Realizing the Benefits of Grid Connected Water Heaters

Eric Olson and Brenda Hunt, Northwest Energy Efficiency Alliance
Daniel Colwell and Tristan de Frondeville, SkyCentrics Inc.
Geoff Wickes, Wickes Energy Services LLC
Robert Bass, Portland State University

ABSTRACT

Electric utilities face increasing challenges in maintaining grid reliability due to rapid load growth, wildfire mitigation, and the increasing share of variable renewable generation. Distributed smart grid devices, including flexible loads like electric resistance and heat pump water heaters, offer a promising source of demand-side flexibility by providing low-cost thermal energy storage. Several states, including Washington and Oregon, now require residential electric water heaters to include EcoPort® interfaces that support the ANSI/CTA-2045 communication protocol. While these requirements enable connectivity, they do not guarantee consistent or predictable device behavior during grid events.

This study evaluates the compliance and conformance of grid-connected water heaters using both laboratory testing and field observations. Laboratory tests conducted at Portland State University evaluated eleven electric resistance and heat pump water heaters from multiple manufacturers using CTA-2045 messaging. Field data from utility demand response programs in the Pacific Northwest were analyzed to compare real-world device behavior.

Results show significant variability in device responses to load-management requests, including incomplete load reduction, inaccurate data reporting, and inconsistent recovery behavior. These findings highlight the need for conformance testing, certification, and implementation guidance to ensure connected water heaters provide reliable grid services. The authors recommend service providers, policy makers, and manufacturers implement these findings to improve the value of connected water heaters as distributed grid resources.

Introduction

The U.S. is facing unprecedented risks driven by numerous factors, including data center growth, manufacturing, electrification across multiple sectors, water and wastewater, population growth, and more extreme weather events. These drivers are not distributed evenly across the U.S.; Sandia National Laboratory estimates that some areas of the country may see peak demand increase by as little as 5%, while others may see increases of over 20% by 2028 (Gunda et al. 2025). Revised energy growth forecasts estimate a 5.7% annual growth rate between 2025 and 2030, with peak demand of 166 GW in 2030 (Gramlich et al. 2025). Economic growth alone will increase electricity demand by 828 TWh between 2024 and 2040 (S&P Global 2025).

Contributing to the complexities of load growth are changes in electricity generation. The U.S. Energy Information Administration reports that in 2026, 10.9 GW of natural gas and coal-fired power plants are scheduled to be taken offline, while developers plan to add 43.4 GW of solar nameplate capacity and 11.8 GW of wind nameplate capacity (EIA 2026b, 2026a). By 2034, the U.S. could require net additions of up to 100 GW of gas-fired capacity and over 900 GW of renewable and battery capacity to keep up with demand (S&P Global 2025).

The increase in demand, combined with the replacement of consistent baseload power with variable renewable generation, means that economical, reliable power may not always be available when consumers have historically used it. Leveraging grid connected electric storage water heaters as thermal storage provides multiple grid benefits without having a negative impact on the user experience. However, to be reliable grid assets, service providers, such as utilities and aggregators, need reliable performance to balance loads and be seen as a valid grid resource to their regulators.

The Changing Utility Landscape

Utilities are experiencing significant load growth due to several factors. 24 states, plus Puerto Rico, have either legislated or enacted, through a Governor's executive order, a move towards a net-zero economy, greenhouse gas reduction targets, or 100% renewable energy (CESA 2026). For example, New York’s Climate Leadership Community Protection Plan of 2019 requires a “decarbonized electric system by 2040” (NYISO 2024), while Washington State’s Clean Energy Transformation Act requires that all retail sales of electricity come from non-emitting or renewable sources by January 1, 2045 (CETA 2019). These aggressive renewable energy targets lead service providers to build utility-scale solar and wind farms or enter into power purchase agreements with independent power producers. Consequently, solar and wind may account for over 75% of all capacity additions through 2035 (S&P Global 2025).

With the transition to intermittent generating resources, identifying and leveraging opportunities for demand-side flexibility will help service providers continue to provide low-cost, reliable electricity to their customers. Smart grid devices (SGD), such as connected water heaters, offer service providers a reliable and predictable way to leverage renewable resources and inexpensive electricity. SGDs are grid-enabled, customer-owned generation, storage, and flexible load assets that can provide grid services, such as demand response, peak load shifting, and demand charge mitigation, among others (Brown et al. 2023, Adham 2025). However, as noted by Nordman et al. (2024), aggregator models currently favored by utilities, have fractured the market with the frequent use of proprietary mechanisms between the aggregator and the device. The increased adoption and use by manufacturers and aggregators, of open, non-proprietary standards, such as CTA-2045, define a standard set of commands that guarantee minimum functionality to enable grid-flexible behavior of the SGD (CTA 2021).

Compliance and Conformance of SGDs

Service providers use SGDs to provide grid services, such as load shaping, peak load shaving, and energy arbitrage. Service providers use several communication protocols, including CTA-2045, to communicate with SGDs. The ability to receive a request from a service provider is not currently an indicator of how an SGD will respond to the request. Service Providers need a high level of assurance that SGDs will be impactful participants within their programs.

For grid service programs to be effective, SGDs must be both *compliant* with the communications protocol and *conformant* to the intent of the protocol messaging. Compliance pertains only to protocol messaging; a compliant SGD understands and responds to messaging as defined by the protocol. However, compliance alone does not guarantee an SGD will be a contributing program asset. SGDs must also be conformant; they must also behave in response to messaging in ways that make them useful program participants. Only conformant SGDs can contribute to successful delivery of grid services.

Smart grid communications protocols provide compliance criteria. They do not specify SGD conformance behaviors, principally because conformance is unique to the type of SGD while the communications protocols are general to all SGD. How a conformant heat pump water heater responds to a CTA-2045 *shed* request will differ from how an AC system will respond to that same request. Some organizations provide limited conformance guidance for residential unitary heat pump water heaters (AHRI 2022, CA 24 JA 13), but comprehensive conformance implementation guides have not been developed for other categories of SGDs.

Market Conditions in Oregon and Washington

The Pacific Northwest is facing new challenges as the region rapidly shifts from historically low, stable electricity prices to more volatile, time-varying rates. For decades, abundant hydropower supported flat electricity pricing; most consumers did not need to consider electricity use. That environment is now changing quickly (NWPCC 2024). A major driver is the rapid increase in electricity demand from data centers and AI infrastructure. Utilities describe this as a "nine-gigawatt problem," reflecting the massive new load these facilities place on the grid (Burdick et al. 2026). Oregon and Washington have residential retail electricity rates below the national average ($0.1730/kWh), with average residential rates of $0.1537 and $0.1311/kWh, respectively (EIA 2026), and some rates as low as $0.028 per kWh (Chelan PUD 2026). While average residential electric rates remain below the national average, the rate of increase has been greater, 28.6% and 26.4%, respectively, compared to 22.79% for the national average between 2021 and 2025 (EIA 2026). In addition to the transition to intermittent generating resources, the Northwest Power and Conservation Council (2025) forecasts an increase in peak demand between 32% and 69% by 2046. To support the transition to renewable energy resources and accommodate load growth, Washington and Oregon, amongst other states, now require all electric storage water heaters with a capacity of 40-120 gallons sold within the state to come with an EcoPort. This port enables ANSI/CTA-2045 (CTA 2021) communication with the water heater (WAC 2023, ODOE 2025) when connected to a universal control module (UCM). CTA-2045 not only defines the communication protocol but also defines the physical interface between the UCM and the SGD. Aligning with open source non-proprietary and industry standards promotes lower fees that are favorable to cost effectiveness, encouraging the market to move more quickly.

The Challenging Value Proposition in the Northwest

Electric utilities in Oregon and Washington have invested heavily in grid upgrades, with the costs largely passed to residential customers. As a result, electricity rates for households served by some utilities have risen by nearly 50 percent since 2021 (EIA 2026). This has prompted regulatory responses, including Oregon's POWER Act, which aims to shift more infrastructure costs back to large energy users. These policy changes create uncertainty not only for water heaters but also for SGDs that were programmed around older, subsidized rate structures.

The region's demand patterns are also becoming more complex. Traditionally, the Pacific Northwest had been a winter-peaking system due to electric heating. Increasingly severe summer heatwaves are creating new seasonal peaks. At the same time, hydropower output varies with precipitation conditions. Low-water years can sharply increase wholesale electricity costs during peak periods. The hydroelectric system generates about 16,000 aMW per year on average, but in low-water years, generation falls to 12,000 aMW (NWPCC 2024). These dynamics complicate the ability of SGDs to predict and respond to optimal energy-use times.

Time-of-use (TOU) pricing adds another layer of difficulty. The Pacific Northwest has historically had low adoption of TOU rates, and many customers are not accustomed to time-varying electricity prices. Utilities such as Snohomish PUD are only beginning to implement full TOU rate structures. Many existing smart devices lack the programming needed to respond effectively to dynamic pricing signals, such as shoulder periods or critical peak events, though new solutions can address real-time variable grid congestion.

Also, infrastructure constraints limit the extent to which smart technologies can help. Aging electrical infrastructure and limited transmission capacity struggle to support rising demand from electrification and new technologies. As a result, even when smart devices successfully shift demand, local grid bottlenecks may still create reliability risks because electricity cannot always be physically delivered where it is needed. Also,

To help address these issues, in 2024 the Northwest Energy Efficiency Alliance (NEEA) developed a specially funded project funded by 10 regional utilities in Oregon and Washington, to support the development of a regional portfolio to leverage NEEA's 30-year track record of successful Market Transformation and accelerate the availability and adoption of SGDs (NEEA 2025). The project vision includes: 1) connecting end-use loads to the grid using non-proprietary pathways that link the utility directly to the customer, 2) end-use loads remain connected, the supply chain and consumers are educated on the value of load flexibility, and cost-effective scale is achieved quickly, 3) end-use load flexibility delivers optimized, predictable, secure, and consistent value to consumers and utilities, and 4) DERMS requirements and dispatch cases are in place for utility operations with a seamless and consistent consumer experience.

Product Performance

As noted above, the CTA-2045 standard defines the physical EcoPort interface between the SGD and the UCM, as well as a minimum set of requests that the SGD must support. In addition to the request descriptions in Table 1, CTA-2045 also defines Commodity Codes for the SGD to report its energy consumption and energy-consumption capacity, accessible through a *CommodityRead* request. Commodity data provide the service provider with guidance on how much energy can be shifted or shed and, with experience, how long the service provider can expect the device to remain within the event.

Table 1. Selection of CTA-2045 requests and their usage

Request Description	Usage
Shed	Requests that the SGD limit energy consumption for a specified period.
Critical Peak Event	Requests the SGD enter a deeper curtailment and limit energy consumption unless necessary for a specified period (e.g., the customer will run out of hot water).
Grid Emergency	A Grid Emergency is occurring (as defined by the service provider). The SGD should limit energy consumption to only the most necessary functions of the SGD for a specified period.
End Shed/Run Normal	The device resumes normal operation.
Load Up	Requests the SGD consume energy if possible, to a pre-determined point, such as a setpoint temperature.

Advanced Load Up	Requests the SGD consume energy above the amount absorbed during a basic Load Up request.

Lab Testing

Laboratory testing investigated two questions: Do heat pump and electric resistance water heaters consistently comply with CTA-2045 requests? And, do devices conform to the intended grid-support behavior? Eleven water heaters from three original equipment manufacturers (OEM) across four brands were tested using a common hot water draw profile representing a four-person household. The sample included three electric resistance water heaters (ERWH) and eight heat pump water heaters (HPWH). CTA-2045 requests were issued using a custom UCM. During testing, electricity consumption, water flow, and ambient temperature were monitored using external meters. Each test included a baseline period, a demand response event or series of events, and a recovery period (Adham, Bass, and Paresa 2025, Bass 2025).

Table 2. Sample CTA-2045-B commodity data

Description	**Units**
Electricity Consumed	Watts & Watt-Hr
Total Energy Storage	Watt-Hr
Present Energy Storage	Watt-Hr
Rated Max Consumption Level	Watts
Rated Max Production Level	Watts
Advanced Load Up Total Energy Storage	Watt-Hr
Advanced Load Up Present Energy Storage	Watt-Hr

Conformant Behaviors

In testing grid-interactive water heaters, conformant behavior is concerned with how well the unit balances user comfort (hot water availability) with grid-responsive energy management (load shifting and shedding). Conformant HPWH behavior means the unit effectively shifts electricity consumption away from curtailed periods while limiting the likelihood of cold water draws. Non-conformant behavior includes commodity data that do not align with external measurements, excessive energy use during shedding periods, or failure to deliver hot water during energy shifting events.

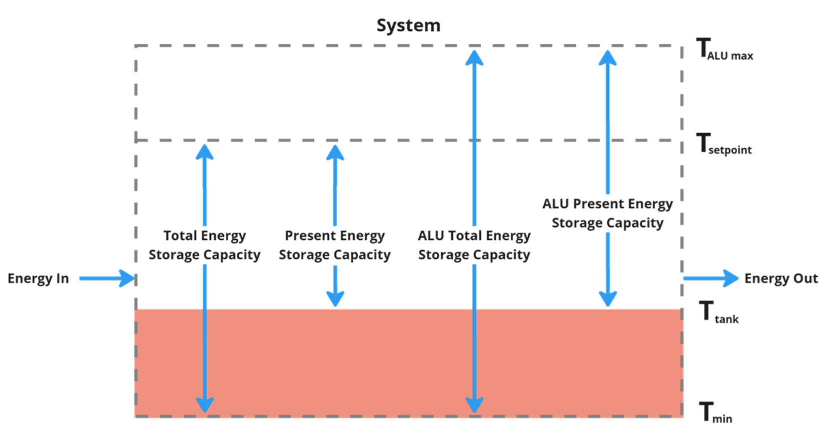

Figure 1. The four types of CTA-2045 energy storage capacity commodity data (CTA 2026).

Differentiation Between Shed Functions

Within CTA-2045, there are three primary shed-type requests: *Shed*, *Critical Peak*, and *Grid Emergency*. Each differs in how aggressively it reduces energy consumption and how much it prioritizes grid stability over customer comfort. While CTA-2045 defines these requests, the OEM determines the exact behavioral response of each appliance to these requests; though the *request* is standard, the behavioral response is not. For example, a HPWH might respond to a *Critical Peak* request by using only its heat pump, while an ERWH model would shut off for a period to achieve a similar load reduction.

Table 3: CTA-2045 Request-Customer comfort cross reference

Request	Aggressiveness	Customer Comfort Priority	Risk of "Cold Event"
Shed	Moderate	High	Low
Critical Peak	High	Medium	Moderate
Grid Emergency	Maximum	Low	High

Methods for achieving load shedding. OEMs use proprietary algorithms to define how their SGD responds to each type of curtailment request, as shown in Table 3. For a *Shed* request, OEMs program their SGD to prioritize customer comfort. The unit will reduce energy consumption, provided it does not cause a "cold-water event" (e.g., running out of hot water). For a *Critical Peak Event*, the SGD is more aggressive and accepts a higher risk of customer discomfort. The unit should use less energy than a standard *Shed*, even if a cold-water event is imminent. Lastly, a *Grid Emergency* request will cause the device to ignore comfort entirely for the duration of the event, often shutting off all power-intensive components, provided it is safe to do so.

Load Shifting Strategies. CTA-2045 facilitates pre-heating a water heater prior to a scheduled shed-type event. A *Load Up* request is sent to the unit, requesting that it raise the tank temperature to its setpoint and store thermal energy to delay the need for consumption during the peak period. CTA-2045-B added the *Advanced Load Up (ALU)* function for water heaters with mixing valves. These units can heat water above the standard setpoint to maximize stored thermal energy, allowing for much longer shed periods.

Rather than sending *Shed* and *Load Up* requests, CTA-2045 also enables price signals to be sent to the device in advance, such as dynamic prices or static TOU prices. The SGD translates these prices into a daily schedule, autonomously deciding when to *Shed* or *Load Up* based on forecasted prices.

Energy Take Measurement and Accuracy Limits

Present Energy Take (PET) refers to the capacity to consume energy on request. This can occur by sending a *Load Up* or *ALU* request or by ending a *Shed* request. The PET commodity value allows service providers to estimate how much energy an SGD can consume upon request. The conformance of PET reporting is verified by comparing device-reported data with external laboratory measurements. Laboratory measurements of PET are conducted by measuring SGD energy consumption during a *Load Up* cycle, when PET is driven from a finite value to zero, at which point it has reached its set point and will stop consuming energy. The energy consumed during this period should equal the PET recorded prior to the start of the period.

PET is very difficult to estimate in unitary residential water heaters, which typically have only two temperature sensors. SGDs use these sensors to calculate the thermal energy required to drive the average tank temperature to a setpoint temperature. However, the temperature gradient from the top of the tank to the bottom is non-linear, particularly during heating cycles and water draws. It is not possible to accurately calculate PET with just two data points, which can only provide a linear estimate of the temperature gradient (Bass and Paresa 2025), as exemplified in Table 4.

Table 4: Present Energy Take data resolution, error percentage, and standard deviation

Unit	Capacity (gal)	Voltage (V)	Resolution (Wh)	PET % error	PET Std. Dev.
a	50	240	75	52%	40%
b	50	240	75	44%	7%
c	50	240	1	89%	11%
d	50	240	51	337%	167%
e	80	240	1	98%	8%
f	50	120	30	41%	17%
g	50	240	22	201%	35%

Findings on Compliance and Conformance

Protocol *compliance* does not necessarily ensure operational *conformance* and consistency in grid-connected water heaters using the ANSI/CTA-2045 communication standard. In other words, devices may successfully receive and acknowledge requests from a service provider but still behave in ways that limit their usefulness as grid resources. Testing has revealed significant differences in behavior across OEMs. One water heater model generally complied with the messaging protocol but exhibited poor conformance. For example, the device treated *Shed* and *Critical Peak* requests identically, eliminating the intended difference in event severity. Additionally, the unit reported PET values that differed substantially from measured energy consumption. This disconnect makes it difficult for service providers to verify participation, predict load-shifting capacity, or accurately compensate customers.

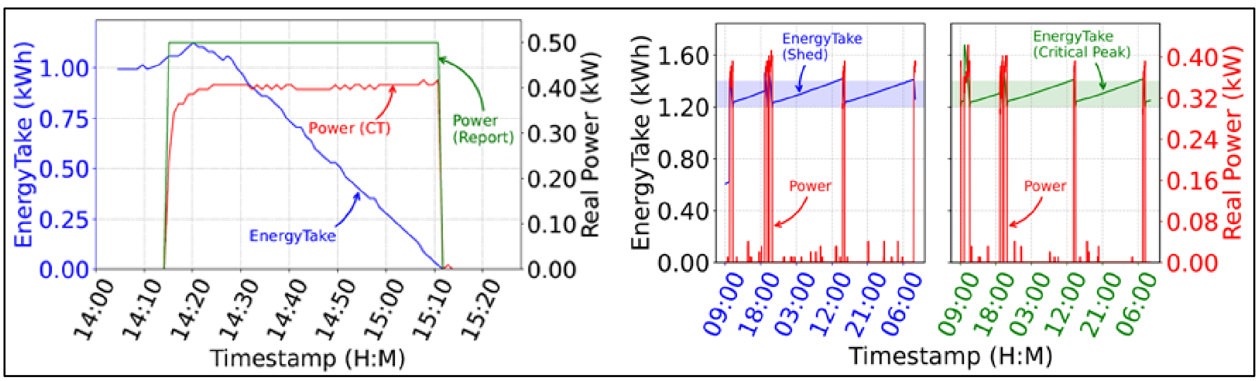

Figure 2. Left: An example of a compliant, but non-conformant, response to a request for power data. The reported power data varies from the measured power. Right: A unit that uses the same response for the Shed and Critical Peak Event requests. *Source:* Bass 2025.

The same unit also demonstrated compliance gaps in required protocol messaging, such as incomplete handling of the Outside Communication Connection Status request. Furthermore, its control logic relied heavily on a single temperature sensor, leading to inconsistent heating and potential customer comfort issues during *Shed* events. In contrast, a second OEM's unit demonstrated both compliance and conformance. It correctly implemented protocol messaging, showed consistent responses to different curtailment requests, and maintained predictable operating thresholds. The device also provided more reliable PET reporting, allowing service providers to better estimate available load flexibility.

Overall, the study concluded that conformance testing is essential for evaluating grid-interactive appliances. Utilities must understand how devices behave in response to control signals to ensure reliable grid services while maintaining customer comfort.

Field Testing Study

NEEA conducted an End-Use Load Flex Field Study from June 2024 to October 2025 and examined the barriers, goals, and opportunities associated with connecting customer-installed CTA-2045 EcoPort-enabled water heaters and having them participate in grid flex requests. Prior field studies relied heavily on coordinated installation of UCMs by contractors (Zandi 2024). This study evaluated the outreach, installation, operation, and long-term connectivity of CTA-2045 UCMs through various methods (Colwell 2026). NEEA partnered with SkyCentrics for the study and used their AC-powered, LTE cellular UCMs and DERMS platform for dispatch and monitoring. The goals of the study were as follows:

1. Determine the location accuracy available when an EcoPort module connects.
2. Evaluate participant sentiment to low-impact water heater control and identify effective value-exchange messaging via surveys.
3. Measure participant retention from installation, enrollment, and service provider control.
4. Quantify how effectively CTA-2045 events shift load (*Load Up* and *Shed*).
5. Compare event performance across different water heater types.
6. Identify DERMS strategies that increase load shifting while maintaining customer comfort

Study Fleet

The study enrolled 110 water heaters (defined as successful installation and completion of terms and conditions). Of these, 76 there were HPWHs and 34 ERWHs. 102 of the water heaters completed the initial onboarding survey; the others were identified by the make-and-model reporting codes sent via the UCM. Units were distributed among four different OEMs. Ultimately, 102 water heaters received load shifting signals for at least three months. The water heaters were installed across the geographic areas of Puget Sound Washington (Everett, Olympia Seattle, Tacoma), the Portland, OR metro area, and a rural Oregon PUD in western Oregon.

Table 5. Study Participation by OEM and Water Heater Type

OEM	HPWH	ERWH	Eligible
A	18	1	19
B	57	28	85
C	0	5	0
D	1	0	0
Totals	76	34	104

NEEA Field Study Results

Connectivity and Load Shift Performance

Of the 110 enrolled water heaters, 104 were eligible for load shifting within the study, while 6 were excluded due to poor CTA-2045-B compliance. 103 received load-shifting signals for at least three months, with one being excluded for heavy hot water use as a precautionary measure. Across the study duration, water heaters were baselined by first measuring power consumption and water heating behavior for two weeks after initial connection, with no controls applied. Subsequently, the fleet was scheduled in alternating weeks of daily events scheduling, and control weeks with no events scheduled. Fleet energy consumption during curtailed periods fell by an average of 49% compared to baseline (ERWH: 44.90% decrease, HPWH: 50.97%).

While significant, this reduction did not fully minimize potential consumption during curtailment periods; higher compliance would likely have produced greater reductions. A large gap emerged between participating and non-participating water heaters during curtailment events. Curtailed units actively heated water less than 3% of the time (ERWH: 2%, HPWH: 4%), while opted-out or non-participating units (running normal or opted out) ran 16–20% of the time. This indicates that with full participation (participation was increased to over 95% through the course of the study via repeat event signaling and opt-out troubleshooting, addressed later), energy use during Shed events could be reduced by an estimated 85% for HPWHs and 57% for ERWHs. All power consumption data from the study are as-reported via CTA-2045. Direct power measurement was not possible outside of a lab environment.

Overall, the results show meaningful load-shifting impacts for both ERWHs and HPWHs. ERWH units averaged 5 kWh of daily consumption and achieved a 57% reduction in energy when curtailed, corresponding to an average daily load shift of 928 W per unit that aligns with Ashley et al.'s estimated 1,000 watts published in "Nontargeted vs. Targeted vs. Smart Load Shifting Using Heat Pump Water Heaters" (2021). HPWH units averaged 4 kWh of daily consumption but demonstrated a significantly larger 85% reduction during curtailment, resulting in an average daily load shift of 1.1 kW for participating HPWH units. Overall, participating HPWHs delivered slightly more load shifting than participating ERWHs, despite lower baseline daily energy consumption, due to their ability to shift a greater proportion of their load to non-curtailed periods.

Opt-Outs

Throughout the field study, an average of 13% of the fleet opted out of any given event. To understand this relatively high rate, the Study analyzed opt-out behavior and identified four primary types (not exhaustive). Customer-initiated opt-outs include: 1) a 24-hour override and 2) vacation mode, which minimizes operation while occupants are away and only runs to prevent freezing. The user can control the opt-out state on the water heater control panel or through a mobile application. Device-initiated opt-outs include 3) OEM safeguards, triggered to prevent excessive on/off cycling within a short period of time, and 4) new-installation opt-outs, where newly installed water heaters remain opted out for 24-48 hours, often when EcoPort modules were installed concurrently. Additional causes may exist, as a device can report an opted-out state whenever it stops responding to grid signals. The Study recorded 265 opt-out events among enrolled devices between August 1, 2024, and October 31, 2025 (as summarized in Table 7). Durations ranged from under one minute to more than 100 days, though several clear duration clusters emerged.

The largest proportion of opt-outs was from the OEM safeguard trigger. This phenomenon was isolated to units manufactured by OEM A, specifically a 50-gallon heat pump hybrid model that lacked an internal timekeeping method. This unit had firmware that limited the amount of "daily" signals it could receive before opting out, but simultaneously did not have a method of recording when one day ended and the next began. SkyCentrics confirmed this issue persists among other models from OEM A, including ERWH, in other fleets. However, this opt-out behavior was overcome by updating the firmware of the UCM to send the updated date and time each hour (Colwell 2026).

Table 7. Observed Opt-Out Types and Operational Characteristics

Opt-Out Type	Events	Typical Duration	Runtime During Opt-Out	Key Insight
Type 1 – Customer Override	162 events (~61%)	~24 hours (23–25 hr)	19% runtime (vs. 30.4% normal)	Customer overrides were common but short-lived and had limited long-term impact on fleet availability.
Type 2 – Vacation Mode	6 events (~2%)	>48 hours	<1% runtime	Rare events consistent with minimal hot-water use; reporting varies by OEM because CTA-2045 does not require this state to be reported.
Type 3 – OEM Safeguards	14 events (~5%)	≥16 days (one >200 days)	7–45% runtime	OEM safeguards disabled grid participation for extended periods and accounted for >82% of total opt-out time.
Type 4 – New Installation	24 events (~9%)	Temporary post-install period	28.5% runtime	OEM-specific safeguard preventing grid control immediately after installation.

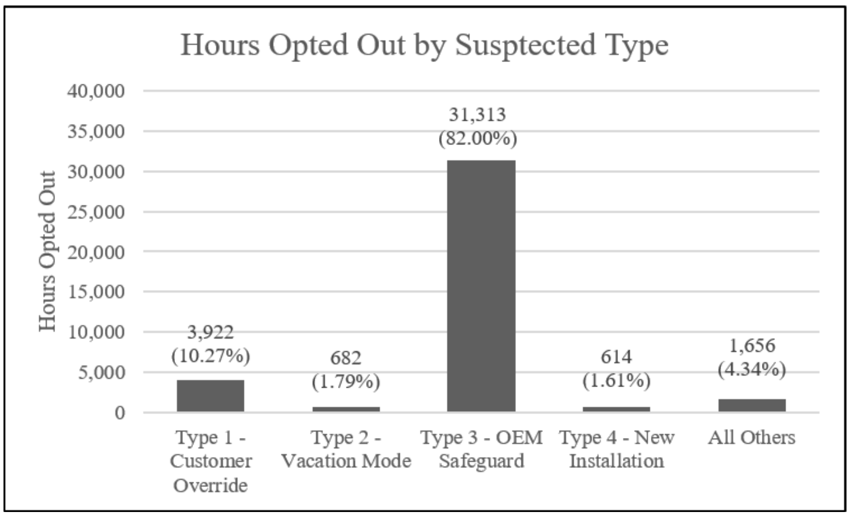

Figure 3: Hours Opted Out by Suspected Event Type.

Water Heater Compliance and Conformance in the Field

104 participating units met the minimum telemetry compliance required to participate in load shifting, specifically the ability to communicate both operational state and instantaneous power consumption (some estimated, some measured by a CT) through the CTA-2045 pathway. These two data points are the baseline requirements for service providers to verify device responses and measure load reductions during demand response events. The high compliance rate (94.5%) across the fleet indicates that most devices could provide the core telemetry necessary for coordinated load management.

The six units that did not meet this baseline compliance requirement were exclusively from OEMs C and D, while all units from OEMs A and B successfully reported both operational state and power values. The nature of the missing telemetry varied by OEM. OEM C units were able to communicate operational state, indicating whether the water heater was running or idle, but did not provide instantaneous power or instant capacity values, limiting the ability to quantify actual load reduction. The single unit enrolled from OEM D provided none of the three key telemetry points: operational state, instantaneous power, or capacity, rendering it unsuitable for measuring or verifying demand response performance within the study.

Even among units that met the baseline compliance reporting requirements, some anomalies in conformance telemetry were observed. All ERWH from OEM B correctly reported instantaneous power and operational state, allowing them to participate in load-shifting events. However, not all units reported present capacity values correctly. Some ERWHs reported instant capacity values exceeding 1 billion watt-hours, strongly suggesting an integer overflow or a similar firmware-related reporting error. While this issue did not prevent event participation or measurement of real-time load reduction, it did limit the ability to use telemetry to underpin more advanced orchestration strategies that depend on storage capacity information.

Critical compliance issues:

- Missing power, instant capacity, and operational state values
- Discovery failure: Without a commodity code, the service provider may not recognize the appliance when it is plugged in or brought online.
- Request Rejection: The OpenADR Alliance (2026) notes that certification verifies "correct sending and receiving messages."
- Prolonged periods of opting out of grid signals
- If the system cannot identify the device as a "Water Heater," it may fail to send appropriate requests because it cannot predict the device's behavior.
- Operational state of 0 (idle normal) reported when 400+ W of power was being actively consumed

Critical conformance issues:

- Power values that show discrepancy from actual power usage
- Large variance in reported 'total capacity' (1.5-11 kWh reported for 50-gallon HPWH)

Additional Conformance issues:

- Insufficient separation of behavior between Shed and Critical Peak commands
- "Present capacity" not reaching 0 when water heater completes heating cycle

Overcoming Poor Compliance and Conformance

As service providers increasingly rely on SGDs to support grid reliability, ensuring that these devices behave predictably in response to control signals becomes important. While standards such as ANSI/CTA-2045 enable communication between service providers and appliances, protocol compliance alone does not guarantee useful operational behavior (Adham, Bass, and Paresa 2025). Devices may acknowledge and receive requests but fail to perform in a manner that provides meaningful grid services.

Addressing compliance and conformance gaps provides significant value for service providers, OEMs, and customers. NEEA's field research confirmed that it is possible for an aggregator to mitigate poor SGD conformance once its behavior is understood. Still, for service providers, reliable device behavior enables more accurate forecasting of available flexible load, improved peak-demand mitigation, grid balancing, and the integration of renewable resources.

Conformance testing allows service providers to understand how devices actually respond to requests such as *Shed*, *Load Up,* and *CommodityRead*, enabling more effective demand response program design and dispatch strategies. For OEMs, improved compliance and conformance testing provides a pathway to develop products that perform consistently in grid-service programs. By verifying how appliances interpret control signals and ensuring accurate telemetry, such as energy consumption and storage capacity, OEMs can improve product reliability and interoperability across platforms. This supports broader adoption of grid-interactive appliances and strengthens their value proposition in the marketplace.

Most importantly, addressing conformance ensures that grid services are delivered without compromising customer comfort. Reliable temperature control and predictable device behavior reduce the risk of negative user experiences, which historically has limited participation in demand response programs (Adham, Bass, and Paresa 2025). Ultimately, overcoming compliance and conformance issues enable scalable SGD aggregation, allowing service providers to confidently deploy connected appliances as dependable grid resources while maintaining high levels of customer trust and participation. The data provided through the UCM throughout the study enabled the development of several strategies to maximize the value of connected water heaters to the utility while maintaining customer comfort.

Customer Feedback from Field Study

Customer feedback from the End-Use Load Flex Study indicated that connected water heater control had minimal perceived impact on comfort or hot-water availability. Most participants reported no noticeable change in hot water supply during load-shifting events, and several indicated they would not have known their water heater was being controlled without being informed. These findings suggest that well-designed load flexibility programs can operate largely invisibly to customers while maintaining comfort and providing grid benefits. Improved customer visibility into device data and program performance may further increase engagement and participation.

The Water Heater Opportunity and Next Steps

Policy Implications

The Oregon and Washington policies requiring the EcoPort on ERWH are an important step in enabling water heaters to be a valuable grid resource. However, policy alone does not remove other significant market barriers, such as a low perceived value proposition among consumers, skepticism among installers, and a lack of demand response programs. Other states considering requiring the EcoPort on water heaters should align with service providers so that load-flexibility programs can be launched in tandem with the product's market entry.

Need for Certification, Compliance Testing, and Certification Body

NEEA’s lab and field tests show that certification to a standard does not guarantee proper behavior. AHRI developed Standard 1430-2022 for demand-flexible electric water heaters, including using CTA-2045-B for communication. The standard defines basic SGD response but not reporting accuracy. Experience now allows service providers to guide OEMs on expected water heater responses. Once these guidelines are set, OEMs can ensure their products meet consumer and service provider needs.

Implementation guide

To support OEM and service provider needs and accelerate customer participation in residential demand response programs, NEEA and Portland State University are working with industry stakeholders, including water heater OEMs, UCM manufacturers, program implementers, and service providers, to develop an implementation guide for grid-connected water heaters. The guide will provide useful guidelines on variables that determine how a connected water heater will respond to grid requests. The three goals of the project are to: 1) Maintain customer comfort to continue participation in demand response programs; 2) Allow OEMs the freedom of design to maintain product line specifications and performance; and 3) Create a product that can serve as a meaningful participant in the requested grid service. Once published, the guide can be referenced by other industry standards such as future revisions of AHRI-1430 or be integrated in part or whole into the standard. Other equipment types, such as central commercial water heaters and residential HVAC systems would necessitate the development of their own implementation guides in the absence of industry standards that define and test for equipment conformance performance.

Summary and Conclusions

This study evaluated the performance of grid-connected electric water heaters equipped with EcoPort (ANSI/CTA-2045) communication interfaces through both controlled laboratory testing and a field deployment in the Pacific Northwest. The research examined device compliance with CTA-2045 load-management requests, operational characteristics that influence load-shifting capability, and practical barriers affecting service providers, installers, and customers participating in connected appliance programs.

Laboratory testing evaluated how water heaters interpret and respond to CTA-2045 load-management requests under controlled conditions. Results showed that while most devices could receive and acknowledge CTA-2045 signals, device responses varied significantly across OEMs. Differences in internal control algorithms, energy capacity reporting, and the implementation of load-management requests resulted in a range of operational behaviors during events. These findings highlight the important distinction between protocol compliance, which indicates that a device can receive and acknowledge a communication request, and functional conformance, which reflects whether the device responds in a way that delivers predictable and useful grid services.

The field deployment evaluated the performance of 110 connected water heaters enrolled in demand-response programs. Participating devices reduced electricity consumption during curtailment events by an average of approximately 49%, demonstrating the ability of connected water heaters to provide meaningful load flexibility. HPWHs achieved particularly strong reductions due to their lower baseline energy consumption and flexible heating cycles. However, the deployment also revealed several operational factors that limited the fleet's overall performance. These included customer opt-outs, communication interruptions, and device-specific behaviors that temporarily removed units from participation. In particular, OEM-implemented safeguard opt-outs sometimes resulted in extended periods during which devices were unavailable for program participation, reducing the aggregate fleet responsiveness.

Taken together, the findings show that EcoPort requirements successfully enable device connectivity but do not guarantee grid service participation. While the CTA-2045 provides a common interface for service providers, differences in device behavior can affect program performance and the amount of flexible load that can be delivered.

This study identifies several opportunities to strengthen the role of connected water heaters. These include the development of stronger device certification requirements, improved compliance and conformance testing procedures, clearer implementation guidance for OEMs, and program design strategies that account for operational constraints. Addressing these gaps can help ensure that connected water heaters deliver predictable, scalable load flexibility that supports both grid operations and customer participation in demand-response programs.

Key Findings

Connected water heaters can provide substantial load flexibility. Devices in the field deployment reduced electricity consumption during curtailment events by approximately 49% on average, demonstrating the potential for meaningful demand-response capacity from residential water heating loads.

Protocol compliance does not guarantee grid-useful behavior. Devices that successfully receive CTA-2045 signals may still respond in ways that limit their usefulness as demand-response resources due to differences in internal control logic and request implementation.

Operational factors significantly affect fleet performance. Customer opt-outs, communication disruptions, and safeguard logic can temporarily remove devices from participation, reducing the aggregate responsiveness of connected fleets.

Improved testing and certification could increase program reliability. Stronger compliance and conformance testing requirements would help ensure that devices enrolled in demand-response programs provide predictable and consistent responses to load-management events.

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