Guidehouse INSIGHTS

White Paper

Capturing Value from Electric Water Heaters as a Non-Invasive Demand Response Resource

Market Trends, Applications for Grid Services, and Recommendations for Utility Program Design

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Executive Summary

Utilities are facing a myriad of new and potentially disruptive technologies. Distributed energy resources (DER) and utility-scale intermittent generation are connecting to the grid, affecting the supply and demand sides of the meter. As the grid becomes more dynamic, legacy transmission and distribution infrastructure shows its age under the growing pressure of capacity constraints from the electrification of existing technologies and the new two-way energy flows of distributed generation. Utilities will need to take advantage of non-invasive, easy-to-engage technologies located behind the meter to enable a smooth transition toward the decentralized energy future. Water heaters exemplify one such technology and are becoming a more central tool in the utility toolbox to help customers reduce their bills and monetize their onsite assets. These already-deployed grid resources also serve as a low-cost way for utilities to deploy energy storage and improve grid stability.

The difficulty in measuring and managing the capacity achieved from individual water heaters has traditionally inhibited their use in utility demand response (DR) programs. However, retrofit control technologies and smart water heaters, when paired with intelligent software platforms that enable load control, allow secure, two-way communication between these devices and the grid. The growing penetration of these grid-communicating water heaters allows grid operators to use water heater data in new ways and broaden the array of services these assets can provide. As deployments of two-way communicating water heaters increase, grid operators are seeing real benefits from the aggregation of these micro-loads, both to the utility and the wholesale grid.

Water heater participation in DR programs offers unique benefits on the utility and customer sides of the meter. By engaging water heaters, utilities can mitigate the strain to grid resources caused by rebound effects after an event or outage. Additionally, water heaters' ability to hold their temperature over extended periods lessens customer awareness that a given DR event is occurring. This avoids customer fatigue challenges often associated with other DR technologies.

Water heaters are becoming a more central tool in the utility toolbox to help customers reduce their bills and monetize their onsite assets. These already-deployed resources serve as a low-cost way for utilities to deploy energy storage and improve grid stability.

This white paper summarizes Guidehouse Insights' view of key market trends regarding water heater use as a multi-application tool for load management. It also explores the various grid services applications of water heater technologies. Case studies illustrate results from water heater management programs deployed to single-family and multifamily customers. These studies demonstrate direct demand management and wholesale market bids and illustrate how utility infrastructure has benefitted from water heater curtailment during periods of strain. Finally, Guidehouse Insights provides recommendations for utilities and their partners that are considering using water heaters to implement and scale DR programs.

North American Demand Response Landscape

Investor-owned, municipal, and cooperative utilities in North America and around the globe are facing bidirectional pressure to secure flexible grid capacity. Growing capacity constraints create new pressures on aging grid infrastructure, particularly during load peaking seasons. At the same time, customers desire low utility bills while simultaneously pursuing clean energy access and often enabling more electrified technologies in their homes.

Utilities should use already-deployed assets to maximize their performance objectives alongside customer demands in the near term. Demand response (DR) programs that activate capacity provide one such rapidly deployable tool. Barriers to adoption of these customer-sited devices are minimal relative to larger, often costly, equipment. Similar to a smart thermostat, a two-way enabled water heater takes up no extra room in a customer's home and requires little-to-no additional maintenance. Moreover, water heaters have the ability to meet grid objectives without compromising customer comfort. These features put water heaters among the first wave of truly non-invasive communicating technologies to integrate into utility DR programs.

Figure 1 Water Heaters as Tools for Evolving Utility Load Management Programs

Water Heater Technology Landscape	Two-Way Connected Device Maturation	Utility Objectives	Customer Needs
• Retrofit options to easily transform already deployed assets • Integration of equipment into the smart home environment • Cost reduction through energy control and better maintenance data	• Growing need for controlled appliances, easy-to-engage customer-sited devices • Data streams to inform usage patterns and maintenance requirements • Rapid-response equipment to provide a variety of grid services	• Systemwide and targeted peak demand management • Load-shift to absorb surplus, low cost generation • Demand response for renewables integration • Transition of customers to time-varying electricity rates	• Lower utility bills • Electrification of new technologies • Monetization of onsite energy assets • New revenue streams for multifamily and low income customers • Comfort and home energy management solutions

(Source: Guidehouse Insights)

Background

The North American DR landscape supports a growing number of applications for retrofit smart water heater control technology as a grid resource. Communicating water heaters can serve as an asset in a variety of DR applications by receiving automated signals from the grid; these applications include:

- Peak demand reduction
- Cost reduction under time-varying rates
- Renewables firming

- Frequency regulation

By heating water around high demand periods, water heaters act analogously to batteries in electricity load shifting efforts, and these events can occur without inconveniencing the utility customer. The tank size of the typical residential water heater is such that, during a DR event, an enabled water heater will not suffer sufficient heat loss to affect the household.

Load Management Technologies for Water Heaters

According to the US Energy Information Administration's most recent *Residential Energy Consumption Survey*, 45% of US households relied on electric water heating, compared to 48% that used natural gas heaters and 7% that used an alternative fuel source.[1] As stakeholders across the power and clean energy sectors promote electrification, this balance will shift toward electric water heating. Shipments of residential electric water heaters, as a proxy for the number of new installations, indicate that 4.2 million devices entered the US market in 2019 alone.[2] However, most electric water heaters cannot participate in DR events off the assembly line, and to date, most of the North American water heater fleet is not contributing to grid support. To engage existing and newly installed water heaters in DR, additional technologies are needed:

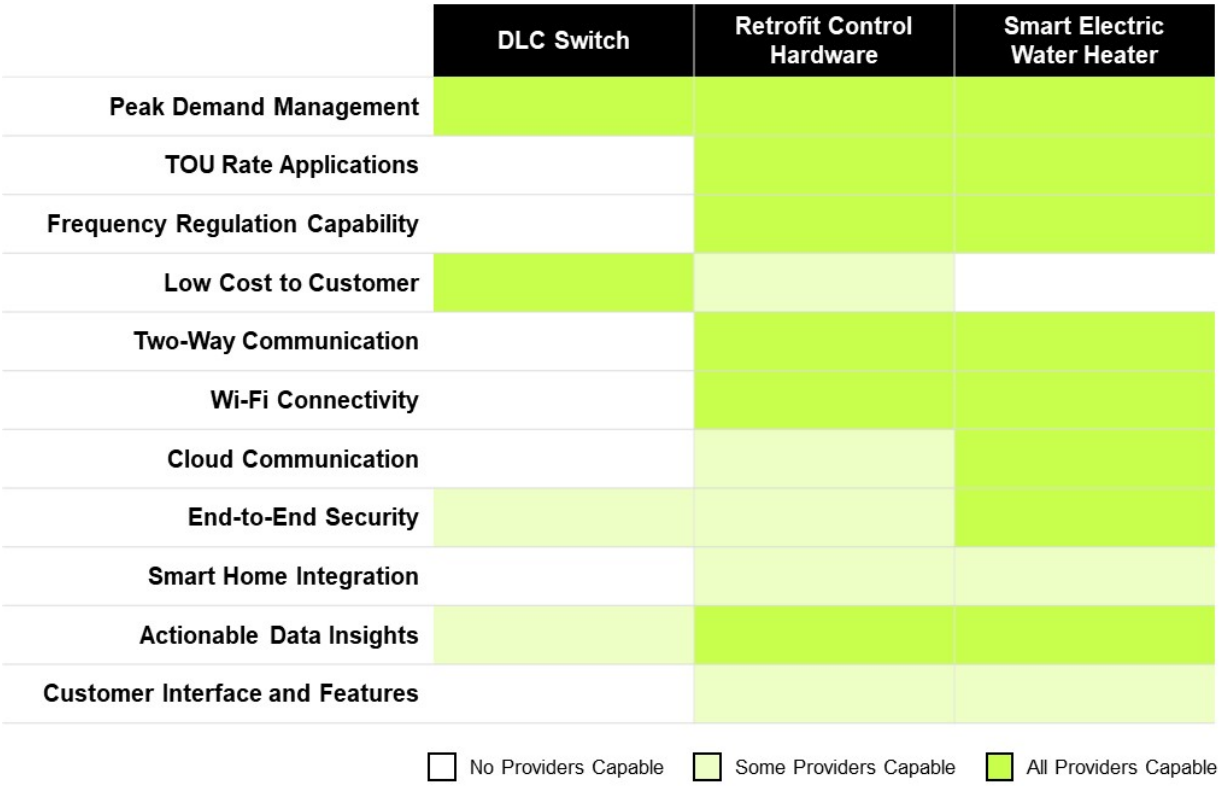
- **Direct load control (DLC) switches** can be used to control load from water heaters for emergency or peak load management events. DLC switches are not two-way communicating, do not provide customers with a user interface through which to engage, and do not provide the grid operator with feedback on load performance or customer impact.
- **Smart retrofit control hardware** can be used on existing electric water heaters to enable them to serve as a resource for relevant DR programs. Retrofit control technology is typically non-invasive and should not require plumbing modifications, though it may require a professional for installation. A retrofit technology solution can communicate through the cloud with embedded security protocols to facilitate customer data protection, and it must handle millions of switching cycles to support advanced grid management programs.
- **Smart water heaters** can be preprogrammed to connect to customer Wi-Fi and smartphone applications or website portals. Wi-Fi connection alone may not always suffice in connecting these water heaters to the grid. Additional software updates, applications, or retrofit technology may be necessary to enable smart water heaters to participate in DR programs.

[1] US Energy Information Administration. "Table HC8.1 Water Heating in U.S. homes by housing unit type, 2015." Residential Energy Consumption Survey (RECS). https://www.eia.gov/consumption/residential/data/2015/hc/php/hc8.1.php Accessed June 19, 2020.

[2] Air-Conditioning, Heating, and Refrigeration Institute. "HFRI Releases December 2019 U.S. Heating and Cooling Equipment Shipment Data." February 2020. http://www.ahrinet.org/App_Content/ahri/files/Statistics/Monthly%20Shipments/2019/December_2019.pdf and

Flink Energy Consulting. "Electric Water Heaters as Grid Energy Storage." Prepared for the Energy Trust of Oregon. June 2017. https://www.energytrust.org/wp-content/uploads/2017/11/Water_Heater_Energy_Storage_wStaffResponse.pdf

Figure 2 DLC, Retrofit Control, and Smart Water Heater Technology Comparison



(Source: Guidehouse Insights)

Because the hardware is designed to enable already-deployed assets, retrofit controls often prove an attractive solution to a range of customers looking to enroll their water heaters in DR programs. These smart retrofit control options can also provide greater management opportunities and data than a DLC switch. In addition to allowing two-way communications, retrofit technologies may generate new data streams that utilities and aggregators can use to meet grid and customer objectives. Such data streams might include local frequency sensing, top and bottom of tank temperature probes, leak sensing and alerts, and data encryption and other security features.

Importance of a Water Heater Management Platform

Water heater management platforms should combine a hardware solution with a scalable software solution to provide grid-level services. These platforms allow a grid operator to program and set control parameters for their fleet of water heaters and integrate real-time control signals for renewables firming, load shaping, or other ancillary services. Software programs should be able to coordinate scaling water heater fleets and engage water heaters to provide the variety of grid services noted throughout this white paper. Cloud communications are a preferred connection mechanism between hardware solutions deployed in the field and the control platform. However, cloud communications must

A quality retrofit technology solution must communicate through the cloud with embedded security protocols to ensure customer data protection, and it must handle millions of switching cycles to support advanced grid management programs.

continually update to meet security protocols and cybersecurity standards. A secure platform is critical for broader grid security and can provide participating customers with ease of mind concerning the transmission of their customer data.

Market Drivers

Several factors act as catalysts for utility growth and DR program development. These catalysts vary depending on location, but generally include:

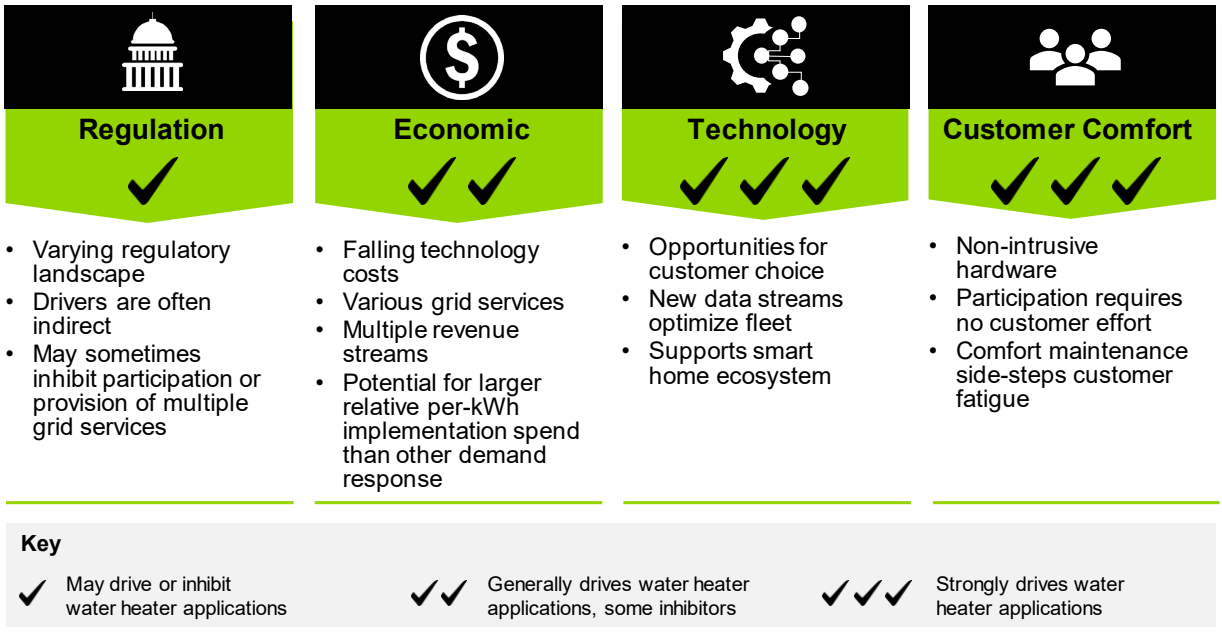
- **Growing renewables penetration:** As more intermittent renewable generation connects to the grid, water heaters act as a powerful balancing tool. In areas with high solar penetration, water heaters can shift load, activating during periods of peak production to capture excess generation capacity. This load shifting can reduce the burden on utility infrastructure and behind-the-meter energy storage systems.
- **Customer choice:** Residential and, where eligible, multifamily customers want simple yet integrated home energy management solutions. Retrofit controllers attach to most commercially available water heaters, so customers can integrate their water heater of choice into their smart home design; these technologies can help households save money and reduce their carbon footprint.
- **Avoidance of customer fatigue:** The ability to maintain water temperature allows water heater-based DR programs to occur with a low risk of opt outs. Enabled water heaters automatically turn off or cycle as needed, requiring no effort from the customer. Households should not notice that their water heater is participating in DR, thus avoiding customer weariness sometimes associated with thermostat programs.
- **Financial incentives:** Because water heaters are already-deployed resources, utilities may earn performance incentives by meeting their DR or other portfolio standard goals at a reduced cost. Simultaneously, end customers could be motivated by incentives for granting the utility access to their eligible water heater. Water heater rebate programs may help accelerate customer adoption of eligible devices or provide an opportunity for utilities to market DR programs featuring retrofit devices.
- **Time-varying rates, including time-of-use (TOU) rates:** Two-way communicating water heaters can respond to utility price signals. The growing number of customers on time-varying rates will then be eligible to enroll their water heaters in programs that automatically shift their load to times when low cost power is readily available.
- **Trade ally networks:** OEMs and their trade allies may assist customers in securing or enabling grid-communicative water heaters where they are aware of local DR programs. Utilities working with distributor networks can provide installers with program information and marketing materials to supply to eligible customers. Trade allies may also help customers choose a smart water heater or install a retrofit device and program it to participate in a local DR program.

Market Barriers

On average, water heaters last 8-12 years before requiring a replacement. Given this lifespan, many OEMs believe it will take more than 15 years following any future mandates to reach full deployment of grid-communicating water heaters. Even considering retrofits, factors inhibiting a more rapid deployment of load management-eligible water heaters could include the following:

- **Efficiency-focused metrics:** Investor-owned utilities (IOUs) subject to public utility commission regulation could be required to meet energy efficiency targets. Where utility program budgets remain siloed, resources may shift toward traditional efficiency programs and away from innovative DR. Investing in efficiency-only metrics might detract from programs that engage water heaters for a variety of grid services. Further, some efficiency programs provide rebates for water heaters not capable of DR services.
- **Prohibitive costs:** Smart water heaters are a relatively new water heating technology and come at a price premium relative to conventional options. Retrofitting technologies offer a more affordable solution but can still cost a customer more than $150 in the absence of rebates or other incentives.
- **Emergency repair situations:** Many water heaters are replaced during emergency repairs. Customers who need to replace equipment in an emergency often work to keep their upfront costs low given the unplanned nature of the expense, even when aware of incentive programs. Therefore, when a water heater breaks down, customers may be more likely to purchase a similar or lower cost model rather than a smart water heater or additional enabling hardware.
- **Enrollment challenges:** Unlike plug-and-play technologies, new smart water heaters and many retrofit technologies require an onsite technician to install. Once the technology is in place, the customer will also need to configure the device or otherwise enroll it in a program using a utility portal. Busy customers might find these factors as significant barriers to enrollment.
- **Weak basement Wi-Fi:** Customers in larger homes or with weaker routers might find the Wi-Fi signal does not reliably meet the placement location for the water heater. Wi-Fi repeaters or other networking solutions may be necessary to facilitate cloud communication, but their purchase or installation could be a deterrent to customers.

Figure 3 Market Trends Summary



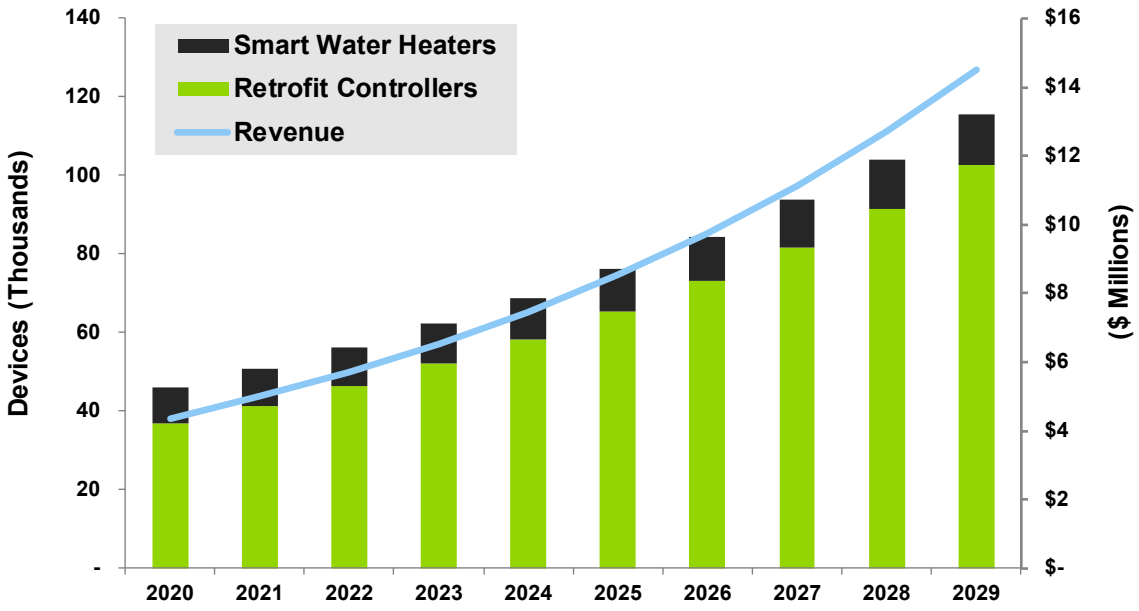
(Source: Guidehouse Insights)

Market Forecast

Guidehouse Insights estimates more than 46,000 two-way water electric heaters will be enrolled in DR programs across North America by the end of 2020 as utilities leverage these devices as load management assets. The number of units enrolled is expected to grow at a compound annual growth rate (CAGR) of 10.7%, totaling more than 115,500 participating two-way communication devices by 2029.[3]

For this forecast, North American revenue earned from two-way communicating water heaters is calculated based on payments from wholesale markets and utility programs to aggregators and their customers for program participation. Guidehouse Insights expects a growing share of DR-enabled water heaters will participate in utility TOU and ancillary services programs throughout the life of the forecast. The bulk of revenue is expected to be earned by devices enabled through a retrofit hardware solution paired with an asset management platform. In 2020, two-way communicating water heater programs are anticipated to generate more than $4.3 million in revenue across North America. By 2029, revenue earned from DR-enabled water heaters is expected to increase to over $14.5 million.

Chart 1 Two-Way Communicating Water Heater Units and DR Revenue, North America: 2020-2029



(Source: Guidehouse Insights)

[3] This forecast excludes water heaters enrolled through DLC switches. The market will trend toward retrofit, smart, and grid-interactive water heater technologies.

Water Heaters as a Tool for Load Curtailment

Water heaters have traditionally been overlooked as demand management solutions, in part because of the small amount of load available from each available device compared to large industrial loads. Yet, water heaters are in almost every building—sometimes with multiple units in a building—across a given utility's service territory. Accordingly, aggregated load from already-deployed water heaters can play a meaningful role in improving grid stability as more electric devices interconnect with the grid.

Water Heater Storage and Power Capabilities

A 50-gallon electric resistance water heater can store about 6 kWh/4.5 kW of heat energy. Portland General Electric and Pacific Power estimate that 500,000 water heaters across their territories have the potential to provide more than 2,000 MW of controllable load.[4] As water heaters become more efficient, customers are less likely to run out of hot water while their heater is providing grid services.

Loss of hot water is also a diminishing concern as some retrofit control devices can curtail load via short shutoffs; much like an AC cycling program, the water heater cycles on and off via an automated signal dispatched to the control device. Short shutoff systems can save customers hundreds of dollars over the course of the year, with no noticeable impact on water temperature.

Energy stored varies by water heater type. Various electric water heaters are used for electric demand management solutions.[5] For example, more efficient heat pump water heaters maintain customer comfort but have less load shifting capability because of compressor cycle constraints and longer thermal recovery time. It is in the interest of utilities to gather as much device-level data as possible from their water heater fleet to support forecasting of available capacity and bids into wholesale markets.

Grid Service Applications

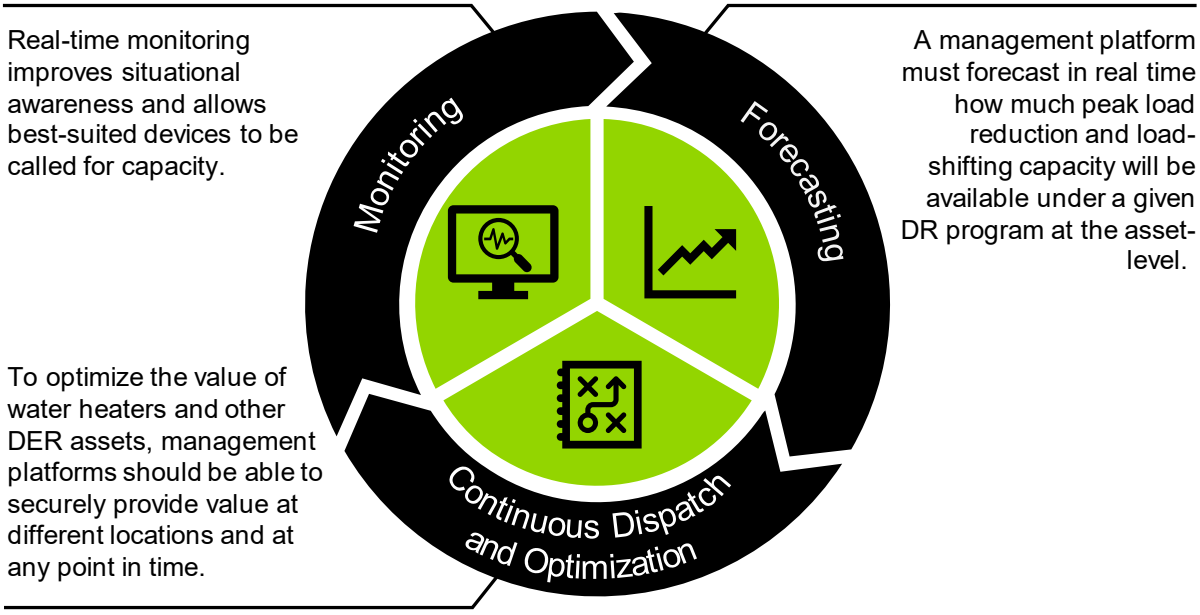
Peak reduction, time-varying rates, and renewable firming capabilities are the most common utility applications for aggregated water heater loads. Where regulations allow, water heaters providing these services may also provide frequency regulation into wholesale markets, allowing customers to stack the value of their water heater's participation in DR programs. These applications, discussed in the following sections, must be supported by a water heater management platform. This backend software solution should offer security, 24/7 monitoring, continuous dispatch and optimization, and forecasting of available load based on usage patterns.

More efficient heat pump water heaters maintain customer comfort but have less load shifting capability because of compressor cycle constraints and longer thermal recovery time.

[4] Flink Energy Consulting. "Electric Water Heaters as Grid Energy Storage." Prepared for the Energy Trust of Oregon. June 2017. https://www.energytrust.org/wp-content/uploads/2017/11/Water_Heater_Energy_Storage_wStaffResponse.pdf

[5] Gas-fueled heaters are also used for gas demand management, albeit deployed to a significantly lesser degree in 2020.

Figure 4 Management Platform Enables Multiple Grid Services



(Source: Guidehouse Insights)

Peak Reduction

Efficient tank-based water heaters can hold temperatures for an extended period, making them a reliable tool to reduce load without affecting customer comfort. Because large numbers of water heaters are located across utility service territories, engaging them may allow utilities to lower the costs associated with other direct install programs. Further, unlike newer customer-sited batteries and EV charging equipment, older generation water heaters can be made eligible to participate in peak reduction through a DLC switch or retrofit option, which makes their participation in utility programs attractive to a broader demographic of customers. Water heater controllers should have nearly limitless cycle ability and can be used to manage fast fluctuations in power, preserving the life of expensive electrochemical batteries. These widespread assets can then be used to augment an existing fleet of grid-scale batteries.

Case Study: Aggregated Fleet Savings During a Peak Load Event

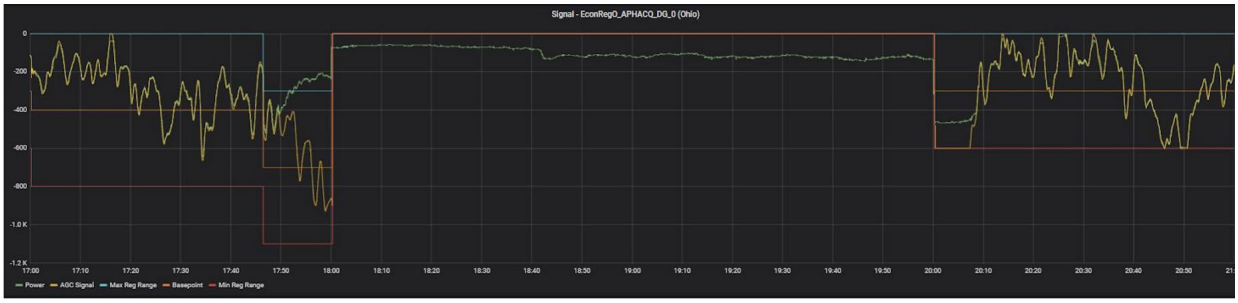
Water heaters can participate in utility and wholesale market peak reduction events, giving residents in eligible territories the ability to stack value from their participation in multiple programs. The following example of retrofit water heaters, managed by Armada Power, highlights how water heaters that perform frequency regulation for the PJM RegD market can also support utility peak load events.[6]

Aggregated, two-way communicating retrofitted water heaters responded to a DR event in the AEP Ohio service territory in May 2020. An unusually warm day, Armada Power's Fleet Commander forecasting called for the curtailment of the approximately 1,100 water heater fleet between 6 p.m. and 8 p.m. ET. Leading up to the curtailment window, the water heaters were preheated to their maximum setpoints before being turned down for the event. Participating water heaters, monitored and managed 24/7 with Armada Power's Fleet Commander software, were disconnected from the PJM RegD market and turned

[6] For a full explanation of frequency regulation offerings, see the Frequency Regulation section.

off for the duration of the event. The Fleet Commander control platform set an allowance for the coolest tanks to draw some power to help maintain customer comfort during event hours.

Figure 5 Fleet Curtailment for a 2-Hour Event, May 2020



Note: The green "actual load" line indicates that between 60 kW and 100 kW of energy may be drawn to mitigate customer impacts during the event.

(Source: Armada Power)

Approximately 400 kW were curtailed during the 2-hour event window. Because the demand charge is roughly $9 per kW, the curtailment event resulted in a savings of approximately $3,600 across the participating fleet. While water heaters were temporarily pulled from the PJM market, the aggregate $3,600 in savings exceeded the opportunity cost of approximately $4 per kW. After the event, a limit was set on the total load consumed by the fleet to avoid a rebound effect and to promote stability of the local distribution grid.

Time-Varying Rates

Smart water heaters and retrofit water heaters that have established two-way communication with the electric grid may be able to help customers save money on time-varying or TOU rates offered by utilities. TOU rates typically charge customers significantly more per kilowatt-hour during on-peak periods.

Participating water heaters can preheat leading up to a peak period, raising the overall temperature in the tank by a matter of degrees, and then turn off during the peak period. Customers will not typically notice the slight temperature increase in their water heaters leading up to the event. Following the cessation of peak price periods, water heaters return to their normal setpoints. In doing so, energy load shifts to periods outside of the peak event window.

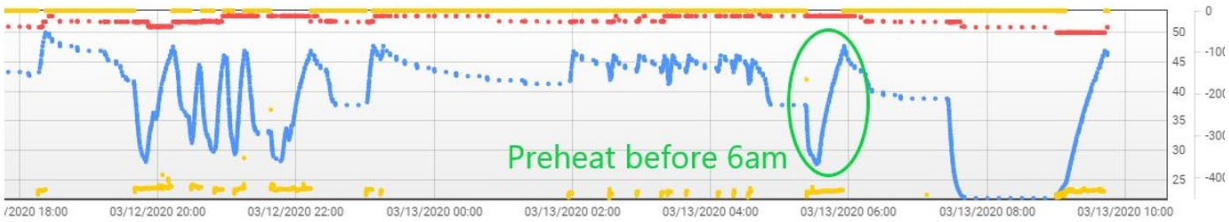
Case Study: Single-Family Home Savings on TOU Rates

Armada Power's Fleet Commander platform, paired with the company's retrofit hardware, optimizes a water heater's energy use to avoid utilities' on-peak rates. This optimization results in direct utility bill savings for the customer.

One of Armada Power's utility clients has implemented a TOU rate schedule. To optimize water heaters in the utility's service territory, Armada Power holds a given retrofit water heater tank's temperature setpoint slightly below a normal rate during the winter season. This hold allows the water heater to preheat leading up to the utility's 6 a.m.-9 a.m. winter peak rate period, where prices are $0.29 more per kWh. Throughout the 2019-2020 winter season, the TOU rate went into effect 252 mornings during which the water heater responded by preheating and then turning off. Thus, a single-family home in the service territory can save

approximately $0.73 per peak pricing day—or about $183.87 in 2020—by enrolling its retrofitted water heater in the TOU program.

Figure 6 Single-Family TOU Optimization, March 12-13, 2020



(Source: Armada Power)

Because TOU pricing is a load shifting mechanism, water heaters in the territory that respond to the variable price average 33 minutes of heating following the peak period. Responses resulted in an average of 2.46 kWh of energy demand shifted to off-peak periods per responding water heater, helping residential customers save money while reducing the strain on the utility's electric grid.

Renewables Firming

As intermittent renewable generation makes up a greater percentage of load on the grid, water heaters can act as thermal storage solutions to capture excess load and serve as a source of capacity during periods absent high levels of clean energy generation.

Aggregated water heater fleets can be deployed to absorb the differences between forecast and actual outputs of utility-scale renewable loads. These assets can help to reduce or eliminate the so-called duck curve.[7] This solution can be of particular benefit in regions with high solar penetration and late afternoon peak periods such as California and Arizona.

Frequency Regulation

Ancillary services help balance the transmission system and keep system frequency within a tight range. These services can be split further into regulation and reserve markets. Where reserve markets require backup power on demand in case of a lost generator, the frequency market operates 24/7 to regulate near-constant mismatches between electricity supply and demand.

Grid-connected water heaters paired with battery storage are unique in their capability to cycle rapidly in response to signals from the ancillary services market without causing damage to the device.[8] Water heaters allow for a level of control not available from many other behind-the-meter devices.

Aggregated water heater fleets can bid reliable capacity into the ancillary services market on an hourly basis. Because of the high value of ancillary services and the inability of many distributed energy resources (DER) to participate, a strong value proposition exists for participation from aggregators and

[7] The duck curve typically refers to the imbalance between peak renewable generation periods and peak customer demand in jurisdictions with high solar penetration.

[8] HVAC and process DR loads are often ineligible to participate in frequency regulation because of their inability to respond to second-level curtailment signals.

device owners. Armada Power found that a water heater participating in PJM's RegD market earned an average of $38.91 due to low pricing in 2019;[9] historically, water heaters would earn between $80 and $100 annually.

Absence of Rebound Effects

Water heaters can help utilities mitigate load rebound following a DR event or an outage. Because water heaters hold their temperature for an extended period, delayed starts at the end of an event should go unnoticed by the customer. When aggregated with load from HVAC units, water heaters can remain turned off while HVAC setpoints return to lower levels during the summer cooling season. This ability can protect grid infrastructure at the close of a DR event. Further, intelligent, two-way communicating devices can report temperature data, so utilities can stagger individual devices' return to water heating setpoints. The warmest units in an aggregated fleet may delay turn on while the coolest return to active warming at a more rapid pace to help maintain customer comfort.

Staggering the return to heating can also benefit grid infrastructure outside of DR events. Retrofits enabled with cold load pickup mitigation can be encoded with algorithms that randomize the time they remain offline following an outage event. This randomization helps mitigate the spike in load that occurs following an extended power outage. This strategy can prevent unintended peak load charges from the utility and minimize current spikes, which could hinder outage recovery efforts.

Maintaining Customer Comfort

Adjusting the setpoints on an individual's HVAC thermostat produces a perceptible change to the individual's environment, even if only adjusted by a matter of degrees. Water heaters, however, do not noticeably affect customer comfort in the same manner for a variety of reasons:

- **Customers will not notice a change in water temperature:** A water heater's ability to hold temperature allows DR events to take place with minimal changes to the water at the top of the tank (where water is typically drawn from). Hot water rises to the top of a water heater, while cooler water stays at the bottom with minimal mixing between temperatures. The customer will continue to draw warmer water from the top of the water heater, thus experiencing consistent temperature.
- **Water heater retrofit technologies are not intrusive:** Small retrofit devices take up negligible amounts of space in the home and can be applied in single-family and multifamily residential settings. Some retrofit technologies can be self-installed and many that require a professional technician can be installed in under 15 minutes. Further, retrofit technologies can be installed without voiding the warranty or safety mechanisms on a customer's water heater.
- **24/7 load monitoring can generate revenue streams:** Water heaters optimized for frequency regulation services may be bid into markets on a near-constant basis every day. Water heater management platforms can survey entire water heater fleets, within milliseconds, to determine which devices have capacity to provide to the market at any given moment. Automated and in real time, these short shutoffs can add up to save customers hundreds of dollars over the course of a year.

[9] Armada Power. "Cost Savings through Optimization." 2019. https://static1.squarespace.com/static/5e4c70c1fb505b04b8b53846/t/5ea032274cd84c706691effb/1587556904394/Armada_Power_Booklet.pdf

Conclusions and Recommendations

As utilities move to integrate their DER programs, water heaters will be among the first wave of non-invasive devices commonly used to support grid services. Water heaters will prove a valuable technology in maintaining comfort and avoiding the fatigue associated with customer-based demand management solutions. Incentives from these programs, alongside reduced utility bills, will support the ROI on retrofit technologies and grid-connected units. Guidehouse Insights provides the following conclusions and recommendations for utilities and their partners in implementing DR solutions:

A complete water heater solution consists of customer-sited hardware and backend management software.

Water heater DR programs consist of more than customer-sited hardware: Utilities are trending away from deploying DLC switches and toward installing smart retrofit control devices or smart water heaters to enable these as grid assets. A complete water heater solution also consists of customer-sited hardware and backend management software.

> A utility's chosen management platform needs to monitor and optimize water heaters 24/7, scale to manage a near-infinite number of grid-edge devices, and continually update to meet data transmission and cybersecurity protocols.

Customer education is a key component of marketing successful water heater programs: Installation of water heater retrofit technologies is minimally invasive. Most buildings have installed water heaters, so the hardware will not take up additional room or require extra attention from customers. Prospective participants may not understand this. Program design and marketing must meet customers where they are and should consider the possibility of limited understandings of DR.

> Utilities and program providers must educate customers on the minimal disruption and maximum comfort associated with water heater DR programs.

Water heaters are an integral part of integrated DER (iDER) program planning: Utilities are beginning to break down the silos between their energy efficiency and DR or other DER programs where regulations allow. However, utilities may still be subject to stringent efficiency standards. These utilities must engage in innovative stakeholder education and should model their approach after successful iDER programs. If regulators consider efficiency more broadly and take carbon reduction metrics into account, DR becomes a tool to help achieve mandated sustainability targets. Integration of DER will enable more innovative programs that can reduce negative environmental (and electric grid) impact through load shifting and peak demand reduction.

> Utilities should develop holistic planning processes and work across silos to design iDER programs that incorporate water heaters to promote grid stability after a DR event. Where they are unable to do so, utilities must double-down on the efforts of regulator and other stakeholder education to move the needle toward integrated program planning.

Aggregated water heater micro-loads can be high value assets to utilities: Individual loads from water heaters in single-family, multifamily, and commercial settings can be aggregated to positively impact the grid. Over time, the use of water heaters helps extend utility transmission and distribution

infrastructure life and supports other DER such as battery storage. Because these devices exist in almost every building in each utility's territory, water heaters can become grid assets at a reduced cost relative to other DER.

> Utilities must use water heater management systems and work with aggregators experienced in providing a range of grid services to capture maximum value and boost ROI from these already-deployed aggregated micro-loads.

Implementing a complete water heater DR solution, inclusive of a secure and scalable management platform, allows utilities to harness a variety of grid service benefits. Water heaters are a readily available tool that utilities can incorporate into DR programs with minimal, low cost retrofitting. Unlike other common DR assets including HVAC and process load, these devices can provide grid services that will go unnoticed to the utility customer. Avoiding fatigue will help drive customer engagement in and satisfaction with water heater DR programs. By using water heaters in DR programs, utilities can mitigate the strain to grid resources caused by rebound effects after an event or outage. Thus, water heaters can serve as an essential tool in utility efforts to support grid reliability through the transition to a clean, distributed electric grid.

Acronym and Abbreviation List

CAGR	Compound Annual Growth Rate
DER	Distributed Energy Resources
DLC	Direct Load Control
DR	Demand Response
ET	Eastern Time Zone
EV	Electric Vehicle
HVAC	Heating, Ventilation, and Air Conditioning
iDER	Integrated Distributed Energy Resources
IOU	Investor-Owned Utility
kW	Kilowatt
kWh	Kilowatt-Hour
MW	Megawatt
OEM	Original Equipment Manufacturer
ROI	Return on Investment
TOU	Time-Of-Use
US	United States

Table of Contents

Table of Charts and Figures

Scope of Study

Armada Power commissioned Guidehouse Insights to analyze key market trends within DR programs and regarding electric resistance water heater applications for grid services, including peak demand reduction, time-varying rate applicability, renewables firming, and frequency regulation. Following an exploration of electric water heater applications for DR, the white paper concludes with Guidehouse Insights' recommendations for utilities and program implementers considering electric water heaters as part of an aggregated micro-loads for grid services strategy. This white paper does not analyze natural gas-fueled water heater applications for natural gas DR.

Sources and Methodology

Guidehouse Insights' industry analysts use a variety of research sources in preparing white papers. The key component of Guidehouse Insights' analysis is primary research gained from phone and in-person interviews with industry leaders including executives, engineers, and marketing professionals. Analysts are diligent in ensuring that they speak with representatives from every part of the value chain, including but not limited to technology companies, utilities and other service providers, industry associations, government agencies, and the investment community.

Additional analysis includes secondary research conducted by Guidehouse Insights' analysts and its staff of research assistants. Where applicable, all secondary research sources are appropriately cited within this report.

These primary and secondary research sources, combined with the analyst's industry expertise, are synthesized into the qualitative and quantitative analysis presented in Guidehouse Insights' reports. Great care is taken in making sure that all analysis is well-supported by facts, but where the facts are unknown and assumptions must be made, analysts document their assumptions and are prepared to explain their methodology, both within the body of a report and in direct conversations with clients.

Guidehouse Insights is a market research group whose goal is to present an objective, unbiased view of market opportunities within its coverage areas. Guidehouse Insights is not beholden to any special interests and is thus able to offer clear, actionable advice to help clients succeed in the industry, unfettered by technology hype, political agendas, or emotional factors that are inherent in cleantech markets.

Notes

CAGR refers to compound average annual growth rate, using the formula:

$$\text{CAGR} = (\text{End Year Value} \div \text{Start Year Value})^{(1/\text{steps})} - 1.$$

CAGRs presented in the tables are for the entire timeframe in the title. Where data for fewer years are given, the CAGR is for the range presented. Where relevant, CAGRs for shorter timeframes may be given as well.

Figures are based on the best estimates available at the time of calculation. Annual revenue, shipments, and sales are based on end-of-year figures unless otherwise noted. All values are expressed in year 2020 US dollars unless otherwise noted. Percentages may not add up to 100 due to rounding.

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