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Battery Killers: How Water Heaters Have Evolved into Grid-Scale Energy-Storage Devices

An E Source White Paper

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Contents

Notes

EXECUTIVE SUMMARY

Grid-interactive water heaters (GIWHs) add bidirectional control to electric resistance water heaters, allowing a utility or third-party aggregator to rapidly toggle them off and on. This functionality turns a fleet of water heaters into a flexible energy-storage medium, capable of increasing and decreasing the load on the grid on a second-by-second basis. And GIWHs are currently the least expensive form of energy storage available. Utilities can use fleets of grid-enabled water heaters for load shifting, demand response, arbitrage, ancillary services, or to respond to unexpected grid-stabilization events. Traditional dissemination of new water heater technology has been a painstakingly slow process, but water heater rental programs may greatly accelerate this process. The largest hurdle this market is currently facing is a ruling by the US Department of Energy (DOE) that bans electric resistance water heaters over 55 gallons. A waiver system has been proposed but has yet to be ruled into code, and the industry is awaiting the DOE's decision.

WHAT IS GRID-INTERACTIVE WATER HEATING?

Most people think of their water heater as a device designed solely for heating bath water or helping to wash a sink full of dishes. But electric water heaters can provide some of the most rapidly responding, flexible, scalable, and cost-effective energy storage available.

By adding bidirectional control to electric resistance water heaters, GIWHs enable a utility or third-party aggregator to quickly and repeatedly turn the devices off and on. Bidirectional control is a much more powerful tool than standard direct load control, which only allows devices to be turned off, because it effectively turns the water heater into a battery. Traditional batteries supply power when generation is low and absorb power when generation is high. In this way, they help modulate the supply of electricity to follow the load. GIWHs can't supply electricity, but they provide exactly the same functionality by reversing this equation: They can modulate the load in order to follow generation. In times of overgeneration, fleets of water heaters can be switched on to absorb excess power, and in times of undergeneration, they can be switched off to shed load and redistribute the existing electricity on the grid. Thus, aggregated GIWHs can act as virtual power plants to quickly and effectively control the amount of power on the grid. Moreover, these fleets are completely scalable and can perform this functionality within seconds.

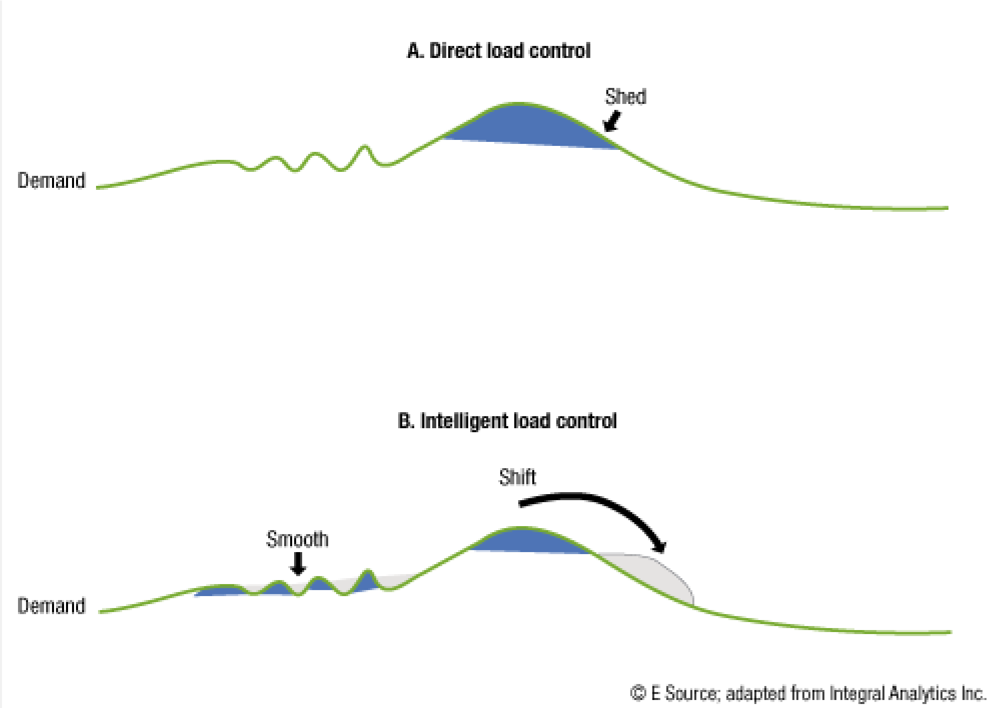
BENEFITS TO THE UTILITY

GIWHs enable the utility or aggregator to shift loads, perform demand response, conserve revenue via the arbitrage of wholesale electricity, generate revenue via ancillary services, and keep the grid stabilized during unexpected events.

Load shifting and traditional demand response. In addition to traditional demand response, which sheds loads in times of peak demand, GIWHs can be used to shift loads and perform intelligent load control. Pre- or postcharging of GIWHs around peak times and smaller spikes throughout the day can smooth the load curve while maintaining customers’ supply of hot water. Instead of simply shedding the peak load, the energy consumption is redistributed to times of lesser demand (**Figure 1**).

FIGURE 1: Standard direct load control versus intelligent load control

Standard direct load control may not charge the water heater before or after a peak load event, potentially leaving the customer without hot water (A). Intelligent load control, on the other hand, allows the utility to shift peak loads to times of lesser demand (B). This adjustment enables the customer to receive the full amenity of the energy service, but with consumption that isn’t coincident with peak demand.



Arbitrage of wholesale electricity. Electricity providers can charge GIWHs when the price of energy is low and discharge them when the price is high, saving utilities and their customers money. This strategy can be especially useful for cooperatives and municipal utilities, where the savings can easily be passed along directly to customers.

Revenue from ancillary services. Utilities can also use GIWHs for frequency regulation or other services. Frequency regulation—or just regulation—is the second-by-second matching of generation to the load. Depending on the market, there can be significant revenue potential from regulation. Furthermore, the need for regulation will only increase as more intermittent renewables are added to the grid. Solar and wind power, for example, inherently fluctuate with the availability of sun and wind, causing generation to spike and dip unexpectedly. Regulation is required to smooth these fluctuations and keep generation matched to the load. Not many resources are flexible enough to provide this service, but energy storage can do it very well.

The monetary value of frequency regulation depends on the transmission organization that monitors and controls the delivery of high-voltage electricity on the grid. Regional transmission organizations (RTOs) cover large interstate areas, and independent system operators (ISOs) cover smaller geographical areas. The RTO PJM Interconnection puts a much higher price on frequency regulation than most other RTOs or ISOs, making the financial incentive for GIWHs much higher in this organization’s territory. For PJM, a single water heater providing overnight (eight hours per day) frequency regulation can generate roughly $140 per year in revenue.[1] Vendors claim that the use of GIWHs in the PJM territory can result in a negative annual energy cost to the customer; that is, customers could potentially earn money by providing this service, according to the 2012 Steffes Corp. white paper Grid-Interactive Electric Thermal Storage (GETS) Water Heating (PDF). However, we have not seen any confirmation of these numbers.

Heat pump water heaters (HPWHs) can’t provide frequency regulation nearly as well as electric resistance water heaters can. Although they’re a great energy-efficiency technology and are gaining in market share due to efforts by the DOE and Energy Star, HPWHs can’t be cycled off and on nearly as quickly as electric resistance water heaters can. They also don’t draw as much power as electric resistance water heaters. As such, the revenue potential from regulating HPWHs is only one-eighth the revenue of electric resistance water heaters.[2]

Grid stabilization. Perhaps one of the most valuable services that GIWHs provide is the ability to respond to grid stabilization events within seconds. If a transformer trips or another unexpected event occurs, GIWHs allow the utility or aggregator to shed or increase load within seconds.

Additional benefits and implications. Not all locations on the grid are created equal. GIWHs are more valuable to distribution-constrained areas than to areas with excess distribution resources because they can reduce peak demand, potentially allowing the utility to defer distribution upgrades.

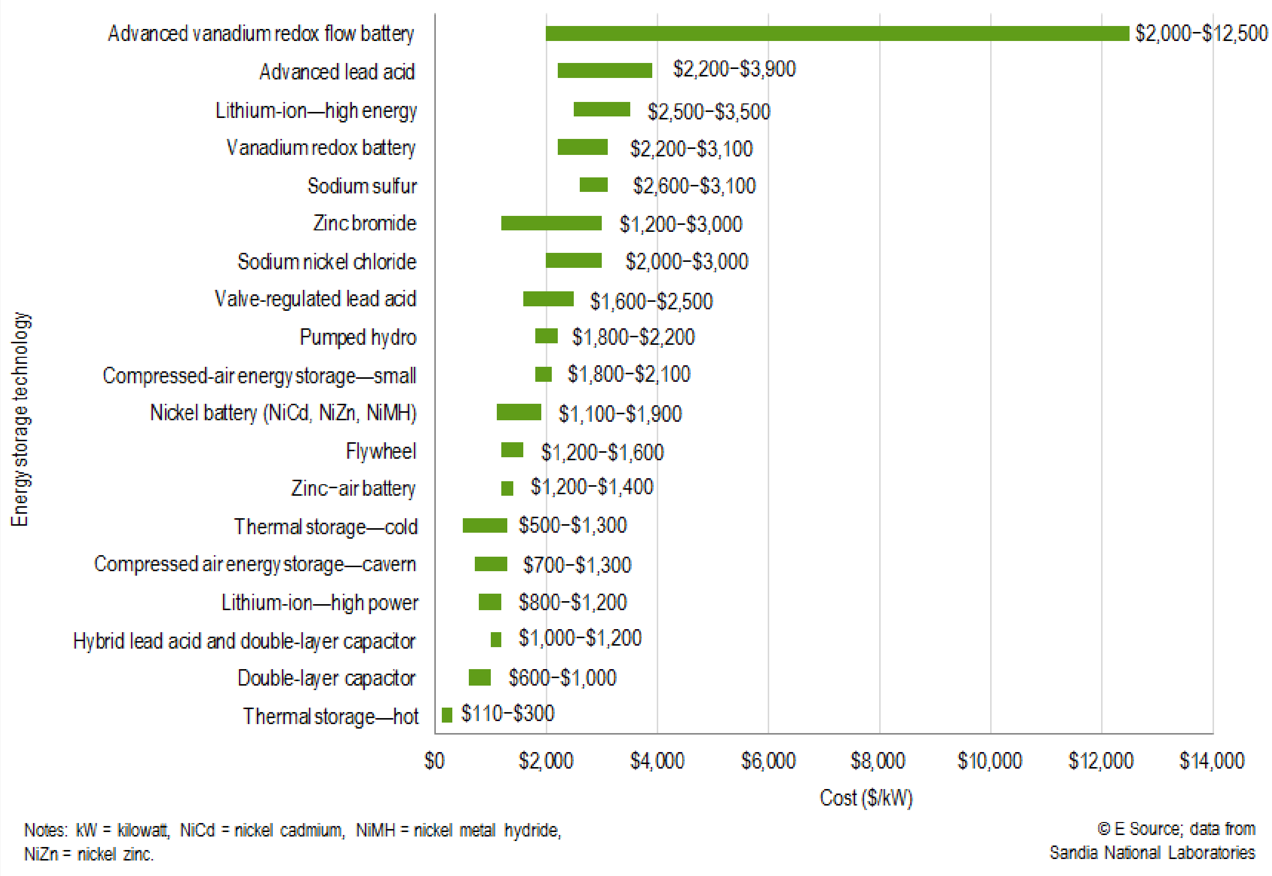
For territories that have plentiful renewable energy resources, utilities or aggregators can consider a renewable storage water heater (RSWH). RSWH systems use a dedicated auxiliary thermal storage tank (or tanks) to capture low-cost or no-cost excess renewable electricity. The auxiliary tank sits next to the original hot water tank and supplies the renewably generated hot water when it’s available. The tank uses a mixing valve to dilute the hot water to reduce temperatures to standard domestic hot water (DHW) levels before delivering the water to the customer.

LOWEST-COST ENERGY STORAGE

In an April 2014 letter to the DOE (PDF), Terry Boston, the CEO of PJM, stated, “Electric water heater storage is the most cost-effective form of energy storage available.” In fact, GIWHs are about an order of magnitude cheaper than most other technologies. Comparing costs of different energy storage technologies exported from the ES-Select Tool from Sandia National Laboratories shows the relative cost of water heater storage versus other forms of storage (**Figure 2**).

FIGURE 2: The cost of electric water heater storage is less than any other storage medium

Electric water heater storage falls under the category “Thermal storage—hot” in the figure. The data, gathered from the ES-Select Tool from Sandia National Laboratories, indicates the minimum and maximum costs for the different storage mediums, using alternating-current technology.



NEW CONTROL TECHNOLOGIES

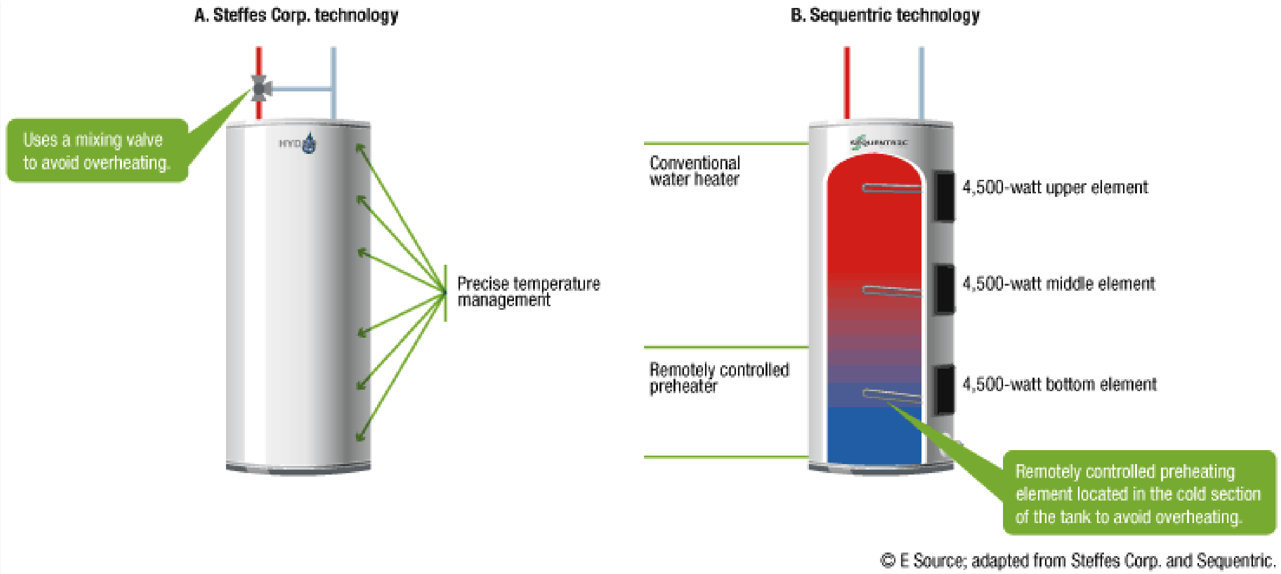
Two new water heater controls have been introduced to the market that are specifically designed for grid interaction.

The first solution is made by Steffes Corp. and uses a well-insulated tank and an external control box. The company is currently working on integrating the control box into the water heater as a factory-installed original equipment manufacturer (OEM) solution. Steffes' algorithm can control water heaters as they are, without modification, or it can allow overheating of the water in the tank, essentially doubling the energy-storage capacity. A mixing valve can then be used to dilute the water, reducing the temperature to standard DHW levels before delivering it to the customer. In a Hawaiian Electric Co. field test, which was documented in the Demand-Side Management Programs Annual Program Modification and Evaluation Report, Docket No. 2007-0341 (PDF), overheating the water in the tank didn’t reduce the efficiency of the water heater. This is because the water heater spent essentially the same amount of time at lower-than-normal temperatures as it spent at higher-than-normal temperatures, making the efficiency change a wash.

The second solution is offered by Sequentric, which has developed an OEM control box that can be incorporated into a water heater to add grid interoperability. Sequentric’s approach adds a remotely controlled resistive heating element to the bottom of the water tank. Unlike the Steffes technology, a mixing valve isn’t needed because temperatures never exceed standard DHW levels. Since the water in the tank will naturally stratify, the utility or aggregator will have control of the initially cold water at the bottom of the tank. The remotely controlled resistive element is used to preheat this cold “make-up” water as needed to any temperature up to standard DHW temperatures. Thus, consistent DHW temperatures are maintained at the outlet. Additionally, if the grid-controlled heating element fails or bidirectional control of the water heater is lost, the customer is simply left with a standard, functioning, electric water heater (**Figure 3**).

FIGURE 3: Water heater controls

Steffes Corp.’s and Sequentric’s technologies differ in their approach to controlling water temperature. The Steffes solution heats the water in the tank to a temperature that’s higher than standard domestic hot water (DHW) levels (A). It then uses a mixing valve at the outlet to dilute the water, reducing temperatures to DHW levels. Sequentric technology preheats the cold “make-up” water at the bottom of the tank to bring it up to standard DHW temperatures (B). The water heater’s internal thermostats provide a safety limiter, never allowing the temperature to go over the water heater’s setpoint.



In addition to the individual water heater controls, a utility or aggregator will need a software service to aggregate the GIWHs into controllable fleets. This software needs to keep track of the charge level (temperature) of the individual water heaters to ensure that each GIWH isn't overcharged (resulting in higher temperatures than intended) or undercharged (resulting in a shortage of hot water available to the customer).

Both Steffes Corp. and Sequentric have their own software and can use their respective controls to provide fleet controllability of GIWHs. A competing fleet aggregation service was developed by Service Logic in conjunction with Battelle Memorial Institute. This offering has the ability to control any type of water heater, even standard electric resistance models not designed for grid interaction.

Of course, keeping the customer satisfied with an adequate supply of hot water is paramount. So far, all tests that we're aware of have shown success in this area.

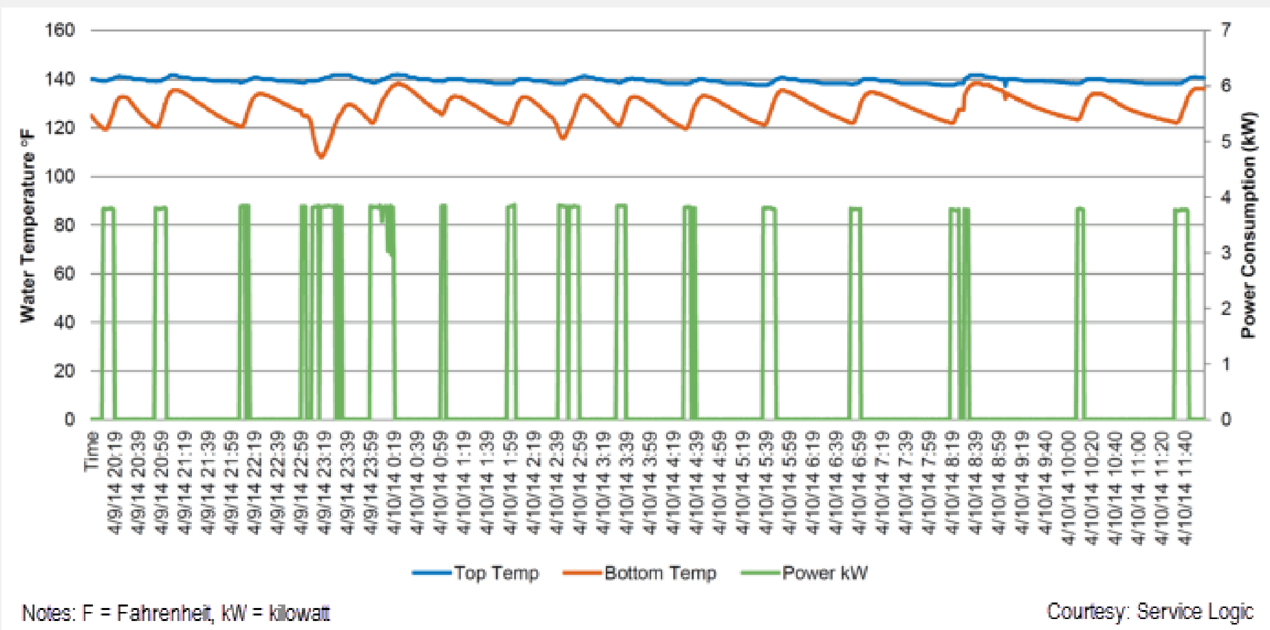
SO FAR, NO NEGATIVE IMPACT ON CUSTOMERS

In the case of Steffes water heaters controlled with Steffes software, pilot testing has not shown any negative customer impacts on the availability of hot water. In the field test by Hawaiian Electric, a prime conclusion was that "hot water was always available for the end user.”

In manufacturer-reported tests of standard electric resistance water heaters using Service Logic and Battelle Memorial Institute software, the temperature of the delivered water at the top of the tank remained consistent, despite fluctuations in the temperature at the bottom of the tank (**Figure 4**). We have not seen independent validations of this data, however.

FIGURE 4: Service Logic’s and Battelle Memorial Institute’s self-reported test results

In Service Logic’s self-reported tests, the water temperature at the top of the tank (blue line) maintains standard domestic hot water temperatures. The water temperature at the bottom of the tank (orange line) fluctuates with the on/off cycling of the resistive elements in the water tank (green line).



Sequentric’s technology has been tested by the Electric Power Research Institute and is now being deployed by Hawaiian Electric, but we have yet to see the results of these studies.

GETTING GIWHS INTO CUSTOMERS' HOMES

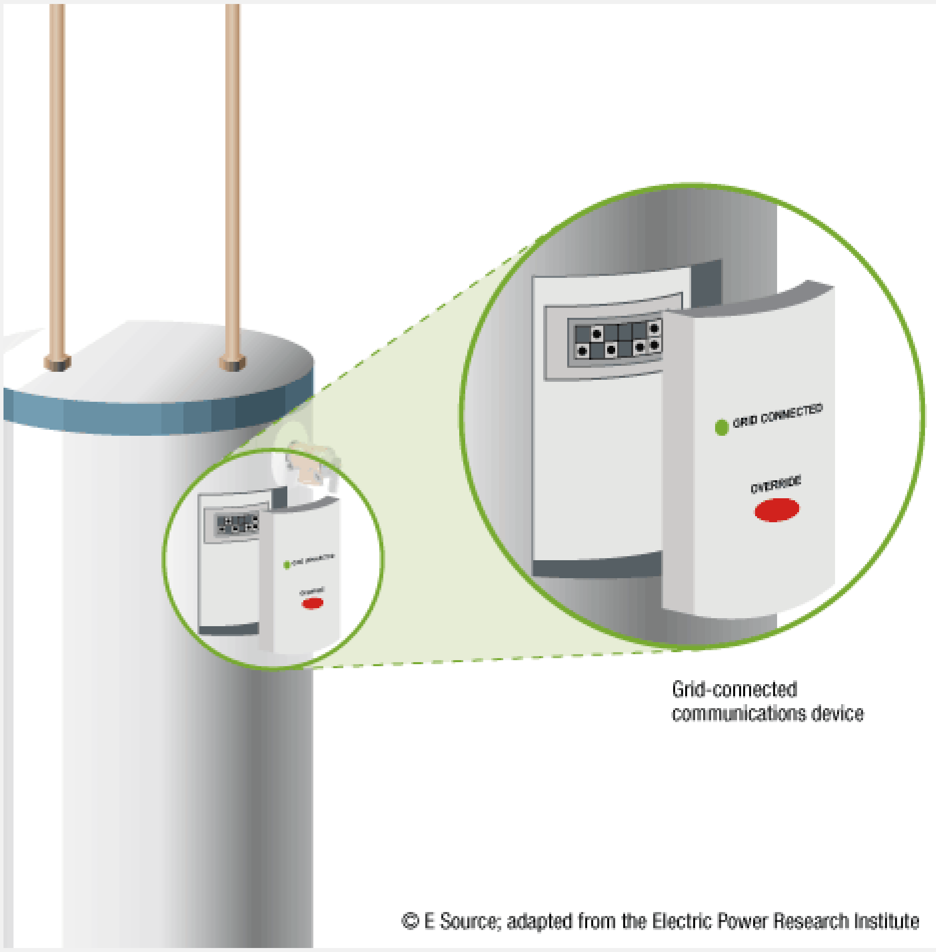
Alternative business models—such as the utility or a third party providing a service rather than a commodity—may prove beneficial. In Canada, approximately 15 percent of all residential water heaters are owned by the utility or by third-party rental companies, and are rented to the customer. If a utility or third party chooses to adopt this model, it can replace a customer's existing water heater with a GIWH at the time of failure. At a failure rate of about 8 to 10 percent per year for standard water heaters, this would disseminate GIWHs at a pace much faster than the market has provided for previous technologies (for example, tankless water heaters). Water heater leasing has many benefits:

- A failed water heater is often able to be replaced in less than 24 hours at no up-front cost to the customer. A low monthly fee (approximately $15) for water heater rental is often more attractive to the customer than a high one-time expense for a plumber-installed water heater replacement.
- The replacement water heater often has a larger storage tank, offering the customer longer durations of hot water than he or she likely had before.
- If the water heater leaks, any damage may be covered by the utility or third party's insurance policy instead of the homeowner's.[3]

A new technology standard has also been developed that could simplify the dissemination process. The Consumer Electronics Association 2045 standard is essentially a control box that clicks into a compatible standard water heater and adds grid interoperability (**Figure 5**). The value of this standard is twofold: It can accommodate any communications technology (including Wi-Fi, cellular, and radio frequency), which makes the interface agnostic to the utility or aggregator's network infrastructure. It can mitigate the need for truck rolls (visits from service technicians to customers' homes) by allowing customers to install the add-on themselves, once the utility or aggregator and the customer are ready to add grid interoperability.

FIGURE 5: Modular communications control

The Consumer Electronics Association 2045 standard offers utilities or aggregators a communications-agnostic appliance and can potentially eliminate the need for a costly truck roll to the customer’s home.



WHAT’S HAPPENING WITH GIWHS NOW?

Great River Energy, a generation and transmission company in Minnesota, currently controls about 70,000 large-capacity water heaters for arbitrage benefits to its customers. The co-op charges the GIWHs at night, when the wholesale market price for electricity is low, saving its customers money while providing the same amenity. Dairyland Power Cooperative, another generation and transmission company in Wisconsin, also has a large fleet of water heaters it uses for arbitrage. We’re not aware of any utilities or aggregators that are currently controlling GIWHs for frequency regulation, although PJM has tested the strategy and found that GIWHs were able to successfully follow the regulation signal.

The biggest hurdle the GIWH market is currently experiencing is a 2012 DOE ruling that mandates a phaseout of large-capacity (over 55 gallons) electric water heaters by 2015 and a supplantation of HPWHs. Unfortunately, as previously mentioned, the revenue potential from frequency regulation of HPWHs is only about one-eighth that of standard electric water heaters. Many parties have opposed this DOE ruling. In response, the DOE proposed a waiver system to allow manufacturers to produce GIWHs over 55 gallons. However, the proposed waiver has not yet been passed. In PJM Interconnection's April 2014 letter to the DOE, which was referenced earlier, the RTO urges the government agency to expedite its decision-making process and rule the waiver system into code. The status of the decision-making process is available on the federal regulations website.

Notes

1 Scott Baker (August 2014), Senior Business Solutions Analyst, PJM Interconnection, 610-666-8980.

2 Levi Reeves, Corporate Development Manager, Service Logic, presentation at the Peak Load Management Alliance, "Making the Case for Grid-Interactive Electric Water Heating in 2014," workshop (April 14, 2014).

3 Daniel Flohr (July 10, 2014), CEO, Sequentric Energy Systems, 704-817-2080.