate of 50%. The second survey was sent to installers once they completed five installations; among the four installers who met this threshold, three responded, for a response rate of 75%. The third survey was sent to installers who had completed 10 installations. Of the two installers who qualified, only one responded, for a response rate of 50%.

Key Metrics

- Survey participation (total): 55.0%
- Assisted customer with EcoPort module installation: 85.7%
- Assisted customer with study sign-up process: 28.6%
- Ease of app use: 3.9 / 5.0
- Ease of installation and connection: 5.0 / 5.0
- Likelihood to recommend the program: 5.0 / 5.0

Survey Response Excerpts

- "Confirming email seems impossible."
- "It's getting much better"
- "Nothing, pretty great so far"

Installer Survey Summary

Installer survey responses indicated generally high satisfaction with the study. Although installers rated the ease of using the enrollment app slightly lower than customers did (3.9/5.0 compared to 4.2/5.0). In follow-up interviews, installers reported being pleased with the ease of installing the EcoPort module. All five installer respondents in the follow-up interviews indicated that they would recommend participation in the study to a colleague. While installers were not supposed to install the EcoPort module for the customer, they were authorized to assist if the customer was having difficulty or requested help.

Results from the first installer survey (collected after the first installation) indicate that customers received assistance for 86% of installations, whereas customers reported needing assistance with EcoPort module installation 46.5% of the time. Due to the small number of installers participating in the study and the limited number of installer surveys (seven), we cannot draw a conclusion about the variance in results.

Customer Service Contact Analysis

This section summarizes the customer and installer communication with the customer support line established for the study. After preliminary testing confirmed that phone calls were being routed correctly, calls were split among participants, installers, and non-program members.

Table 2: Breakdown of customer support calls

Caller Type	# of Calls
Test	5
Customer	15
Non-Customer	18
Unconfirmed	16
Installer	8
Total	**62**

Customer Calls

The customer support line received a total of 15 calls from confirmed study customers. Of these calls, six were related to the installation and connection of the EcoPort module or issues completing study enrollment through the enrollment app. Five calls focused on questions related to the study's timeline and incentive process, including difficulties claiming incentives and clarification regarding the appropriate time to remove their EcoPort module at the end of the study. Three calls were placed to confirm that their installation and enrollment had been successfully completed. One call involved a request for additional mobile application functionality, namely the ability to see their hot water usage patterns.

There were no calls regarding cold-water events during the study. The absence of such reports may suggest that the load shifting events implemented across the fleet were effective in maintaining adequate hot water availability for customers. However, there was a single report of a cold-water event in a customer survey, but the level of data collected does not reveal if this event was on a day that the water heater was participating in events, was due to higher-than-normal hot water use in the home, or due to a change in size of the water heater.

Installer Calls

A total of eight calls were recorded from installers over the course of the study. These were largely focused on EcoPort module installation and assistance navigating the enrollment application. All installer calls occurred early in the study, before April 21, 2025, indicating as installers gained experience with both the module and the study registration interface, the need for support diminished. Apart from one installer who called twice within a 10-minute period regarding the same installation, no repeat callers were observed. This pattern suggests that installers did not encounter persistent or systematic issues with the installation progress or the enrollment application.

Non-Participant and Other Calls

Approximately 34 calls originated from non-participants (individuals whose affiliation with the study could not be determined). Of these, 10 were labeled “information only”; however, customer service representatives did not provide accompanying notes, making it unclear what information was sought and whether these calls were resolved. An additional 18 calls were from individuals not affiliated with the study, including wrong numbers and callers interested in non-study-related products or services. To reduce misdirected inquiries in future studies or programs, all disbursed materials should clearly state that the dedicated customer service line is for study or program-related support only.

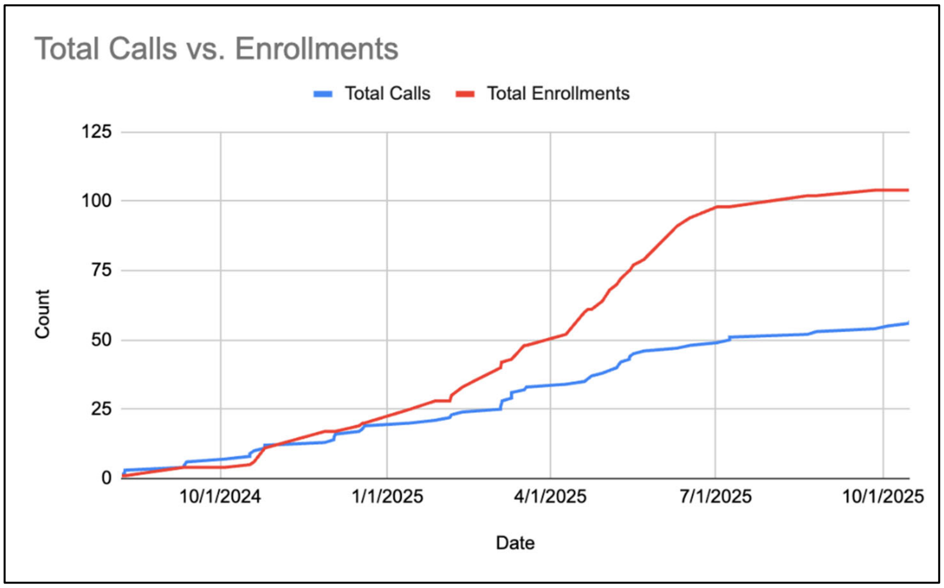

Figure 5: Comparison of calls to support line vs. study enrollments

Water Heater Fleet Composition

A total of 110 water heaters were enrolled in the study from four manufacturers (labeled A through D in this report for anonymity). Of these, 77 were heat pump (hybrid) water heaters equipped with both a heat pump and a backup electric resistance element. The remaining 33 were electric resistance water heaters that relied only on electric resistance elements for heating.

However, six of the enrolled water heaters failed to report, or failed to accurately report, one or more required data streams—instant power consumption, instant capacity, or operational state—or disconnected before completing the two-week baselining period. As a result, only 104 of the 110 enrollments were deemed eligible to participate in load shifting events.

Two additional enrolled water heaters showed abnormally high hot water usage, consistently operating at or near their maximum capacity even without any load shifting signals. These units were included in the study cohort for the purpose of characterizing potential shiftable load among heavy-use households. However, these water heaters were not sent any events. One of these units was briefly sent events before being removed from the event recipient group when it became clear that the events negatively affected the unit's ability to maintain adequate capacity.

Therefore, all load shifting effectiveness metrics presented hereafter will be based on the 104 devices that presented sufficient data conformance for analysis. All event response data are based on the subset of devices that received demand response events, a group that ranged between 6 and 101 devices as enrollment increased throughout the study.

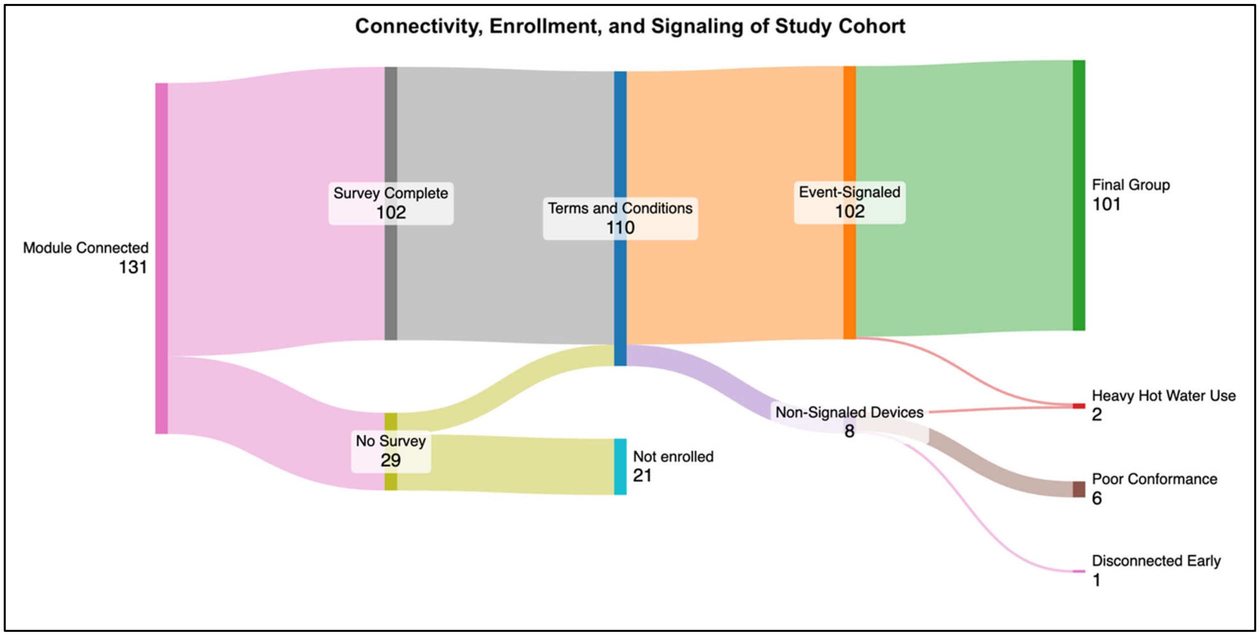

Figure 6: Connectivity and enrollment of EcoPort modules in the study cohort

Of the devices deemed ineligible due to conformance issues, five were electric resistance models and one was a heat pump (hybrid) model. All water heaters exhibiting poor conformance were manufactured by either Manufacturer C or Manufacturer D. The breakdown of the eligible fleet is as follows:

Table 3: Breakdown of enrolled vs. participating SGDs by manufacturer and SGD type

Manufacturer	HPWH	ERWH	Eligible
A	18	1	19
B	57	28	85
C	0	5	0
D	1	0	0
Total	**76**	**34**	**104**

Fleet Composition by Geographic Region Utility

Of the 102 completed surveys, 99 contained correctly formatted pictures of the utility meter, which served as the primary method for confirming the customer's electric utility provider. The remaining three surveys contained unusable images (such as a closed closet or of the water heater itself), thereby preventing confirmation of the customer's utility information. The distribution of devices by utility is summarized as follows:

Table 4: Device count by utility

Utility	Device Count
Portland Metropolitan Area	38
Puget Sound Area	42
Oregon PUD	23
Unknown	3

EcoPort Module Connectivity

Overall, the connectivity of the installed EcoPort modules remained high throughout the study. As illustrated in Figure 7, the number of connected devices remained consistently elevated, with little to no drop-off of device counts through the duration of the event schedule. In total, only five enrolled EcoPort modules ceased communication between their installation date and the conclusion of the study's tracking period, October 31, 2025.

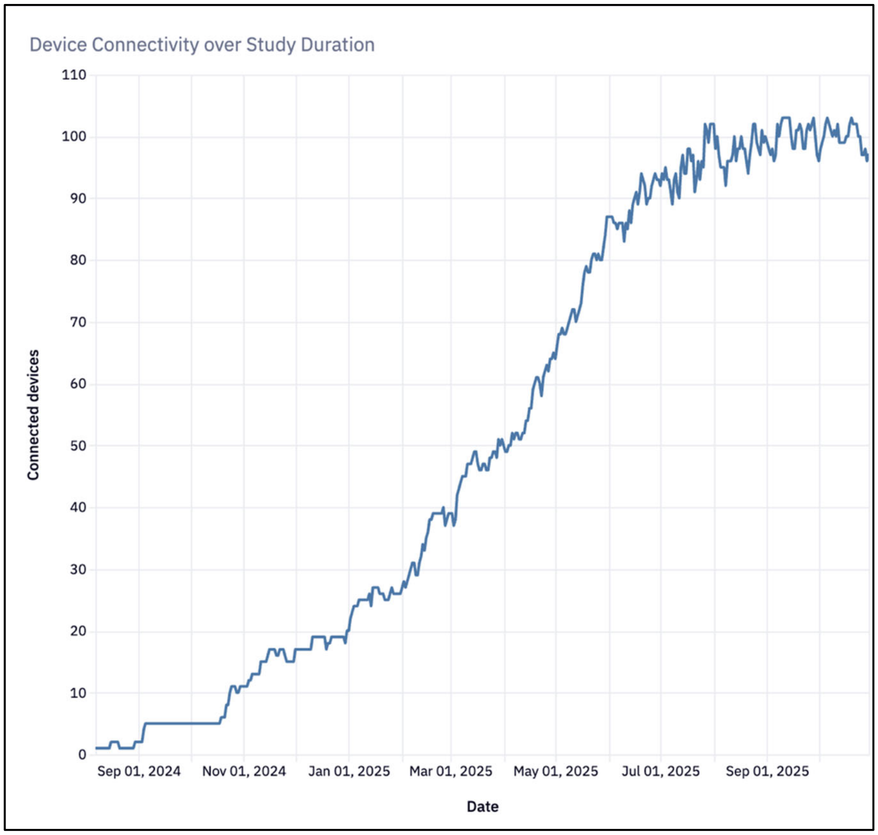

Figure 7: Total number of connected devices throughout study term

Although it is not possible to definitively determine whether a loss of connectivity resulted from a physical issue (e.g., removal of the EcoPort module, loss of power to the water heater) or from a disruption in cellular connectivity, general connection strength can be inferred through analysis of missed information packets. Devices exhibiting consistently poor connectivity—characterized by high packet loss rates—followed by lost connection were likely affected by deteriorating cellular signal strength. Conversely, devices showing strong connectivity (low packet loss) before abruptly going offline for an extended period were more likely to have experienced non-cellular issues, such as loss of power to the SGD, manual disconnection, or in rare cases, full device malfunction.

Table 5: Downtime percentage of devices that disconnected during study's duration

MAC	Downtime Percentage	Days Online	Surveys Completed	Last Recorded Communication	Last Incentive Provided
508066883391	29.58%	0.1	2 (surveys 1 and 3)	3/07/2025	7/28/25
508065104708	29.03%	100.5	3	7/30/2025	7/28/25
508066883961	0.86%	141.1	2	10/28/2025	7/28/25
508066883102	0.28%	187.0	2	10/20/2025	6/04/25
508065105929	0.17%	93.2	3	04/27/2025	4/23/25

Analysis of the five devices that ultimately disconnected indicates that only two exhibited significant connectivity issues before going offline. As shown in Table 5, the "downtime percentage," calculated as the proportion of total minutes during which the device failed to communicate, using a 15-minute communication gap as the floor for identifying a connection gap, was below 1% for three of the five units. This pattern suggests that connectivity was not the underlying issue for these devices going offline; rather, physical removal or loss of power to the device is a more plausible explanation for the connectivity ceasing.

One device (MAC 508066883391) was online for only a few hours after installation. However, the customer completed Survey 3, making it more likely that the disconnection was due to a connectivity issue rather than a withdrawal from the study.

For another device (MAC 508065104708), a poor cellular signal appears to be a credible explanation for disconnection. Over the 101-day period between its initial and final transmissions, the device was offline for 29.03% of that time, suggesting a very poor cellular connection. However, it is also possible that the customer mistakenly believed that the study was complete after receiving their final incentive payment, as discussed in the following paragraph. Therefore, since physical removal or loss of power cannot be ruled out, it is likely that three or four devices disconnected due to removal or power loss, while one or two devices disconnected due to poor cellular connectivity.

Of the five devices that experienced early disconnection, four had already passed the initial 90-day study window, and two had completed and received incentives for all three surveys. One of the five disconnected customers completed the first and third survey, but did not complete the second. For the two customers that completed all three surveys, disconnection occurred within five days of receiving their final incentive payment, suggesting that they believed the study was complete and that the EcoPort module should be removed. Clearer communication regarding the ongoing nature of the study could have potentially mitigated this issue. This issue would be less likely in future programs in which incentives for maintaining SGD connectivity are ongoing rather than limited to a fixed, three-time payment structure.

Self-Installed EcoPort Modules

The “self-installed” EcoPort Modules were those offered to customers as part of their free heat pump (hybrid) water heater order in conjunction with a utility promotion (see section **Self-Installations**). Utility customers ordered approximately 150 water heaters; of those, 46 customers (31%) ordered an EcoPort module packaged with their HPWH. Of the 46 ordered, 31 modules (67%) were installed and achieved cellular connection. It remains unclear whether some modules were installed but unable to achieve cellular connection; however, no reports of such occurrences were made to the study’s customer service line. Anecdotally, the utility reported one customer did not have cell service at their home due to their rural location.

One key challenge associated with self-installation of the module emerged during study enrollment. Among the 31 customers whose EcoPort modules successfully connected, 11 (35%) did not complete the terms and conditions within the enrollment application. As a result, these customers were ineligible for both study participation incentives and inclusion in the load shifting schedule. This stands in contrast to installations with a professional installer present, for which only 10 out of 100 (10%) installed devices lacked an associated study enrollment—defined as both customer account creation and acceptance of the study’s terms and conditions.

Therefore, of the 46 EcoPort modules shipped to customers for self-installation, only 20 (43%) were eligible for full study participation and survey incentives. Figure 8 provides a visualization of customer enrollment and participation through the self-installation pathway.

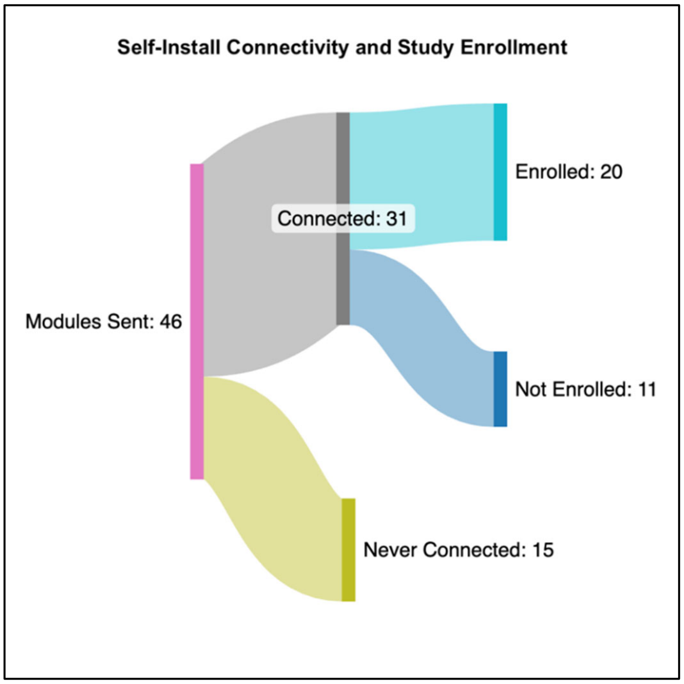

Figure 8: Connectivity and enrollment of EcoPort modules provided for self-installation

Smart Actions

As the study progressed, several additional demand response event call features were introduced to the Load Up and Shed event patterns dispatched to the enrolled fleet. These features were added sequentially throughout the study in response to observed limitations in the initial load shape and were informed by preliminary performance results. Each added feature was intended to refine event effectiveness, improve customer experience, or address operational shortcomings identified during early stages of the study.

Smart Start

The study added a new feature, "Smart Start," that ensured all water heaters fully curtailed at the very start of the event in response to the following discovery: During the early months of the study, it became apparent that a portion of the fleet continued heating beyond the completion of the "Load Up" event and into the first 30–60 minutes of the "Shed" event. This behavior was surprising, particularly as many of these units reported low-capacity values, indicating they were not at risk of a cold-water event and should not have required additional heating.

Subsequent analysis revealed that by the end of the “Load Up” event, some water heaters had not yet reached 0 watts, the indicator of a fully heated tank. As a result, these units continued heating—regardless of operational state commanded by the event—until the tank reached its setpoint temperature. Discussions with manufacturer representatives confirmed that this behavior was an intentional feature of the SGDs’ logic: the devices are programmed to heat to setpoint whenever capacity is available, independent of demand-response event status.

This behavior undermined the intended effect of a Load Up and Shed cycle. Excess heating during the curtailment period increased power consumption at precisely the time when reductions were expected, thereby diminishing the effectiveness of the load shifting strategy, as illustrated in Figure 9.

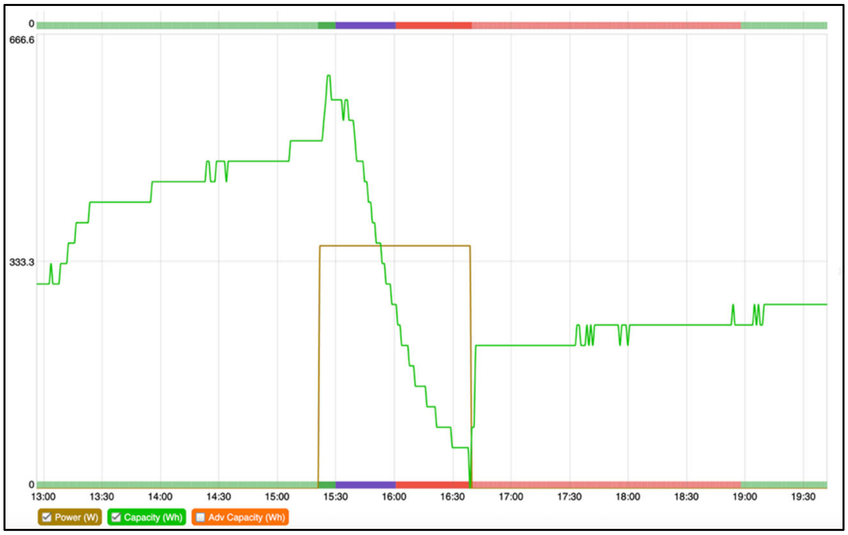

Figure 9: Water heater continues heating during a transition from a Load Up (purple) event into a Shed (pink) event, despite safe capacity level

To address this issue, a “Critical Peak” event was implemented March 31, 2025, followed by the eventual implementation of a “Grid Emergency” event starting June 23, 2025. Each of these commands was applied for a brief, two-minute period during the beginning of each curtailment event. The Grid Emergency event fully disables all water heater power use unless a potential for frozen pipes is detected (A.O. Smith Corporation 2023), making it the most effective mechanism for preventing unintended heating at the onset of a curtailment event.

The short-term Grid Emergency command shut off all power, acting as a system “reset” and ensuring that water heaters no longer continued heating until reaching zero capacity. Instead, water heaters resumed operation only when their curtailed capacity threshold was breached or when the curtailment event had ceased. This intervention successfully mitigated the unintended heating behavior and restored the intended performance of the Load Up and Shed cycle. This is seen in Figure 10 below, where a unit has not yet achieved 0 capacity at end of Load Up event (purple bar), but ceases heating until curtailment event (pink bar) ends.

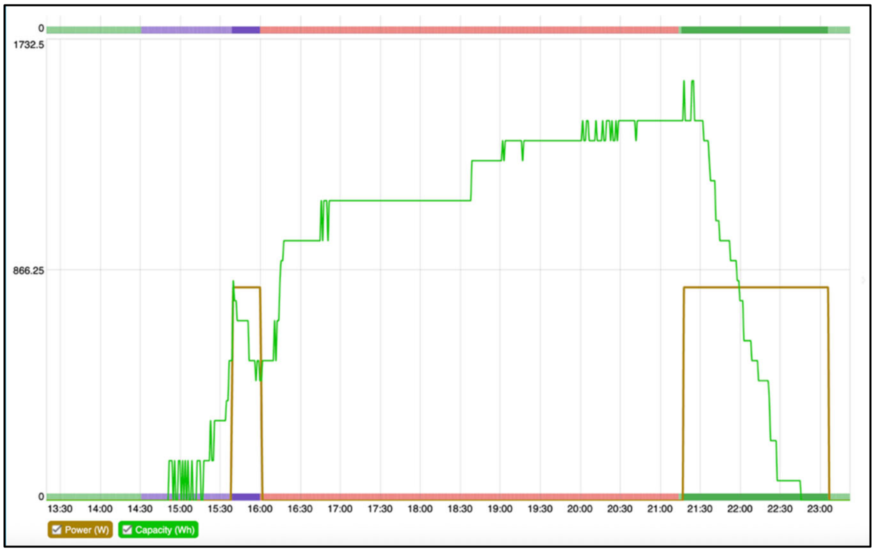

Figure 10: Water heater responding to a "smart start" event

However, although isolated cases demonstrated a noticeable improvement, the overall effect of this intervention was modest when evaluated across the entire fleet. Events conducted without the Smart Start command exhibited an average power consumption of 55.74 watts across the fleet during the first hour of the curtailment period, whereas events with the Smart Start in place averaged 53.63 power consumption during the same duration. This represents a reduction of 2.11 watt-hours per unit, per event, or a 3.79% decrease in power consumption.

Table 6: Average power consumption during first 60 minutes of curtailment event with no Smart Start, critical peak Smart Start, and grid emergency Smart Start.

Smart Action	Total Events	Avg Power, First 60 Mins
1: No Smart Start	1,351	55.74
2: Critical Peak Smart Start	2,855	45.76
3 Grid Emergency Smart Start	8,375	56.31
All Smart Start	**11,230**	**53.63**

Feathering

The second issue observed during the study was a sharp increase of power consumption directly following the conclusion of a curtailment event. Commonly known as "snapback," this occurs when previously curtailed devices simultaneously resume heating to recover lost thermal capacity. Although this rebound reflects successful compliance during the load shifting event—demonstrating that the water heaters successfully reduced power consumption when instructed —it also produced a pronounced short-duration spike in power consumption once the water heaters returned to their "normal" operational state.

While snapback poses minimal concern for a small, geographically dispersed fleet of SGDs, it can cause operational issues when large numbers of SGDs receive identical event schedules, particularly when many units are in close proximity. In such cases, synchronized post-event recovery can generate localized demand spikes that may strain distribution-level infrastructure or offset some of the intended benefits of the curtailment event.

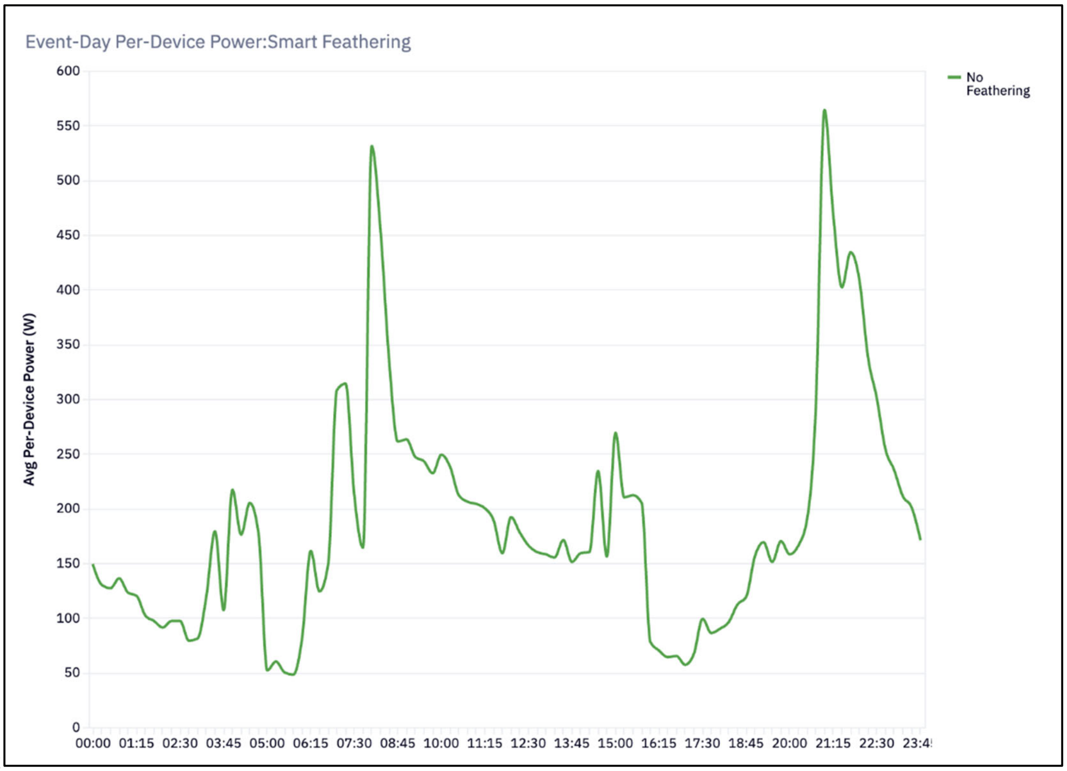

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Figure 11: Sharp snapback occurs at end of event (event days 1/1/25 – 3/31/25)

To mitigate this issue, Snapback Mitigation was added to the study's event schedule on March 31, 2025. The initial snapback mitigation strategy consisted of dividing the participating fleet of water heaters into groups and then sequentially staggering the end times of the curtailment event group-by-group, rather than all at once. Initially these groups were randomized, and each device's event end time was specified when the initial curtailment event was sent. By distributing reheating activity over a 30–60-minute window, this approach reduced the magnitude of the post-event load spike (snapback effect). However, randomized distribution of event durations introduced a potential drawback: participants with high hot-water usage faced an increased risk of experiencing a cold-water event if their water heater happened to be assigned a longer curtailment duration.

To address this limitation, Smart Feathering was implemented in the study event schedule on May 29, 2025. This enhanced snapback management strategy used each water heater's instant capacity value to dynamically rank participating devices from highest to lowest risk of cold-water events. Curtailment end times were then assigned accordingly: water heaters with the highest reported instant capacity value (i.e., higher risk) were released from the event earlier, while those with lower instant capacity values remained curtailed longer. This approach simultaneously reduced the snapback effect post-curtailment event and prioritized customer hot water availability.

Smart Feathering was further expanded on September 15, 2025, extending the staggering-release window to 90 minutes, by starting the feathering process at 8:00 PM rather than 9:00 PM. This extension allowed for a more comprehensive evaluation of the fleet's ability to mitigate the sharp snapback effect under a longer, more distributed recovery period.

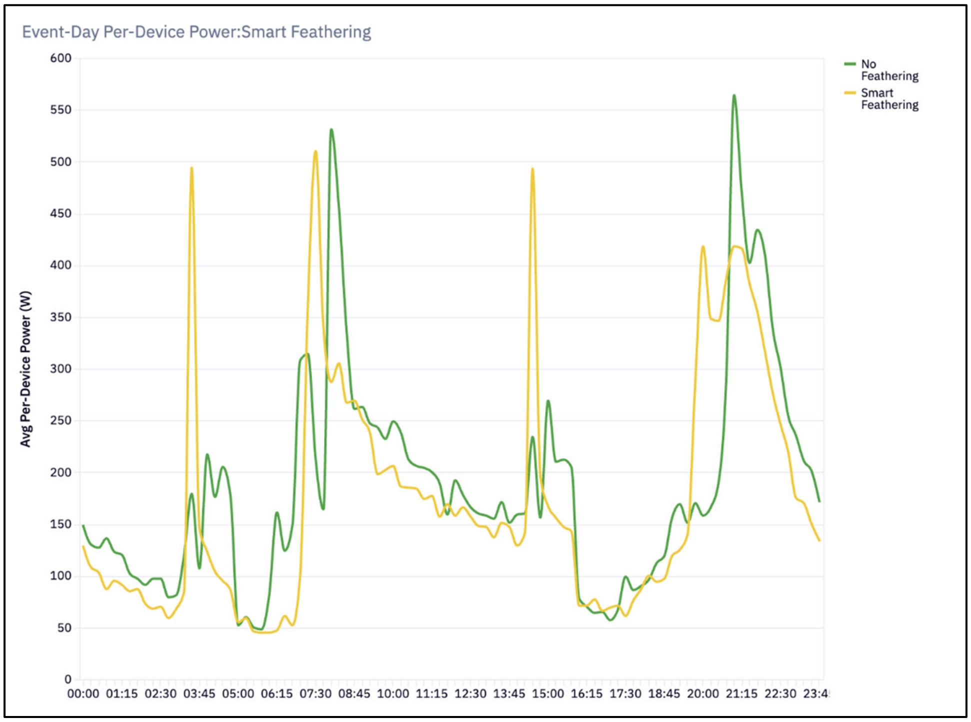

Figure 12: Comparison of pre-feathering load shape (green) and post-feathering load shape (yellow), showing particularly in the evening, a reduction in peak snapback

However, the effectiveness of Smart Feathering heavily relies on the accurate reporting of instant capacity values—an assumption that did not hold true for a significant portion of the participating study fleet. In principle, when a water heater reaches its setpoint temperature, the energy required to raise the real-time temperature to the setpoint should be 0 watts, indicating a fully charged tank. In practice, many SGDs failed to report a minimum capacity of 0 watts, even immediately after completing a heating cycle. Some devices never reported values below 2,690 watts capacity regardless of operating conditions.

This inconsistency made it impossible to reliably compare values across water heaters or to determine which units were at higher risk for cold-water events. To address this issue, the study team developed “Smart Capacity Translation,” a method designed to establish the “true zero” capacity value of these SGDs and normalize reported capacity values across the fleet.

Smart Capacity Translation

One “smart” feature implemented for the fleet was Smart Capacity Translation. Although this feature does not directly send any CTA-2045-B commands to SGDs, it plays a critical role in informing the other smart actions by providing a more accurate representation of each unit’s capacity (energy take).

Many units in the SGD fleet reported unexpected capacity values. In principle, capacity value should reach 0 when the SGD has reached setpoint temperature (Paresa and Bass 2024). However, 57.4% of evaluated units reported instant capacity values above 0 at the end of their heating cycle.

This inconsistency poses a significant issue, especially when attempting to rank all water heaters from “furthest-from-setpoint” to “closest-to-setpoint.” Devices that incorrectly reported artificially high capacity values, such as when they are fully or near-fully heated, would appear to be at a higher risk of a cold-water event than they actually were. As a result, these units could effectively “cut the line” during a smart feathering event, ending their curtailment prematurely.

To correct for this, a capacity translation logic set was implemented. For each SGD, the system registered the minimum recorded capacity value (ignoring any null values that were sometimes incorrectly converted to 0). The translated capacity was then calculated by subtracting this minimum value from the SGD’s current reported capacity.

For example, if an SGD had never reported a capacity below 575 watts, even immediately after a heating cycle, and its current instant capacity reading was 900 watts, the translated capacity would be:

900 W – 575 W = 325 W

This translation established a corrected capacity for each device, enabling more accurate reporting and improving the performance of downstream “smart features” such as smart feathering.

Estimated Load Shifted from CTA-2045 Events

Demand Response Operation State Compliance

To track the operational state of an individual SGD or the fleet as a whole during the study, each device's operational state was evaluated at each heartbeat (individual transmission of power, capacity, and operational state from the EcoPort module to the cloud) during each curtailment or heightening event. Each timestamp was categorized into one of three classifications.

1) Compliant: Reported operational state fell within the expected bounds of the active DR event. For example, during a fleet curtailment event, an operational State 2 or 4 (running curtailed or idle curtailed, respectively) was deemed compliant.
2) Non-Compliant: Reported any operational state inconsistent with the DR event. These included heightened, normal, or any error condition. These states indicated that the SGD was not following the event instructions.
3) Opted-Out: Reported the device was set to not respond to DR events. In this mode, it is not possible to determine whether the module received the event signal, nor would the SGD be expected to modify its behavior in response. Opted-out states were therefore tracked separately from compliant and non-compliant states.

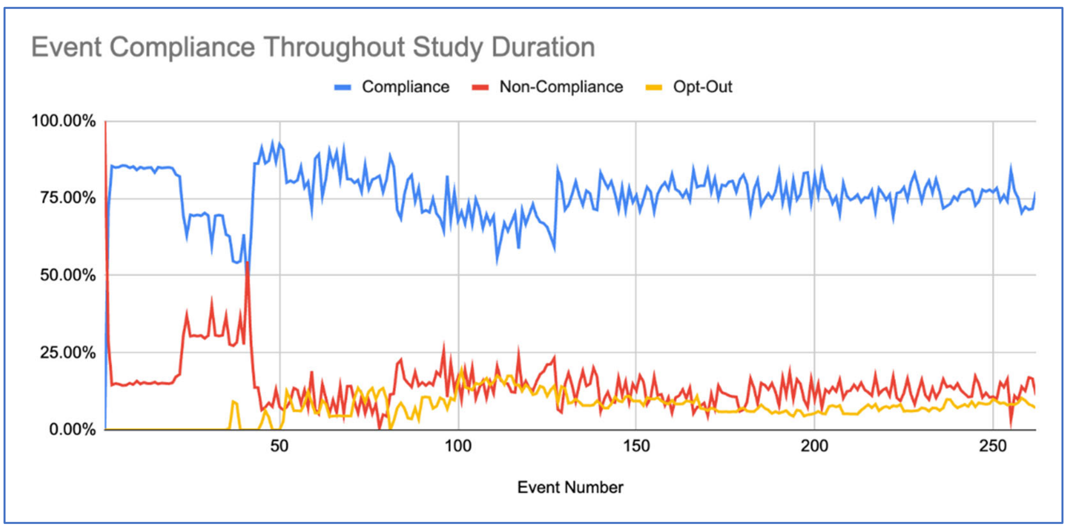

Figure 13: Event compliance by operational state throughout study duration

Throughout the duration of the study, the fleet achieved an average event compliance rate of 78.69%, with 13.28% non-compliant and 8.03% categorized as opt-outs. To better understand the drivers of event non-compliance, the following sections examine the distribution of opt-out types as well as the relationship between connectivity rates and event uptake performance.

Opt-Outs

Analysis was performed across the fleet to characterize the typical "opt-out period" and its underlying causes. Four primary categories of water heater opt-outs were identified – Customer-initiated 24-hour opt-out, vacation mode, OEM safeguard opt-out, and new installation opt out—though this list may not be exhaustive.

Type 1 – Customer-initiated 24-hour opt-out: Customers may manually opt out of demand response signals for a 24-hour period using the water heater control panel. This action is typically taken to ensure hot water availability when the customer anticipates elevated hot water usage.

Type 2 – Vacation mode opt-out: Customers may also select a vacation setting on the control panel through the OEM's phone application when they expect to leave their home for an extended period. In this mode, the water heater minimizes energy use and reheats only as needed to prevent freezing. This behavior is reflected in very low hot water consumption during the opt-out period (A.O. Smith Corporation 2023).

Type 3 – OEM safeguard opt-out: Manufacturers incorporate protective logic to prevent excessive cycling. If the water heater turns on and off too many times within a short period, the system may automatically enter an opt-out state to protect equipment and maintain performance.

Type 4 – New install opt-out: Newly installed water heaters that have an EcoPort module co-installed at the time of installation often remain in an opt-out state for 24–48 hours after installation. This appears to be a feature that prevents customers with newly installed water heaters from experiencing a demand response-induced cold-water event, appearing to be transitional behavior as the device initializes.

Type 1 and Type 2 are triggered directly by customer interaction with the control panel, whereas Type 3 and Type 4 originate from the water heater's internal logic. Additional opt-out mechanisms may exist, as any condition that prevents the SGD from responding to grid signals can be reported as an opt-out.

A non-exhaustive analysis of common opt-out events is presented below. Across the study (August 1, 2024–October 31, 2025), a total of 265 opt-out events were recorded among enrolled devices. Event durations ranged from under one minute to over 100 days, though several distinct clusters of duration were evident, shown in Table 7.

Table 7: Opt-out periods by duration

Duration	Number of Instances
<1 Hour	16
1–23 Hours	11
1 Day (+/- 1 hour)	178
1 Day–1 Week	46
Longer than 1 Week	14
Total	265

Type 1 Opt-Outs: Customer-Initiated

Of the 265 recorded opt-out events, 178 (67.2%) had durations between 23–25 hours. Minor variations are expected due to the imprecise timing of information packet delivery. Most events in this cluster are assumed to represent Type 1 opt-outs, in which customers intentionally disable demand response participation for a single day. Fifteen events within this group are assumed to be Type 4 opt-outs, occurring immediately after installation when the unit was not yet ready to receive grid signals (see section **Type 4 Opt-Outs: New Install**).

Within this group, water heaters were actively heating for 19.2% of the opt-out period and remained idle for 80.8 percent. For comparison, on a "non-controlled" day—when the device is in standard operating mode—units were active approximately 30.4% of the time. This finding is somewhat unexpected, as one might anticipate that customers initiate 24-hour opt-outs on days when they foresee higher than usual hot water demand.

Type 2 Opt-Outs: Vacation Mode

"Vacation mode" opt-outs were relatively uncommon in this dataset. Several factors may contribute to this rarity. Most notably, it is unclear whether all OEMs configure their water heaters to report an "opt-out" state when vacation mode is activated. Manufacturer A confirmed that electric resistance water heaters do report an opt-out state under this condition, but it is unclear whether this behavior is consistent across all models among other manufacturers. Since reporting vacation mode as an opt-out is optional under the CTA-2045-B specification, full confirmation across OEMs is not possible.

To identify potential vacation mode events, the 265 total events were filtered to include only those greater than 48 hours, which totaled 28 events. Of those, only six events (21.4%) exhibited less than 1% runtime—an operational pattern consistent with minimal hot water use and therefore characteristic of vacation mode. The remaining long-duration opt-outs showed runtime levels of at least 4.7%, indicating a clear distinction between vacation mode behavior and other forms of extended opt-outs.

Type 3 Opt-Outs: OEM Safeguard

OEM-triggered opt-outs occur when a hot water heater experiences an excessive number of relay activations within a short period, based on 24-hour and 30-day rolling averages. The precise thresholds for these safeguards are not publicly disclosed. Discussions with Manufacturer A revealed that this protective feature may activate erroneously when the SGD does not maintain accurate date and time information. This is the only confirmed cause of OEM-triggered opt-outs to date, though additional triggers may exist but remain unidentified.

During the study period, 14 suspected OEM-triggered opt-outs were identified across eight unique SGDs. These events were isolated by filtering for opt-out periods longer than 48 hours that did not exhibit minimal power consumption; units with near-zero power use would be instead classified as Type 2 (vacation mode) opt-outs. All suspected Type 3 events lasted at least 16 days, with one extending over 200 days—continuing beyond the end of the study period. Runtime levels ranged from 7% to 45%, indicating normal hot water use. All SGDs associated with these events were manufactured by Manufacturer A and were hybrid heat pump models.

Although only 14 such events were observed, their durations far exceeded that of any other opt-out type. As illustrated in Figure 14, suspected Type 3 opt-outs accounted for 82% of all opt-out time recorded during the study. Consequently, this opt-out type represents a significant factor in assessing fleet responsiveness and should be carefully considered in future studies or program designs.

Type 4 Opt-Outs: New Install

There were 24 instances of “new install” opt-outs, representing 9.1% of all recorded opt-out periods. These events are presumed to reflect an OEM-implemented safeguard designed to prevent the water heater from receiving grid signals immediately after installation. Although this safeguard is unnecessary for the purposes of the study given the two-week baseline period applied to all newly enrolled devices, it nonetheless appears consistently in the data.

The average runtime during these opt-out periods was 28.5%, closely aligning with the expected runtime for water heaters operating under normal conditions across the study (30.4%). This value is slightly lower than anticipated, as newly installed water heaters typically begin with water at the inlet temperature and therefore require significant energy input to reach the setpoint.

All 24 new install opt-outs were associated with water heaters manufactured by Manufacturer B. This indicates that the behavior is not a standardized feature of the CTA-2045-B specification but rather a manufacturer-specific implementation.

Table 8: Opt-Outs by Type and Total Hours

Opt-Out Type	Count (percent of Opt-Outs)	Hours (percent Opted Out)
Type 1: Customer-Initiated	178 (67.2)	3,922 (10.3)
Type 2: Vacation Mode	6 (2.3)	682 (1.8)
Type 3: OEM Safeguard	14 (5.3)	31,313 (82.0)
Type 4: New Install	24 (9.1)	614 (1.6)
Other/Unknown	43 (16.2)	1,656 (4.3)

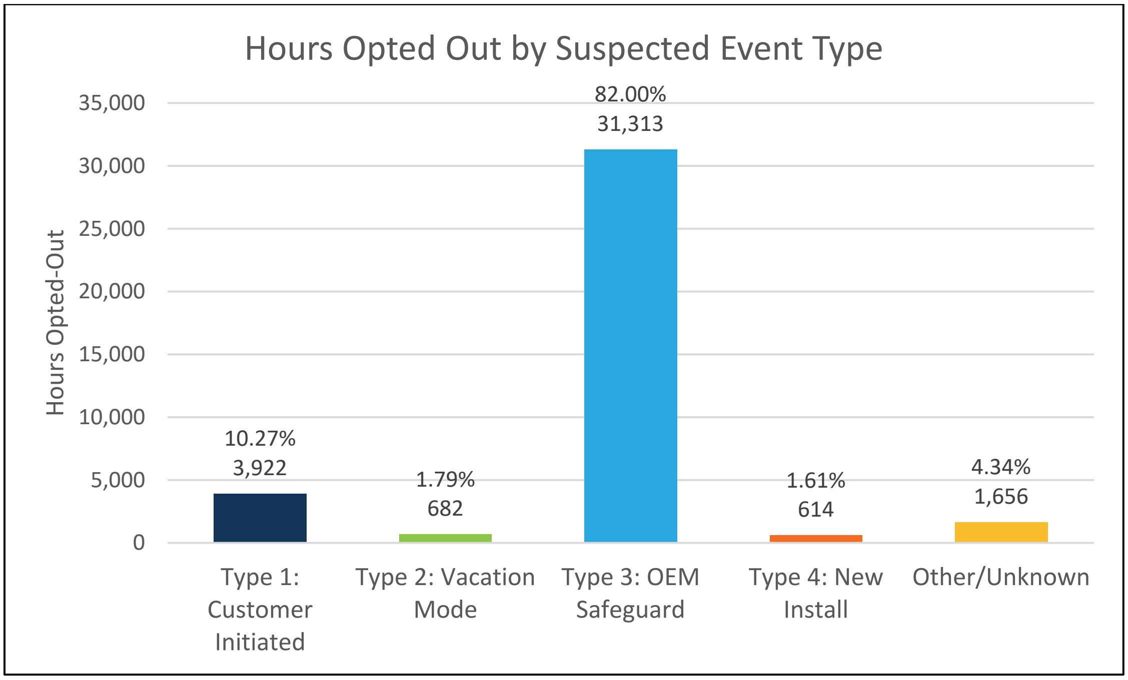

Figure 14: Hours opted out by suspected opt-out type

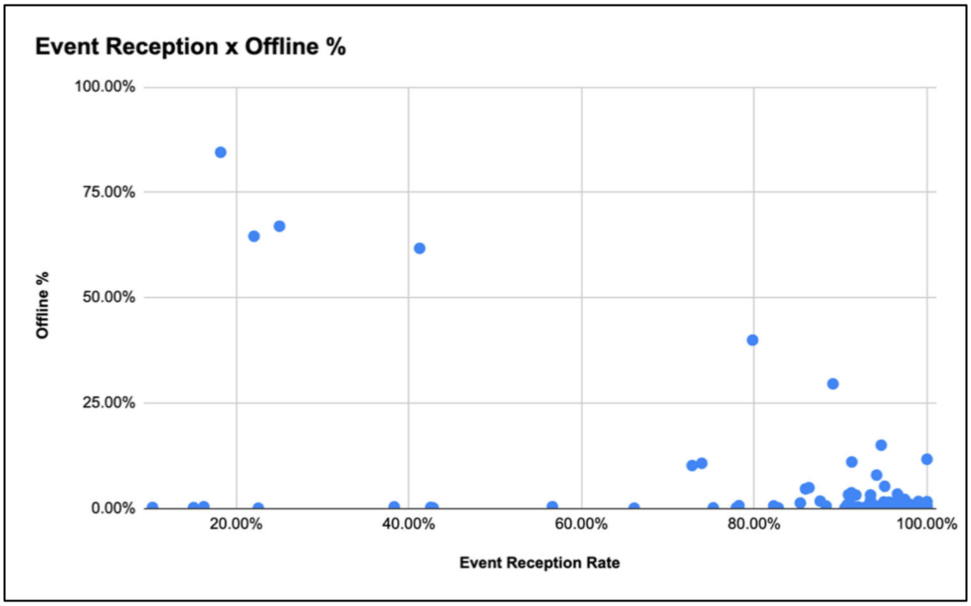

Figure 15: Correlation between offline rate and event reception rate

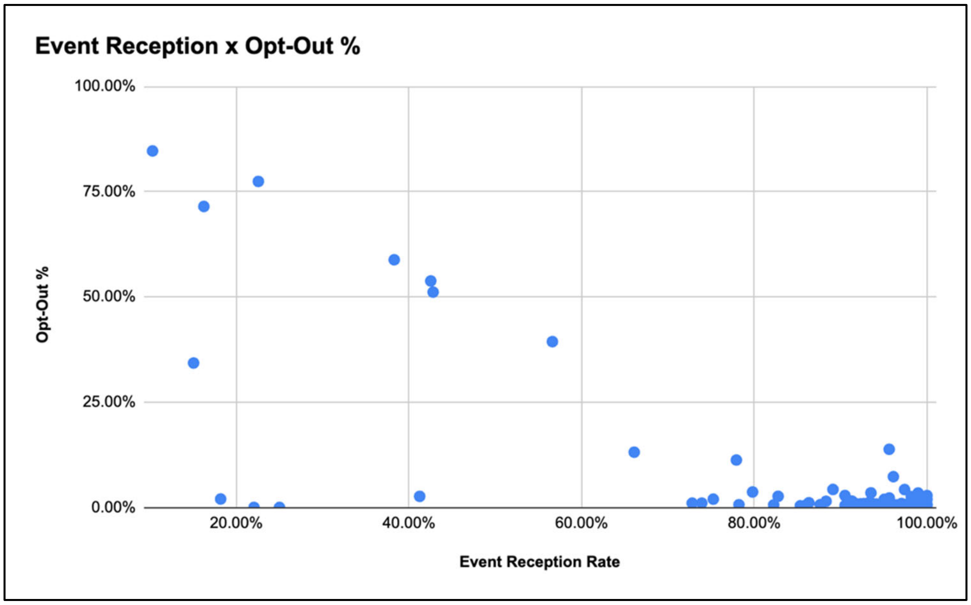

Figure 16: Correlation between opt-out rate and event reception rate

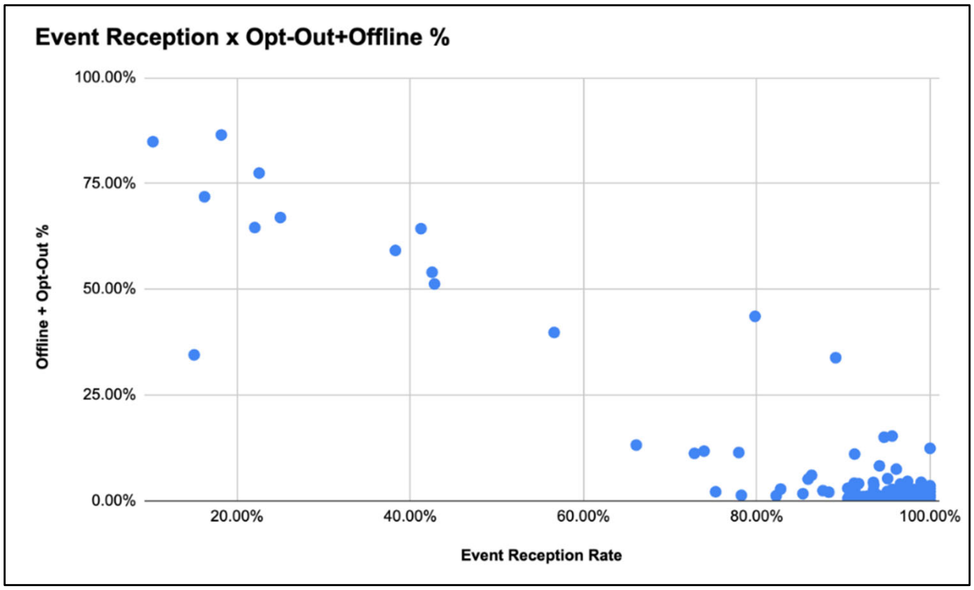

Figure 17: Correlation between device connectivity + opt-out rate and event reception rate

As shown in Figures 15–17, the two strongest predictors of event transmission success were a device's offline rate and its opt-out rate. Offline rate was calculated by identifying all communication gaps longer than 15 minutes—the maximum allowable interval between expected device heartbeats without indicating a service interruption—and summing the duration of these gaps. If a device went offline and never returned, the time between the last communication and the end of the study period was counted as "offline."

Opt-out rate was calculated similarly by summing all time in which a device reported in either operational State 11 or 12 (idle opted-out or running opted-out, respectively) and dividing by the time between the device's first heartbeat and the end of the study period.

Clear negative correlations emerged between event reception rate and both offline rate (R^2 = 0.25) and opt-out rate (R^2 = 0.54). The strongest negative correlation was observed when offline and opt-out rate were combined (R^2 = 0.85). This outcome is expected: devices that are either disconnected from the cellular network or intentionally not responding to grid signals will naturally exhibit lower event compliance rates.

One significant outlier appears in the lower-left corner of Figure 17 (Opt-Out + Offline % = 34.46%, Event Reception Rate = 15.05%). This device entered operational State 5, "SGD Error Condition" for 142 days during the study period. This error state is broad and typically indicates a malfunction within the SGD itself, generally unrelated to the EcoPort module or event signals. Since "Event Reception Rate" is defined by whether a device reports "heightened" or "curtailed" operational states during the event window, it is unclear whether this device responded appropriately to demand response events while in the error state.

NOTE: One water heater (Manufacturer B, electric resistance) received demand-response events throughout the study but was excluded from this analysis. The device appeared to have a defect in operational state reporting, consistently reporting “idle normal” even when power consumption was observed. As a result, its calculated event reception rate would have been 0, though it remains unclear whether the device complied with events despite the reporting anomaly.

Estimated Energy Shift

Across all study events, the fleet achieved an average of 48.9% reduction in energy consumption relative to baseline operation (ERWH reduction: 44.9%, HPWH reduction: 51.0%). This represents a substantial decrease, though it does not reflect the maximum possible reduction during a curtailment period. Higher device-level compliance, particularly reductions in offline time and opt-out behavior, would likely have yielded even greater load reduction during curtailment events.

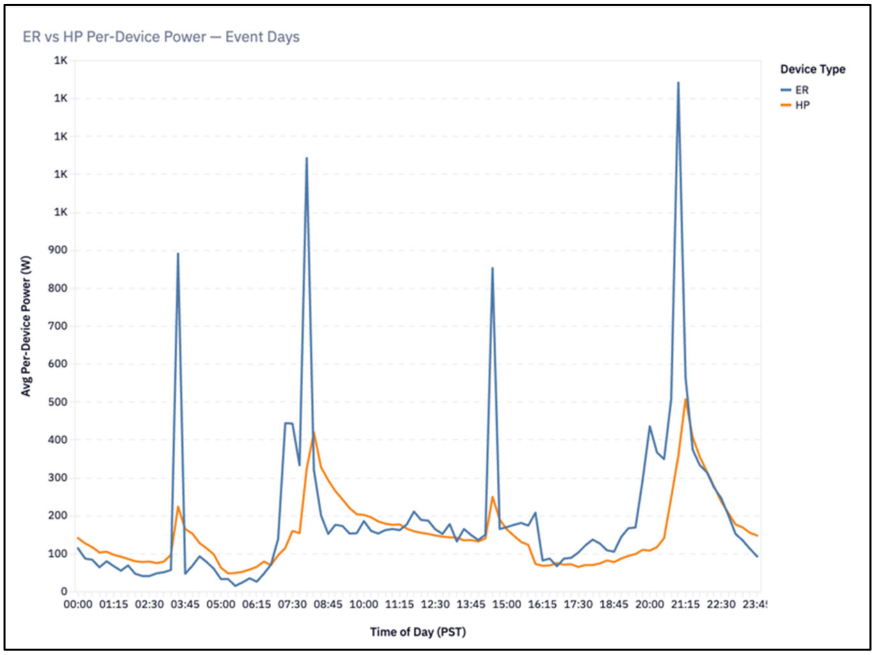

Figure 18: Load shape of "event days" versus "non-event" days (average power consumption of each connected unit post 14-day baselining period)

There was a substantial difference in runtime during curtailment events between water heaters that successfully participated and those that did not. Units classified as “curtailed”—those that received and responded to event signals—were actively heating for less than 3% of the curtailment window (1.94% for ERWH and 3.64% for HPWH). In contrast, “opted out” and “non-participating” units—identified by operational States 11 or 12 and 0 or 1 respectively— operated between 16% and 20% of the time during the same events.

This discrepancy suggests that, with perfect event participation (i.e., no opt-outs and no missed events), energy use during Shed events could be reduced by an estimated 85.2% for HPWHs and 56.5% for ERWHs. This estimate also reflects the finding that electric resistance element usage in HPWHs was approximately the same during curtailment events as during uncontrolled periods.

The assumed use of electric resistance elements was determined by reported power consumption exceeding 1,000 watts—a threshold generally not achievable in heat pump mode. This approach mirrors the methodology used in Obi et al.'s "*Nontargeted vs. Targeted vs. Smart Load Shifting Using Heat Pump Water Heaters"* (Obi et al. 2021). During normal operation, water heaters reporting a "running" operational state exceeded 1,000 watts of power consumption 6.36% of the time. During a curtailment event, the percentage of time during which the water heaters reported that they were running at more than 1,000 watts was 5.45%, indicating that under a Shed event, the HPWHs were no more likely to use their heating element (ER models will report ER usage of 100%).

Additionally, heat pump water heaters exhibited a greater likelihood to opt out (9.96%) and miss events (17.38%) compared with ERWHs (0.78% and 12.12%, respectively). As a result, the potential gains from perfect event participation are considerably larger for HPWHs than for ERWHs.

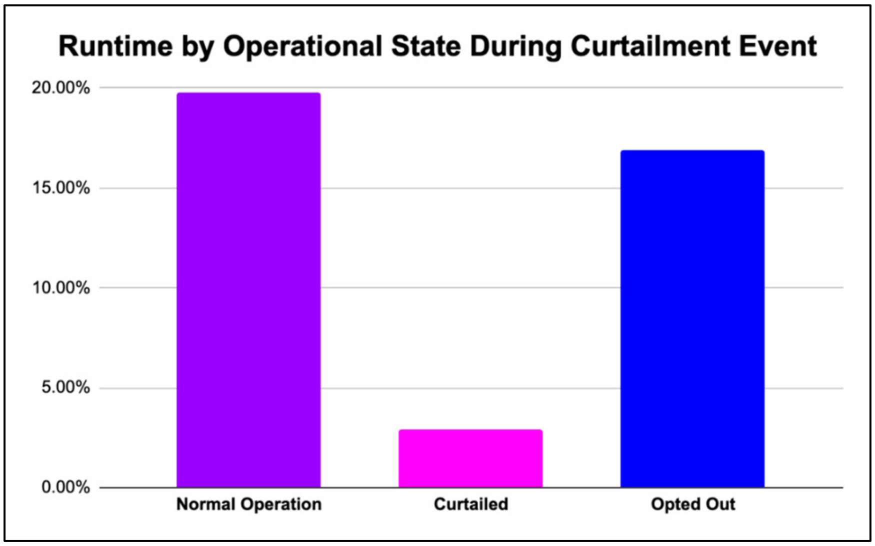

Figure 19: Runtime percentage of SGDs that complied with curtailment event, exhibited normal operation, or opted out

Average energy shifted per unit per event was estimated by counting all devices that were sent an event. The cohort of the study grew over time as more customers were recruited into it. For example, if 10 devices received an event signal early in the study and 104 received an event later, this could total 114 device events. Across the study period there were 6,902 morning device events and 7,071 evening device events. Morning events shifted an average of 227 watt-hours per device, while evening events shifted an average of 418 watt-hours per device as compared to baseline.

Among enrolled devices, this per-unit energy shift was significantly higher, as non-participating devices considerably reduced the fleetwide average. During curtailment events, 63.31% of all running minutes were attributed to the 21.31% of units in normal or opted-out operational states, while the 78.69% of devices in curtailed mode accounted for only 36.69% of running minutes. Based on this distribution, a fully compliant fleet could likely shift 800–1,000 watt-hours per water heater per day, compared to the study's observed average of 645 watt-hours per day.

Energy curtailment performance also improved over time as additional smart features were deployed and the study cohort grew. During the final five months of the study (June 1, 2025 to October 31, 2025), energy shifted from the curtailed period increased markedly. Over the final five months, the fleet achieved a 53.61% reduction relative to baseline, compared with an average 39.27% reduction during the preceding seven months. This suggests that enhanced control strategies and more sophisticated Load-Up and Shed protocols contributed to improved curtailment effectiveness.

However, these findings should be interpreted cautiously. Seasonal and weather-related factors may have influenced results. Previous research indicates that hot water usage decreases during summer months, especially in colder regions such as the Pacific Northwest (Bonneville Power Administration 2022). Reduced hot water demand during summer and early fall months may have increased the shiftability of water heating loads independent of control system improvements. This effect is unlikely to be driven by higher event uptake, as the participation rate during the final five months of the study (80.02%) was similar to the overall study rate (78.69%).

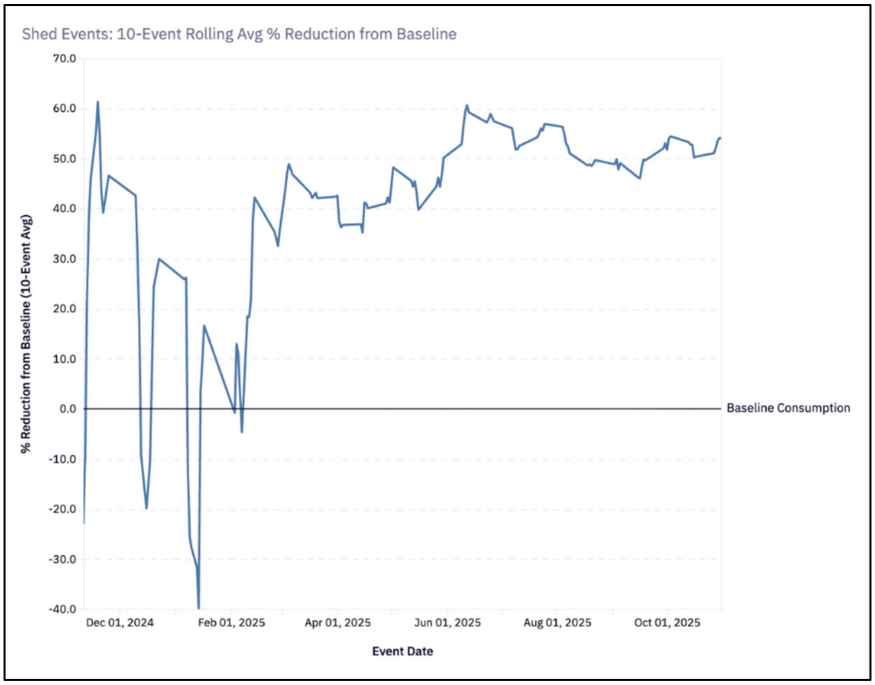

Figure 20: 10-event rolling average of load-shift effectiveness (reduction from baseline)

Morning vs. Evening

No significant difference existed between the percentage of load shift between morning and evening load events when compared with baseline energy use. On average, evening events shifted 48.02% of energy consumption away from the curtailment period (418 Wh per unit per event), while morning events shifted 49.57% (227 Wh per unit per event). Notably, more overall energy was shifted in the evenings than in the mornings.

Curtailment performance exhibited substantial variability across events. Overall, curtailment had a 61.7% standard deviation, though this decreased to 14.1% when considering only the period from March 1 to October 31, 2025. The latter is more representative of typical variability, as it excludes early-study events characterized by small sample sizes and greater event-to-event fluctuation. From this analysis, morning and evening curtailment events appear to be approximately equivalent in their ability to shift load away from the curtailed period.

However, this analysis does not account for local price of energy or grid stress. If grid peaks occur at different times of day, shifting the same amount of energy may yield substantially different values to utilities or aggregators due to variable strain on the grid.

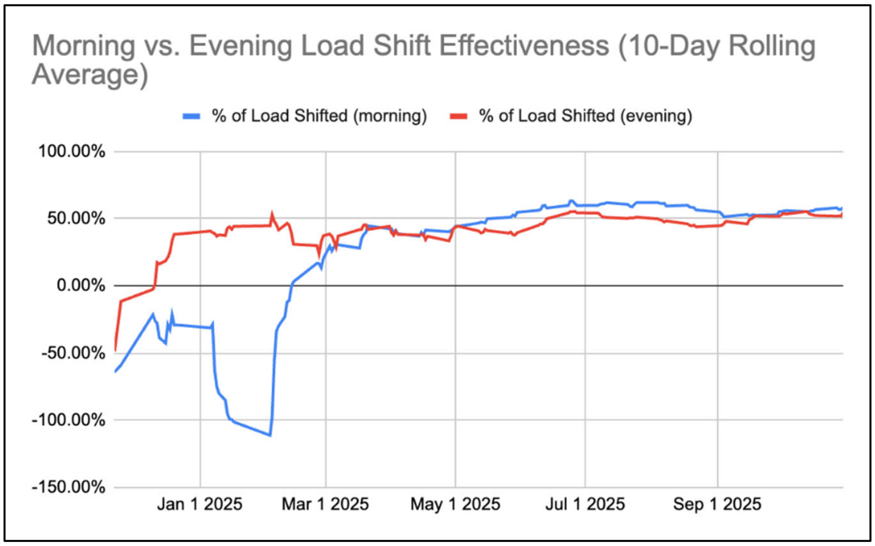

Figure 21: Comparison of morning versus evening load shift effectiveness (10-day rolling average)

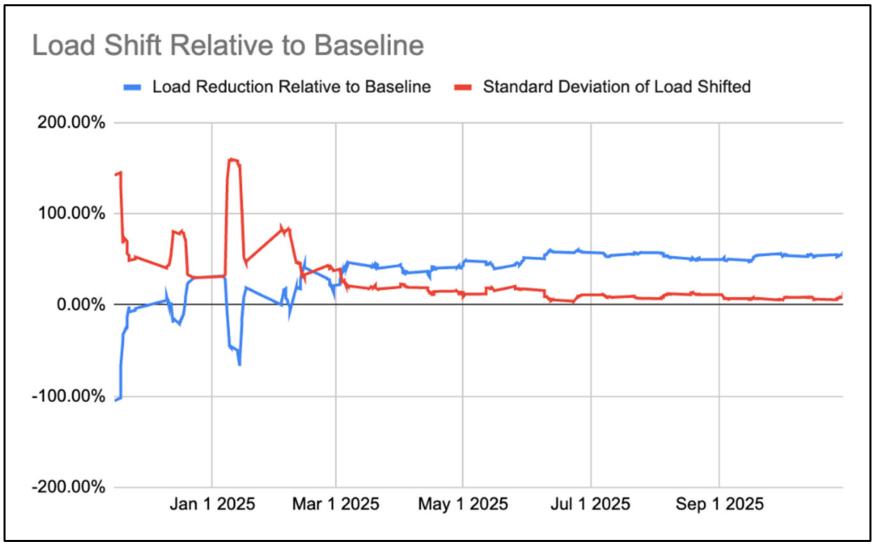

Figure 22: Effectiveness of morning vs. evening curtailment events, expressed as percentage of energy consumption reduced from baseline

Curtailment Event Duration

To assess whether a shorter Shed event could improve load shifting performance, a two-week event schedule was implemented in which the evening curtailment was reduced to 4:00–7:00 PM, rather than the standard 4:00–9:00 PM window used for most evening events in the study. This modification did not yield improved results. During the shortened three-hour window, energy use decreased by only 30.94% (223 watt-hours per unit per event) relative to the previous two-week baseline for the same hours.

Not only was the curtailment period 40% shorter than the standard 5-hour events, it also produced a smaller effect size. The five-hour curtailment events achieved an average 46.37% reduction in energy use across the full curtailment window. Normalized to a 100-unit fleet, the five-hour events shifted approximately 423 watt-hours per unit per event, whereas the 3-hour Shed shifted only 223 watt-hours per unit per event.

Given its comparatively low effectiveness, the shortened event schedule was discontinued after the single two-week cycle.

Electric Resistance vs. Heat Pump

As noted previously, this fleet is unusual in its composition, with a substantial mix of electric resistance water heaters and heat pump water heaters. As expected, electric resistance units exhibited sharper, more pronounced peaks during load shifting events, whereas heat pump units showed more moderate pre-curtailment Load Up periods and post-event recovery periods.

On days without load shifting events, however, the aggregate daily load shapes of the two technologies were broadly similar. Electric resistance heaters consumed an average of 4.93 kWh/day, whereas HPWHs consumed an average of 3.99 kWh/day. The figure below illustrates the average daily load shape for both ERWHs and HPWHs on non-event days.

Figure 23: Load shape of non-event days for electric resistance (blue) and heat pump (orange) water heaters in fleet

On event days, however, the difference in load shape between the two technologies becomes pronounced. Although the overall power consumption ratio between ERWHs and HPWHs remains relatively consistent, the shape of their load profiles diverges significantly. This is largely due to the operational characteristics of ERWHs which cannot modulate to low-power operation, and therefore function as "all-or-nothing" loads. In contrast, HPWHs draw smaller, steadier amounts of power, resulting in smoother pre-curtailment Load Up periods and more gradual post-event recovery.

Table 9: Daily power draw (kW), ERWH vs. HPWH

SGD Type	Non-Event Day	Event Day	Average
ERWH	4.9272	4.752	4.8408
HPWH	3.996	3.9408	3.9696

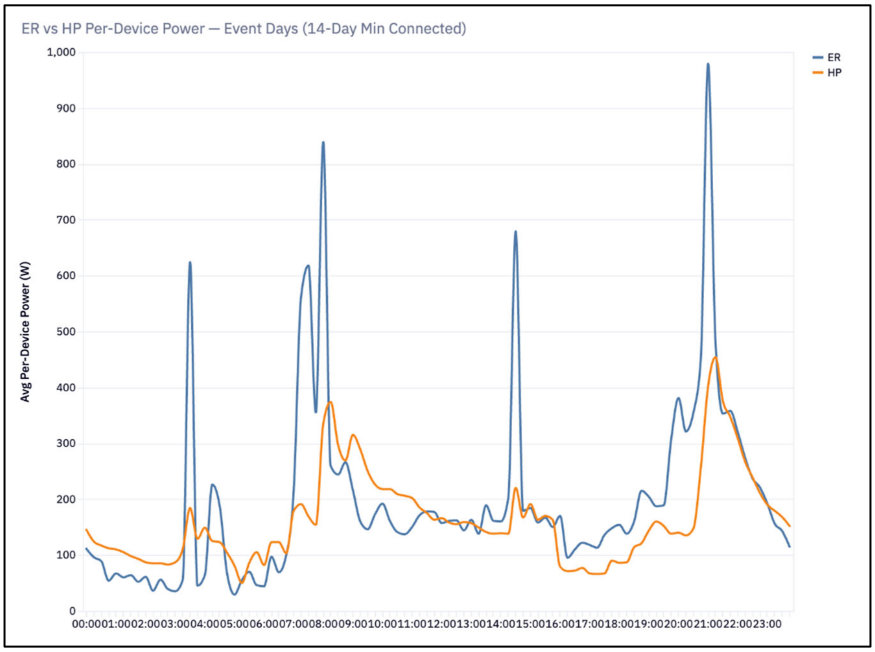

Figure 24: Load shape of event days for electric resistance (blue) and heat pump (orange) water heaters in fleet

As shown in Figure 24, the load shape of ERWHs when curtailing load produces large post-curtailment spikes in total fleet power consumption. Figure 24 aggregates multiple events, and the "double peaks" visible in the figure reflect differences in event timing—for example, some Load Up events began at 3:30 AM rather than 4:00 AM, and some Shed events ended at 8:00 AM during the smart feathering tests. ERWHs were often the first group to be released during smart feathering because their capacity values could not be reliably determined due to inconsistent reporting.

The data also indicate that HPWHs were more effective at reducing power consumption during curtailment events, particularly in the evening. During the critical 4:00–9:00 PM window on event days, ERWHs consumed an average of 693 Wh per unit, whereas HPWHs consumed only 407 Wh per unit. This difference highlights the greater inherent flexibility of HPWHs and their ability to sustain deeper curtailment during peak demand times.

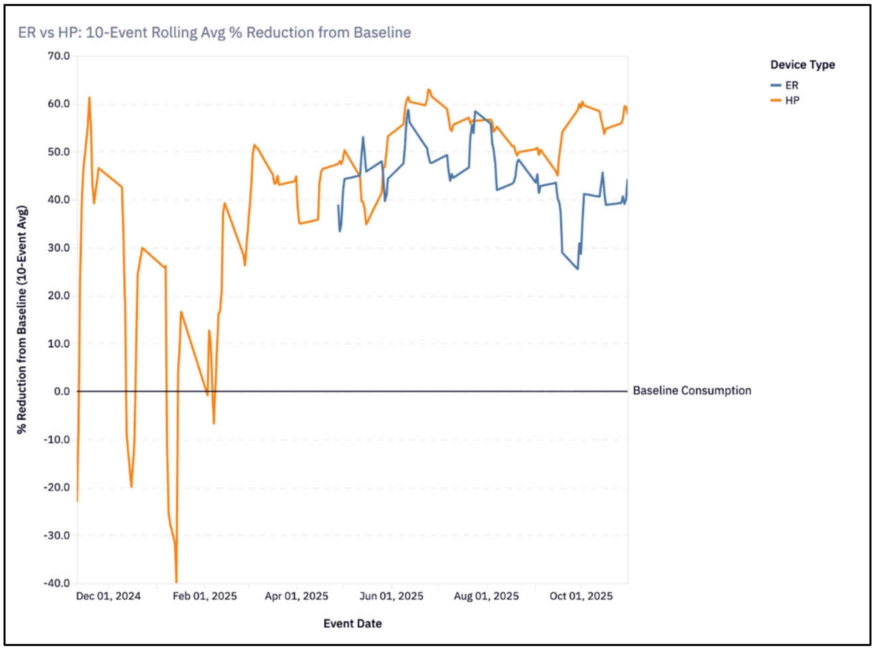

Figure 25: Power reduction during curtailed periods, HPWH vs. ERWH

Due to inconsistent capacity reporting, event signaling for the "poor reporting" ERWHs was postponed until April 28, 2025 (blue line begins, Figure 25), when it was determined that the power consumption data was sufficiently accurate to support load curtailment analysis. Once included, ERWHs demonstrated a meaningful ability to curtail load during targeted periods although their performance was somewhat less consistent than that of HPWHs (Figure 25).

Discussion

Conclusion – Survey Responses

Trends Across All Surveys

User Satisfaction

- Overall ratings averaged above 4.0 out of 5.0, showing strong baseline satisfaction with the study.
- Customers consistently reported no issues with water temperature, an important signal that the demand response events run did not meaningfully interfere with their hot water availability.

Communication and Support Needs

- Some customers expressed a desire for clearer setup instructions during installation and more consistent feedback channels throughout the study.
- Several respondents suggested they would appreciate data transparency—such as how their participation contributes to grid or energy outcomes, or visibility into their own energy or hot water consumption.

Program Engagement Over Time

- Initial enthusiasm was high, but both recommendation scores and survey response rates declined from Survey 2 to Survey 3. This drop-off was likely influenced by limited customer interaction after enrollment or relatively low incentive values. Due to the reduced number of responses, it is not possible to provide a definitive answer to the decline in customer enthusiasm.

Surveys: Lessons Learned and Potential Improvements

Potential Improvements to Survey/Study Design

The study design contains an inherent limitation in assessing the effects of load shifting events on hot water availability. Most study customers were not simply adding an EcoPort module to their existing water heater; rather, they were replacing a water heater—often with a heat pump water heater—while simultaneously installing the EcoPort module. The survey process did not distinguish between customers who enrolled with an existing connectable SGE and those who enrolled after installing both a new water heater and a new EcoPort module.

Additionally, the study did not capture replacements that were "like-for-like" (e.g., an aging electric resistance unit replaced with a new electric resistance unit, which is expected to represent a minority of installations) or whether customers replaced a gas water heater with a new electric model. Future studies would benefit from recording the type—ideally the exact make and model—of the previous water heater. This information would help determine whether changes in hot water availability stem from the transition to a different water-heating technology or tank configuration, rather than from the curtailment events themselves.

Because this data was not collected, customer comments regarding changes in hot water supply cannot be attributed solely to either the new water heater or to the demand-response events implemented during the study. A recommended improvement to the study design is to incorporate a longer baselining period during which the EcoPort module collects operational data but does not issue any load shifting signals on the customer's water heater. A follow-up survey during this baseline phase could assess whether hot water availability changed after installation of the new equipment alone. This approach would allow the study to isolate variables more effectively—first evaluating the difference between old and new water heaters and then assessing the incremental impact of load shifting controls relative to normal operation.

Lastly, this study relied on installer and customer feedback to collect qualitative data on their experiences and satisfaction. Future studies should integrate more structured and formal consumer research to gather collect feedback on the Universal Communications Module (UCM) installation, motivations to participate in load flex programs, and customer experiences with the program.

Lessons Learned from Surveys

- Provide clear written and online instructions, supported by a responsive and knowledgeable customer-support channel, to maximize customer enrollment and long-term retention.
- Refine survey instruments to ensure that questions isolate individual variables—rather than testing both new SGD installations and EcoPort module controls—to better attribute customer experiences to specific factors.
- Communicate customer value more effectively—Several participants expressed interest in greater transparency, including insights into how their participation contributes to grid or energy outcomes, as well as access to their own hot water and energy use data.

Discussion: Customer Support

Throughout the study, the customer service phone line served as an important resource for both customers and installers seeking guidance on study enrollment, EcoPort module installation, and mobile application navigation. Thirteen out of 14 professional installers completed at least one installation; six of them, or 46%, contacted the support line for assistance.

In contrast, among the 110 individual customers who enrolled a device, only 12 unique customers contacted customer support (11%). Installers were more likely than participants to call the study's support line, which aligns with expectations: installers were working with unfamiliar technology and frequently sought clarification during first-time installations. Importantly, the call log does not indicate any systematic hardware or software failures. Most calls involved routine guidance, clarification, or one-off troubleshooting, with no single issue emerging as a recurring failure point.

Customers who installed their EcoPort module without professional assistance were more likely to seek support. Twenty-six percent of "solo" participants called the customer support line, compared to fewer than 7% of participants whose installations were completed by a professional**.**

Call frequency was also higher earlier in the study. As time went on, new enrollments required fewer support calls, suggesting that the study enrollment process improved over time as the marketing literature was refined and installers became more familiar with the technology and program, and were more confident in communicating the opportunity with customers.

Discussion: CTA-2045 Event Scheduling and Transmission

Signal Pathway

Improving event participation rates is critical for maximizing shiftable load. When less than 80% of devices participate in an event, the available curtailment potential is significantly reduced. In evidence of this, water heaters that did NOT participate in the event (operational state 0 or 1) were "running normal" for an average of 19.76% of the time during these curtailment periods. This is in contrast to the compliant water heaters, which were "running curtailed" for just 2.93% of the time during the curtailment events. The "opted out" units were running for 16.86% of the time curing the curtailment events, which is still significantly higher than the 2.93% runtime that curtailed water heaters exhibit.

As previously shown, 82% of the opt-out time, by hours, was due to suspected Type 3 opt-outs, which are triggered by code on the water heater itself rather than any specific action by the EcoPort module or by the customer. Working with the manufacturers to determine the cause of this opt-out behavior and/or determining whether the module can override this behavior would be an important next step to achieve greater load shift from connected water heaters.

Regarding connectivity, it remains to be seen whether providing an ongoing incentive to customers will decrease the rate of manual disconnection (physically removing the EcoPort module from the SGD). Regarding cellular interruptions for modules that remain installed in their respective SGDs, additional strategies to increase connectivity could include:

- Targeting customers only in areas shown to have strong cellular reception,
- Testing cellular reception at the customer's location to confirm cellular connectivity before installation,
- Providing EcoPort modules with connectivity across multiple cellular carriers, and/or
- Providing cellular antenna extenders to ensure the SGD is not placed in a specific cellular "dead zone."

Alternative Event Types

Neither "Critical Peak" events nor "Grid Emergency" events were tested in the study. Only the first level of curtailment, "Shed," was tested as a method of reducing SGD power consumption during the targeted periods. Critical Peak (Level 2) or Grid Emergency (Level 3) events should have had a greater impact on energy use during curtailment periods, but would also result in a higher probability of participant discomfort and hot water shortages (Paresa and Bass 2024) . Further research will have to be undertaken to determine how significantly power consumption decreases relative to a Level 1 curtailment during Critical Peak or Grid Emergency events.

As a minor caveat, short, 2–5 minute "Grid Emergency" events were initiated as a part of the "Smart Start" protocol to ensure SGDs ceased their power consumption at the beginning of a curtailment event, but no Grid Emergency events longer than five minutes were scheduled.

That said, the largest lever for curtailing a greater proportion of power consumption during curtailment events is ensuring all devices in the fleet receive the curtailment event and are in an operational state that allows the unit to do so (not opted out). Units that reported a curtailed operational state were only consuming power less than three percent of the time during a curtailment event, more than six times less frequently than units operating in the "normal" state. Ensuring that all units are curtailed during the targeted period should be the highest priority for any connected fleet looking to shift significant, predictable amounts of energy away from peak periods using CTA event signals.

Customer Value

While the study has demonstrated that the EcoPort module can provide measurable value by reducing power consumption at predictable intervals, there is also potential value delivered directly to customers who install a module on their connectable SGDs. These customer-facing benefits can be grouped into two categories: "active" and "passive" benefits.

"Active" Benefits

- **Remote mode-changing:** Customers who are away from home can remotely toggle "vacation" and "opt-out" modes, providing them greater control over household energy use and allowing them to adjust water behavior without being physically present.
- **Analytics:** Customers gain access to usage analytics, including time of day usage, total power draw, and long-term usage trends. This visibility can help customers better understand their energy patterns and make more informed decisions about efficiency and comfort.

"Passive" benefits

- **Whole-home hot water leak detection:** By leveraging the instantaneous capacity value through the CTA-2045 standard, EcoPort modules can detect potential hot water leaks anywhere in the home. This is accomplished by comparing the unit's passive-cooling slope against expected values for that specific make and model, as well as its location and ambient temperature. If the water heater must reheat more frequently without any recorded hot water draw, the system can flag a likely hot water leak somewhere in the household.

- **Advance failure detection:** EcoPort modules can identify early signs of equipment failure by monitoring commodity values. When power consumption does not correspond to a drop in capacity, or when excessive heating is detected, the system can alert the customer to a potential malfunction before a complete failure occurs.
- **Time-of-use savings:** By enabling customers to create and adjust their own water-heating schedules, modules allow users on time-of-use rate plans to align water heater operation with lower-cost periods. Customers can input their utility's rate schedule and automatically curtail power consumption during high-price windows.
- **Utility program incentives:** Many utilities offer incentives for participation in daily load-shifting or demand-response programs. A connected EcoPort module enables customers to enroll in these programs, verify participation, and document the performance of individual events or event series, unlocking financial benefits while supporting grid reliability.

Conclusions

The study confirmed the ability of EcoPort-connected water heaters to maintain customer comfort and shift meaningful amounts of electrical load from high-demand peak hours to lower-demand hours by using hot water storage as a thermal battery. The ability to shift meaningful amounts of energy benefits both the utility, through reduced grid peaks, and the end user by mitigating high electrical usage rates to charge their water heater if they are on a time-of-use electrical rate, and indirectly for customers with flat electrical rates by reducing the amount of power their utility may have to purchase on the open market or by using backup generating resources. Additionally, thousands of device events were dispatched throughout the study with minimal interruption to customer hot water availability, bolstering the case for domestic hot water as an "invisible" grid asset.

The study also uncovered several important findings. First, the water heater installer's inside sales and customer service teams should be leveraged to recruit customers into utility load-flex programs. Typical water heater installer business models focus on the installing plumber providing an efficient installation process to restore the customers' hot water service. Utility incentives and programs are generally discussed with the inside sales team from the installer and do not rely on the installer to discuss or "sell" programs while on-site.

Next, the value proposition of utility load flex programs can be challenging in areas with relatively low electrical rates and no time-of-use rates. The initial recruitment marketing materials focused heavily on the importance of aligning electrical usage with the utility's supply, integrating renewables into the grid, and the water heater's role as a thermal battery. While all statements were accurate, installers reported that the information was overwhelming to potential participants. Based on that feedback, the recruitment language was simplified to focus on keeping electricity costs low and benefiting the community, and customer recruitment improved substantially.

Throughout the study, the use of cellular-connected UCMs was robust and reliable, with a few exceptions for very rural customers. The high-quality connection enabled the collection of granular data, enabling rapid iteration on dispatch strategies and the uncovering of water heater performance issues. The study identified the importance of segmenting customers by their water usage to maintain their comfort while balancing their ability to support a dispatch event. That is, not all customers should be treated equally, and a smart aggregator strategy is critical to maintaining customer comfort and program enrollment. Further, the study demonstrated methods to maximize the benefits of Load Up dispatch requests to ensure hot water when needed, while also mitigating snapback through smart recovery functions that limit the use of electric resistance elements in HPWHs.

The study also uncovered non-energy benefits of the EcoPort and high-quality connectivity, showing that UCMs can help identify when a compressor is failing by tracking how often it cycles and by detecting potential hot water leaks within the home. These two functions can be tangible benefits for participants in connected water heater programs, as well as a value-add that installers, aggregators, or utilities can offer them.

Lastly, the study revealed that manufacturers can benefit from guidance on implementing CTA-2045 protocols to help ensure compliance and conformance to CTA-2045 for reliable behavior when participating in load flexibility programs.

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APPENDIX A: Full List of Survey Questions

Survey 1

Q1: Did you require any assistance from the installer to connect the Universal Communication Module?
Q2: Did you require any Assistance from the installer to complete your sign-up process?
Q3: On a scale of 1 to 5, where 1 is strongly disagree and 5 is strongly agree, how much do you agree with the following statement: So far, the app has been easy to use.
Q4: On a scale of 1 to 5, where 1 is strongly disagree and 5 is strongly agree, how much do you agree with the following statement: It was easy to install and connect the Universal Communication Module (UCM).
Q5: What recommendations would you make for improving the install process?
Q6: What recommendations would you make for improving the sign up process?

Survey 2

Q1: Over the past 45 days, the device connected to your water heater has been studying your household's hot water use patterns and matching it to times when clean energy is available. What changes, good or bad, have you noticed in the supply, duration, or any other aspect of the hot water in your household or the functioning of your water heater. Please describe?
Q2: How likely are you to recommend to others that they participate in this study? Please rank your choice on a scale of 1 to 5, where 1 is definitely would not recommend and 5 is very likely to recommend
Q3: What recommendations would you make for improving the experience you've had with the program so far?

Survey 3

Q1: Over the past 45 days, the device connected to your water heater has been studying your household's hot water use patterns and matching it to times when clean energy is available. What changes, good or bad, have you noticed in the supply, duration, or any other aspect of the hot water in your household or the functioning of your water heater. Please describe?
Q2: How likely are you to recommend to others that they participate in this study? Please rank your choice on a scale of 1 to 5, where 1 is definitely would not recommend and 5 is very likely to recommend
Q3: What recommendations would you make for improving the experience you've had with the program so far?

Installer Survey

Q1: Did the customer require any assistance to install or connect the EcoPort module?
Q2: Did the customer require any Assistance to complete the Study sign-up process?”
Q3: On a scale of 1 to 5, where 1 is strongly disagree and 5 is strongly agree, how much do you agree with the following statement: "So far, the app has been easy to use."

Q4: On a scale of 1 to 5, where 1 is strongly disagree and 5 is strongly agree, how much do you agree with the following statement: "It was easy to install and connect the EcoPort module."
Q5: What recommendations would you make for improving the signal strength test?
Q6: What recommendations would you make for improving the study sign up process for the customer?
Q7: Any other feedback that might help improve the process?

APPENDIX B: Full List of Event Schedules and Reasoning for Schedule Alterations

Initial Testing Method

Date: 11/11/24–12/23/24

Table 10: Testing schedule 11/11/24–12/23/24

Start Time	End Time	Event Type	Group
5:30 AM	6:00 AM	Load Up	PLUS 2 Weeks
6:00 AM	9:00 AM	Shed	PLUS 2 Weeks
3:30 PM	4:00 PM	Load Up	PLUS 2 Weeks
4:00 PM	9:00 PM	Shed	PLUS 2 Weeks

Note: **PLUS 2 Weeks** is the total population of water heaters after a two-week baseline measuring period.

Description:
Standard Load Up and Shed events were conducted twice per weekday, typically during the 6:00–9:00 AM and 4:00–9:00 PM windows because these are generally the times of highest stress on the energy grid. Since storage-tank water heaters can shift their energy use to lower-stress times, they serve as an excellent tool for reducing peak demand.

Revision 1

Date: 1/6/25–1/7/25
Shifts in Testing Method: Single Load Shifting Event + Longer Load Up for Heavy Users

Table 11: Testing schedule 1/6/25–1/7/25

Start Time	End Time	Event Type	Group
3:15 PM	4:00 PM	Load Up	Heavy
3:30 PM	4:00 PM	Load Up	Normal Usage
4:00 PM	9:00 PM	Shed	PLUS 2 Weeks
3:00 PM	4:00 PM	Load Up	Heavy
3:30 PM	4:00 PM	Load Up	Normal Usage
4:00 PM	9:00 PM	Shed	PLUS 2 Weeks

Reasoning:
Some heavy users of hot water were not fully loaded up by the time the Load Up event concluded. January 6 and 7 represented the first attempts to ensure full Load Up at the beginning of the Shed event, as well as the first separation of water heaters into groups that received different signals. This differentiation would continue for most events throughout the study.

Additionally, January 6 and January 7 showed a unimodal price shape for the day, so tests were run to ascertain whether a single load shifting event would be more effective at shifting load, if the morning event would not have resulted in any appreciable grid benefit.

Revision 2

Date: 1/8/25–1/17/25
Shifts in Testing Method: Return to twice-per-day event scheduling

Table 12: Testing schedule 1/8/25–1/17/25

Start Time	End Time	Event Type	Group
4:00 AM	5:00 AM	Load Up	Heavy
4:30 AM	5:00 AM	Load Up	Normal Usage
5:00 AM	8:00 AM	Shed	PLUS 2 Weeks
3:00 PM	4:00 PM	Load Up	Heavy
3:30 PM	4:00 PM	Load Up	Normal Usage
4:00 PM	9:00 PM	Shed	PLUS 2 Weeks

Reasoning:
With initial once-per-day testing done, return to the normal schedule laid out for the study was resumed, this time retaining the differentiated Load Up lengths based on household hot water consumption.

Revision 3

Date: 2/3/25–2/14/25
Shifts in Testing Method: Morning Load Shift Adjustment, Trial of Shorter Evening Shed

Table 13: Testing schedule 2/3/25–2/14/25

Start Time	End Time	Event Type	Group
5:00 AM	6:00 AM	Load Up	Heavy
5:30 AM	6:00 AM	Load Up	Normal Usage
6:00 AM	9:00 AM	Shed	PLUS 2 Weeks
3:00 PM	4:00 PM	Load Up	Heavy
3:30 PM	4:00 PM	Load Up	Normal Usage
4:00 PM	7:00 PM	Shed	PLUS 2 Weeks

Reasoning: For this two-week period, the grid peak was predicted to be closer to 6:00–9:00 AM than 5:00–8:00 AM, hence the adjustment. Additionally, the evening grid peak was predicted to only continue until approximately 7:00 PM, so testing was implemented to see if a shorter Shed event would be more effective at shedding load within that period.

Revision 4

Date: 2/25/25–3/21/25

Shifts in Testing Method: Lengthened Load Up period, return to 5:00–8:00 AM morning Shed, return to 5-hour evening Shed

Table 14: Testing schedule 2/25/25–3/21/25

Start Time	End Time	Event Type	Group
3:30 AM	5:00 AM	Load Up	Heavy
4:00 AM	5:00 AM	Load Up	Normal Usage
5:00 AM	8:00 AM	Shed	PLUS 2 Weeks
2:30 PM	4:00 PM	Load Up	Heavy
3:00 PM	4:00 PM	Load Up	Normal Usage
4:00 PM	9:00 PM	Shed	PLUS 2 Weeks

Reasoning: A minority of users were still not fully loaded up at the beginning of the Shed event. Since no short-cycling was recorded in the 60-minute Load Up period, 90-minute Load Up events were implemented for the heavy hot water users and 60-minute Load Up periods were implemented for the normal hot water users.

NOTE: "Smart Start" First tested March 19 and March 21. This is a 2–5 minute "Critical Peak" (later changed to "Grid Emergency") event that shuts off all water heaters in the fleet except those at very high capacity. This event was implemented to counteract some water heaters continuing to heat water until the capacity of 0, even during the beginning of a Shed event. This feature works alongside the extended Load Up event to minimize energy draw during the first minutes of a curtailment event.

Revision 5

Date: 3/31/25–5/25/25

Shifts in Testing Method: "Smart Start" fully implemented, "randomized" feathering implemented

Table 15: Testing schedule 3/31/25–5/25/25

Start Time	End Time	Event Type	Group	Feathering?	Feathering Minutes
3:30 AM	5:00 AM	Load Up	Heavy		
4:00 AM	5:00 AM	Load Up	Normal Usage		
5:00 AM	8:00 AM	Shed	PLUS 2 Weeks	Randomized	10
2:30 PM	4:00 PM	Load Up	Heavy		
3:00 PM	4:00 PM	Load Up	Normal Usage		
4:00 PM	4:05 PM	Critical Peak	PLUS 2 Weeks		
4:05 PM	9:00 PM	Shed	PLUS 2 Weeks	Randomized	15

Reasoning: "Smart Start" was shown to have some success in limiting power consumption at the beginning of the Shed event, so it was implemented for the evening events across the fleet. In a beginning attempt to combat the "snapback" effect of all water heaters ending their curtailment event at the same time, randomized groups were created at the beginning of each curtailment event. These groups would start their curtailment events in a staggered fashion, beginning with only 10 or 15 minutes between first and last device, and later extended as it was realized that larger staggering was needed.

Revision 6

Date: 5/26/25–5/28/25
Shifts in Testing Method: Increased Feathering Length

Table 16: Testing schedule 5/26/25–5/28/25

Start Time	End Time	Event Type	Group	Feathering?	Feathering Minutes
3:30 AM	5:00 AM	Load Up	Heavy		
4:00 AM	5:00 AM	Load Up	Normal Usage		
5:00 AM	8:00 AM	Shed	PLUS 2 Weeks	Randomized	30
2:30 PM	4:00 PM	Load Up	Heavy		
3:00 PM	4:00 PM	Load Up	Normal Usage		
4:00 PM	4:05 PM	Critical Peak	PLUS 2 Weeks		
4:05 PM	9:00 PM	Shed	PLUS 2 Weeks	Randomized	30

Reasoning: Snapback was still large with only 15-minute feathering; increased feathering time in both morning and evening to 30 minutes.

Revision 7

Date: 5/29/25–6/13/25

Shifts in Testing Method: Increased Load Up event time of entire fleet to 90 minutes, implemented smart feathering

Table 17: Testing schedule 5/29/25–-6/13/25

Start Time	End Time	Event Type	Group	Feathering?	Feathering Minutes
3:30 AM	5:00 AM	Load Up	PLUS 2 Weeks		
5:00 AM	8:00 AM	Shed	PLUS 2 Weeks	Smart Feathering	30
2:30 PM	4:00 PM	Load Up	PLUS 2 Weeks		
4:00 PM	4:05 PM	Critical Peak	PLUS 2 Weeks		
4:05 PM	9:00 PM	Shed	PLUS 2 Weeks	Smart Feathering	30

Reasoning: No short-cycling was recorded for any 90-minute Load Up units, so to maximize curtailment during the Shed period, Load Up was increased across the fleet. “Smart feathering” is a process in which all water heaters in the group begin the curtailment event at the same time and are assigned into groups from high to low capacity (energy take) at the end of the event. These groups are then “feathered” as in the randomized feathering, wherein a small subset of the fleet end their curtailment event at a time, beginning with those at the highest capacity and therefore at highest risk of a cold-water event. This is a strategy to abate the “snapback” of a curtailment event ending while also safeguarding against cold-water events for participants in the study.

Revision 8

Date: 6/23/25–6/27/25

Shifts in Testing Method: “Smart Start” changed from Critical Peak to Grid Emergency, feathering period reduced to 20 minutes.

Table 18: Testing schedule 6/23/25–6/27/25

Start Time	End Time	Event Type	Group	Feathering?	Feathering Minutes
3:30 AM	5:00 AM	Load Up	PLUS 2 Weeks		
5:00 AM	8:00 AM	Shed	PLUS 2 Weeks	Smart Feathering	20
2:30 PM	4:00 PM	Load Up	PLUS 2 Weeks		
4:00 PM	4:02 PM	Critical Peak	PLUS 2 Weeks		
4:02 PM	9:00 PM	Shed	PLUS 2 Weeks	Smart Feathering	20

Reasoning: Once it was determined through non-EULF study unit testing that a quick, 2-minute "grid emergency" event would not have adverse effects on the water heating fleet, it was determined that the "Smart Start" would have a greater effect if the Level 3 curtailment event, "Grid Emergency"—which ensures full stoppage of power consumption unless there is a risk of frozen pipes—would have a greater effect reducing the "bleed" of power consumption into a curtailment event than the previous Level 2 (Critical Peak) event.

The decrease in feathering duration was an attempt to confirm whether the effect of feathering would be impacted by shortening it. This was an unsuccessful test, as it did not seem to have a great effect. In fact, lengthening the feathering period was much more successful in ensuring the snapback effect was minimized.

Revision 9

Date: 7/7/25–9/5/25
Shifts in Testing Method: Reversion Back to 30-Minute Feathering

Table 19: Testing schedule 7/7/25–9/5/25

Start Time	End Time	Event Type	Group	Feathering?	Feathering Minutes
3:30 AM	5:00 AM	Load Up	PLUS 2 Weeks		
5:00 AM	5:02 AM	Grid Emergency	PLUS 2 Weeks		
5:02 AM	8:00 AM	Shed	PLUS 2 Weeks	Smart Feathering	30
2:30 PM	4:00 PM	Load Up	PLUS 2 Weeks		
4:00 PM	4:02 PM	Grid Emergency	PLUS 2 Weeks		
4:02 PM	9:00 PM	Shed	PLUS 2 Weeks	Smart Feathering	30

Reasoning: Longer feathering durations resulted in smoother post-event recovery, therefore feathering was extended back to 30 minutes. "Smart Start" was retained as a Grid Emergency rather than a Critical Peak.

Revision 10

Date: 9/15/25–10/31/25
Shifts in Testing Method: Lengthening of feathering period, shortening of "base event"

Table 20: Testing schedule 9/15/25–10/31/25

Start Time	End Time	Event Type	Group	Feathering?	Feathering Minutes
3:30 AM	5:00 AM	Load Up	PLUS 2 Weeks		
5:00 AM	5:02 AM	Grid Emergency	PLUS 2 Weeks		
5:02 AM	7:30 AM	Shed	PLUS 2 Weeks	Smart Feathering	90
2:30 PM	4:00 PM	Load Up	PLUS 2 Weeks		
4:00 PM	4:02 PM	Grid Emergency	PLUS 2 Weeks		
4:02 PM	8:00 PM	Shed	PLUS 2 Weeks	Smart Feathering	120

Reasoning:
Feathering was extended to further test the ability of a fleet to reduce the "snapback" effect across multiple hours. The "base event" was shortened slightly, from 3 hours to 2.5 hours in the morning and from 5 hours to 4 hours in the evening, to offset the lengthening of the feathering period. The longest Shed events in the morning then occurred from 5:00 AM to 9:00 AM, and the longest evening events then extended from 4:00 PM to 10:00 PM. 7-hour evening events were not attempted due to concerns for cold-water events for fleet members, but these concerns may be unfounded due to the "smart feathering" aspect in which only those who reported the lowest capacity at the ending time of the event are extended out to the full 120-minute feathering period.

Issues/Errors in scheduling:

- March 24 not scheduled. Manual error.
- Morning Load Up event March 31 not scheduled. System error with the "randomized scheduling" software.
- From June 9 to July 11, 2025, the "Smart Start" grid emergency at the beginning of the curtailment event was handled by the Smart Actions scheduler. However, this "smart action" did not leave a record in the DR Scheduler, so it is not shown in the "Full Fleet Event Log" document. This was amended the week of July 21, 2025.
- September 1, and the morning of September 2 not scheduled. Manual error.

APPENDIX C: Compliance of Connected Water Heaters

Manufacturer A: 19 SGDs: 18 HPWH 1 ERWH

- Some heat pump hybrid models from Manufacturer A exhibited an issue wherein they would opt out after a certain period of time, and either never return to an opted-in state, or return only when the water heater lost power. This would have a significant effect on event uptake when extrapolated over a multi-year period.

Manufacturer B: 85 SGDs: 57 HPWH 28 ERWH

- Manufacturer B's electric resistance water heaters display an impossibly high capacity value that does not seem to be affected by heating, rendering that value useless to ascertain danger of cold-water events, or to schedule custom-length Load Up events. These units were still included in load-shifting events, but were treated as if they were "heavy" hot water users to decrease the likelihood of study-induced cold-water events.
- One electric resistance unit from Manufacturer B presented an operational state of "0," even when power consumption was recorded. Therefore, it is difficult to ascertain whether load shifting events were being properly transmitted to the SGD.
- Manufacturer B's heat pump water heaters often have a "floor" capacity. This number, which ranged from around 300 watt-hours to over 2,000 watt-hours, causes an inaccurate reading of present energy capacity. Adjustments to this capacity are necessary to ascertain danger of cold-water events, which were implemented with "Smart Capacity Translation" (described in the **Smart Actions** section). Instances of water heaters with identical make and model having different "floor" capacities have been recorded, leading to this adjustment being completed on a unit-by-unit basis.
- Some units in this model reported a power usage between 30–60 watts when in "idle" operational states. This was assumed to be the baseline power consumption of the unit when not actively heating water.
- Some units in the fleet showed a tendency to "opt out" for 24–48 hours when initially installed. This was generally not an issue for study purposes, as there was a 14-day period between first installation and first demand response event signal eligibility.

Manufacturer C: 5 SGDs: 0 HPWH 5 ERWH

- No Manufacturer C heat pump water heaters were enrolled in this study, only electric resistance models. These units reported neither power nor capacity values, leading them to be ineffective for studying load shifting potential
- While these units may have been capable of shifting energy consumption, it was impossible to tell how effective they were at doing so, so they were generally excluded for load shifting events and energy shift analysis

Manufacturer D: 1 SGD: 1 HPWH 0 ERWH

- A singular Manufacturer D water heater was included in the study. This water heater did not report power or capacity values, similar to Manufacturer C units, but additionally did not report the operational state of the unit.
- This resulted in an even more limited information stream, and the Manufacturer D unit was similarly excluded from load shifting events and analysis

APPENDIX D: Customer Recruitment Materials

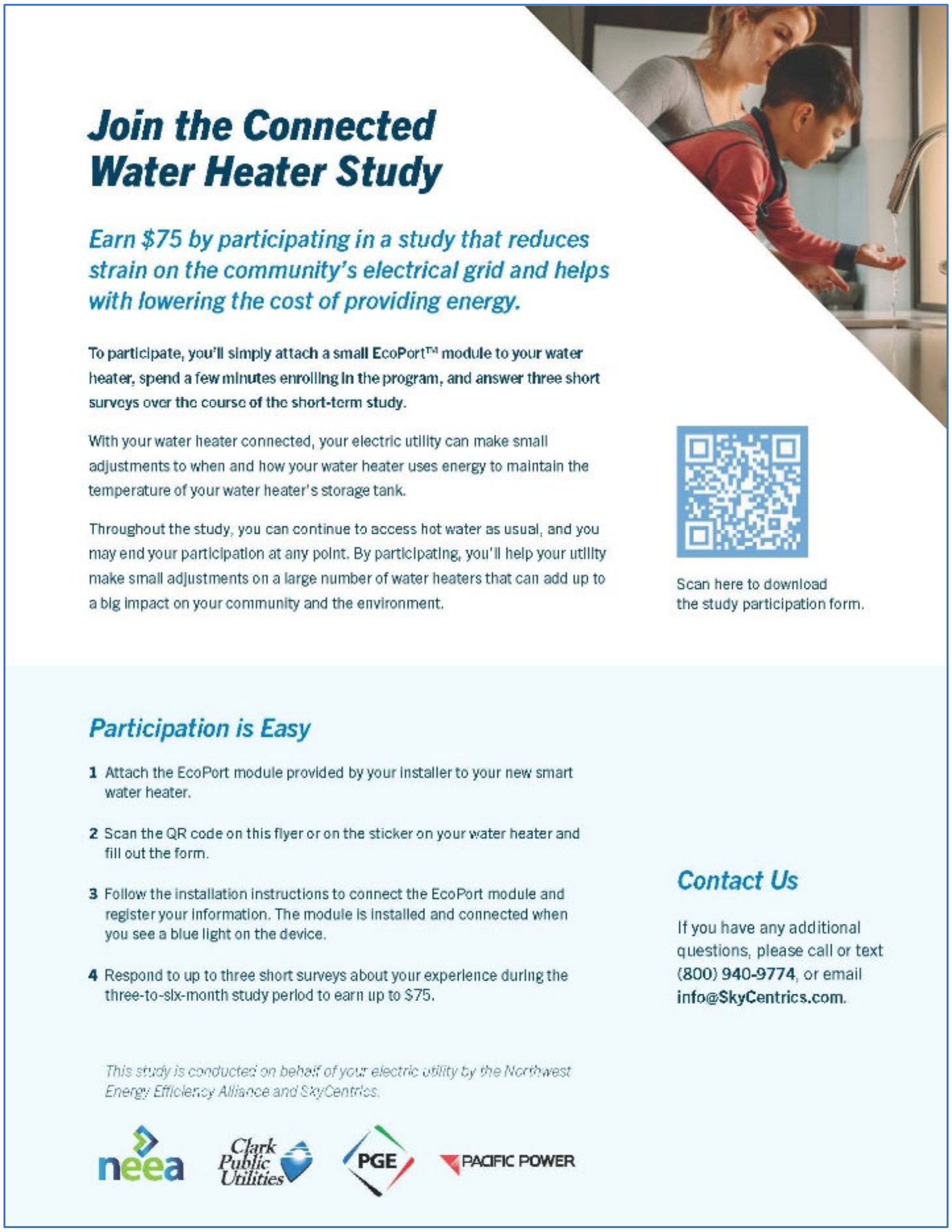
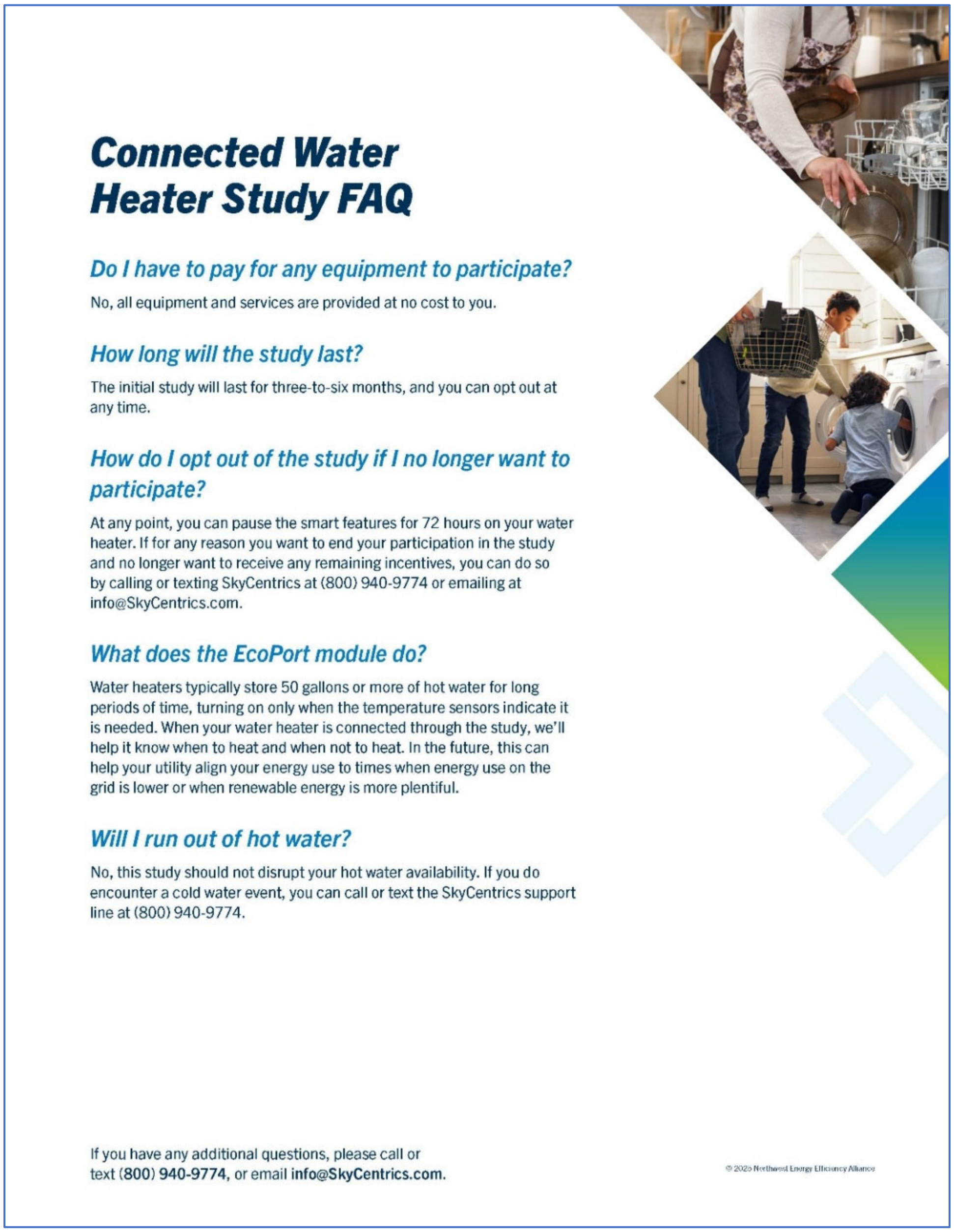


Figure 26: Example customer recruitment flyer for study



Connected Water Heater Study FAQ

Do I have to pay for any equipment to participate?

No, all equipment and services are provided at no cost to you.

How long will the study last?

The initial study will last for three-to-six months, and you can opt out at any time.

How do I opt out of the study if I no longer want to participate?

At any point, you can pause the smart features for 72 hours on your water heater. If for any reason you want to end your participation in the study and no longer want to receive any remaining incentives, you can do so by calling or texting SkyCentrics at (800) 940-9774 or emailing at info@SkyCentrics.com.

What does the EcoPort module do?

Water heaters typically store 50 gallons or more of hot water for long periods of time, turning on only when the temperature sensors indicate it is needed. When your water heater is connected through the study, we'll help it know when to heat and when not to heat. In the future, this can help your utility align your energy use to times when energy use on the grid is lower or when renewable energy is more plentiful.

Will I run out of hot water?

No, this study should not disrupt your hot water availability. If you do encounter a cold water event, you can call or text the SkyCentrics support line at (800) 940-9774.

If you have any additional questions, please call or text **(800) 940-9774**, or email **info@SkyCentrics.com.**

Figure 27: Customer flyer study FAQs