Demand Flexibility of Water Heaters

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Key Findings

- Water heaters store heat, which makes it possible to shift their electric demand without affecting consumer comfort. This demand flexibility can be a key grid resource to reduce peak demand, lower electricity costs, improve power reliability, and enable better use of intermittent renewable power.
- Effective use of electric water heaters for demand flexibility requires that they be manufactured with the necessary controls.
- State laws and a bipartisan federal bill with support from manufacturers and efficiency advocates can make this capability universal. It would not affect consumer privacy, and participation in any program would be voluntary.
- Nationwide, demand flexibility capability in new water heaters, if fully utilized, could provide more electric capacity than 40 large power plants.

Introduction

Temporarily reducing electric demand was critical to keeping the lights on last year in Texas, California, and (in one massive December storm) the Midwest, Southeast, and Northeast when high demand or power plant failures meant generation had trouble keeping up with demand. As variable power sources like wind and solar grow, and as more electric equipment adds more load on the electric grid, the ability to adjust demand will become even more important. Electric storage water heaters can be an excellent tool for this.

Washington, Oregon, and Colorado already require new electric water heaters to have demand response capability. A bipartisan bill to make technical improvements to the federal efficiency standard for water heaters would give the U.S. Department of Energy (DOE) authority to ensure consistent capabilities nationwide. This brief discusses what that would mean and why it is important.

Electric Demand Flexibility and Demand Response

For the electric system to work, the amount of power provided to the grid must always match demand for power. If not, the power can go out. Utilities must build enough power plants to meet the highest amount of demand that could occur (with an extra margin for safety). In most of the country, demand is highest on hot summer weekdays when lots of equipment is operating and air conditioners run at full blast. Utilities run expensive "peaker" plants—typically inefficient natural gas plants—just on those days, or they buy high-price power on the "spot" market. Besides turning power plants on and off, utilities also use certain plants as "spinning reserves" that can quickly ramp up and down, they pump water uphill so that it can later run through turbines ("pumped hydro"), and they increasingly experiment with electric batteries. As electric grids incorporate more wind and solar power, which vary with wind strength and cloud cover, the challenge of matching supply to demand is growing.

It is often cheaper and more effective to adjust electric demand to match available supply, as opposed to ramping up supply to meet demand. Under voluntary demand response programs, utilities pay customers to turn off air conditioners, reduce commercial building loads, or shut down factories when they lack sufficient power. Residential programs work best when customers give permission to utilities to remotely turn off equipment in their homes for short periods, usually in ways the customers do not even notice. With demand flexibility programs, this control may occur on a daily (or even minute-to-minute) basis, shifting demand to times when power is cheapest and most available. Demand flexibility can enable the grid to use more variable wind and solar power by moving demand to match their supply. Individual customers can still override these shifts.[1]

Water Heater Demand Flexibility

Electric storage water heaters are well-suited for demand flexibility programs.[2] They can use electricity at preferred times to heat the water and then store the heat for hours until the hot water is needed. Consumers can still use hot water whenever they like. Programs may do this by delaying heating of the water during peak demand periods when power is scarce and expensive. They may also heat water in the storage tank in advance, when there is surplus

Figure 1. Port and communications module on a water heater. Source: National Rural Electric Cooperative Association.

[1] More broadly, demand measures, often collectively called demand side management (DSM), also include energy efficiency, that is, the reduction in energy use, rather than shifting it to a different time. This brief generally uses "demand flexibility" to include demand response, but the federal bill we discuss uses "demand response."

[2] That is, ones with a storage tank. Electric tankless (instantaneous) water heaters have high electric demand whenever the hot-water tap is turned on, often at the wrong times for the grid.

cheaper power, to ensure no added heat is needed for a time. If the water is preheated to a higher temperature, the water heater may go longer before needing to heat the water more.[3] Water heaters can start or stop heating quickly, so they can be responsive to variable renewable generation.

Electric heat pump (or hybrid) water heaters[4] are highly efficient and reduce total electric demand by more than half compared to other electric water heaters. Their remaining load can be flexible, and they already have most of the electronic components and controls needed to participate in demand response programs. Because heat pumps heat the water more slowly, preheating strategies may be more important in order to avoid using backup resistance heat. While heat pump water heaters have had tiny market share, their use is growing rapidly, and we expect three-fourths of new electric water heaters to be heat pumps under a proposal for a new water heater efficiency standard recently recommended by manufacturers and efficiency advocates.

To participate in demand flexibility programs, water heaters need to have smart controls and either an internal clock or the ability to receive a signal from the electric utility (or from an "aggregator" working with the utility). Thus, as illustrated in figure 1, water heaters designed for demand flexibility will have some combination of the following elements:

- Communications port and internal controls: Electronics in the water heater and a port to enable the water heater to receive signals and adjust operations accordingly.
- Communications module: The module simply plugs into the port and can communicate with the utility by cellular, radio (e.g., Zigbee), Wi-Fi (connecting via the Internet), or other means.
- Clock: Instead of relying on external signals, the water heater can be set up to reduce electric demand at typical peak periods.[5]
- Mixing valve: If the water heater heats the water in advance above typical temperatures, it may need a mixing valve that adds enough cold water to deliver water at the desired temperature.

[3] The water heater may need to mix in some cold water when delivering hot water in order to avoid scalding. While preheating results in a small loss of energy as heat escapes the storage tank, this should be small for well-insulated tanks.

[4] Heat pumps transfer heat from the surrounding air to the water (like a refrigerator operating in reverse), a much more efficient process than electric resistance heating, which uses electric current to heat water directly. Heat pumps usually have electric resistance backup, and thus are also called "hybrid" water heaters.

[5] A clock-controlled water heater does not require a utility program or communications ability. However, it will not be able to respond to real-time grid conditions, and the clock can become set to the wrong time, resulting in shifting the water heater power demand toward, rather than away from, times of peak demand.

These capabilities are relatively cheap to install in the factory but expensive to have a contractor come out and retrofit on an existing water heater. The actual port only costs a couple dollars. All heat pump water heaters and increasingly electric resistance water heaters already include the necessary computer chip and electronic controls, but for some water heaters that would be an added expense. The engineering and design costs also are significant, but can be spread over millions of water heaters.

Utilities that choose to use the demand flexibility of customers' water heaters will pay most of the costs of shifting demand: The communications modules in bulk should be a few tens of dollars each, and the largest costs likely are the program costs for communications, software, and consumer incentives.

Open industry standards ensure that water heaters and utility programs are compatible. ANSI/CTA-2045-B Modular Communications Interface for Energy Management is a protocol for communications and design of the port (with EcoPort certification). The new AHRI Standard 1430-2022 for Demand Flexible Electric Storage Water Heaters builds on CTA-2045 to set minimum requirements and test procedures to ensure effective demand flexibility. It specifies standardized communications methods and water heater response to signals, with an optional internal time-of-use approach and optional mixing valve instructions. There are other approaches to enabling communications and control, but they use proprietary methods and may be limited to programs run by the water heater manufacturer, and thus may be difficult to scale or to include in long-term grid plans.

Utilities around the country already run water heater demand response programs with more limited technologies. Rural electric cooperatives have been leaders; for example, High West Energy in Wyoming, Nebraska, and Colorado provides its customers with water heaters set to switch off from 3–10 pm. The municipal utility Austin Energy provides water heater timers for apartment buildings (which pay for electricity based in part on peak demand). Duke Energy includes water heaters in its EnergyWise program in Florida and parts of the Carolinas. And Bonneville Power Administration and collaborators ran a large pilot with CTA-2045 connected heat pump water heaters in Washington and Oregon—their conclusion was a plan to manufacture all water heaters in the Northwest with this capability.

State Policies and a Proposed Federal Bill

Washington, Oregon, and Colorado currently, or will soon, require all new electric water heaters (residential resistance and heat pump with at least a 40-gallon storage tank) to include a port compliant with CTA-2045 or AHRI 1430. California's building energy code (Title 24) gives a credit for heat pump water heaters that follow time-of-use schedules and respond to demand management signals, and that include a mixing valve, and the state is considering a requirement for all new electric water heaters.[6]

In the 117th Congress, S. 4061 from Senators Debbie Stabenow (D-MI) and Marsha Blackburn (R-TN) and HR 7962 from Rep. Debbie Dingell (D-MI) and 12 bipartisan cosponsors were based on a consensus agreement between manufacturers and efficiency advocates. The bill would direct DOE by the end of 2024 to determine "whether to require that electric storage water heaters possess demand response capabilities," that is, the hardware and/or software needed to participate in demand response programs, and to issue the requirement if the determination is positive.[7] As with current appliance standards, DOE would issue a standard only if technologically feasible and economically justified (including for consumers in demand response programs), DOE would consider industry consensus standards (in this case AHRI Standard 1430) in setting requirements, and DOE's standard would preempt new state and local demand response capability requirements for the water heaters.

Would This Affect Consumer Privacy?

The added capability would have no effect on privacy without consumer consent. The port has no communication capability unless a module is plugged into it, and a module would not work until a consumer chose to join a demand flexibility program. With a clock, a water heater could adjust its electricity demand schedule on its own, with no external communication beyond setting the clock (though without some of the grid benefits).

Once a consumer signs up for a demand flexibility program, the program can signal or direct the water heater to preheat water or to avoid heating for a period. The water heater may also communicate limited information about its status, such as the temperature of water in the tank and the storage capacity, so the utility knows how much electric load will be shifted. The customer can also opt out of participating in the program at any time.

Grid and Economic Impacts

A 50-gallon electric resistance water heater draws about 4,500 watts of power when it is actively heating, the equivalent electricity use of 500 typical LED light bulbs. A similar heat pump water heater may use about an eighth of that. But heat pump water heaters heat more

[6] Most households in California pay electricity rates that vary with time of use, so they directly reduce their electricity bills when they move electric use away from times of peak demand.

[7] The bill also would modify what water heaters are covered by the efficiency standard, clarifying the difference between residential and commercial water heaters and creating a category of solar thermal-assisted water heaters.

slowly and are on more of the time. The average load shift in a demand response program may be closer to 500 watts for an electric resistance water heater and less than half of that for a heat pump (depending on season, climate, water heater design, control strategy, and other factors).

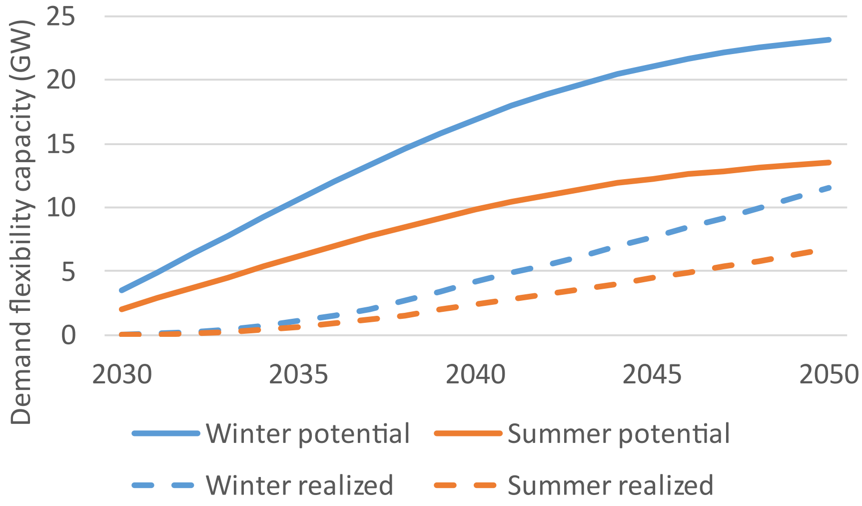

Figure 2. Growth in demand flexibility capacity from all new water heaters and assuming an increasing fraction (up to half) participate in programs

There are currently almost [60 million homes] with electric water heaters in the United States, with annual water heater sales of [4-5 million]. Water heaters with tanks typically last about 10–15 years, so it takes a while for the stock to turn over. As described above, we expect three-fourths of new electric water heaters to be heat pumps by 2029 under a new water heater efficiency standard.

As shown in figure 2, if a demand response capability requirement were to come into effect in 2030, by 2050 we estimate that water heaters could provide 13.5 GW of demand flexibility in the summer (13.5 billion watts)—the power output of 27 large power plants or the maximum output of almost 2 million typical homes with rooftop solar.

In winter the energy use for water heating goes up, creating more load that can potentially be shed—we estimate 23 GW of potential demand flexibility capacity in the winter, the output of 46 large plants. While summer demand peaks are currently of greater concern in almost all the country, as more electric space heating is added (through the increased use of heat pumps, we hope), and with less solar output in the winter, peak demand is expected to shift to winter mornings in much of the country, and winter demand flexibility will be increasingly important.

Not all utilities will run demand flexibility programs, and not all customers will choose to participate. Figure 2 also shows possible growth in actual demand flexibility as more and more consumers have water heaters with the capability, live in areas with demand flexibility programs, and choose to participate in the programs (growing to 25% in 2040 and 50% in 2050). Adding demand flexibility capability to all new water heaters in the factory will make this resource much more affordable, enabling many more utilities to offer this choice to their customers.

A 2021 [paper] by J. Langevin et al. found 7 GW potential in 2030 just from water heater demand flexibility in both winter and summer. Their modeling allowed smaller average load shifts, but also found a total demand reduction of 23 GW in winter and 18 GW in summer from switching to heat pump water heaters as well as demand flexibility.

The value of demand flexibility depends on local grid conditions at any given time, so any nationwide estimate will be very uncertain. A 2019 Brattle Group report estimated that "smart water heating" could account for almost 10% of the 198-GW total load flexibility potential they found for 2030, and they estimated a total demand flexibility value of $16 billion per year, mostly in avoided generation, transmission and distribution (T&D), and fuel costs. A 2015 RMI paper assumed an even higher value per gigawatt of reduced costs for generation and T&D capacity, energy arbitrage, and ancillary services (though lower gigawatt potential).

Conclusion

Water heater demand flexibility can lower the cost of electricity, improve power reliability, and enable the use of more intermittent solar and wind power. But it is hard and expensive for utility programs to retrofit existing water heaters or pay for new ones. To make demand flexibility programs work, new water heaters should be manufactured with that capability. Once these water heaters are widely deployed, utilities can scale up voluntary demand response programs. Individual consumers will have a choice as to whether they want to participate or not. State product requirements or adding this authority to the DOE appliance standards program will help accomplish the goals of lower costs and strengthening the energy system.

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