The Smart Energy Home: Driving Residential Building Decarbonization

March 2019

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Finally, as this is an update to NEEP's 2016 Report *The Smart Energy Home, Strategies to Transform the Region*, NEEP would like to take this opportunity to reiterate acknowledgement of the original authors and contributors of previous versions of this report, which continue to serve as the foundation upon which this update is based.

About NEEP

Founded in 1996, NEEP is a non-profit whose goal is to assist the Northeast and Mid-Atlantic region to reduce building sector energy consumption three percent per year and carbon emissions 40 percent by 2030 (relative to 2001). Our mission is to accelerate regional collaboration to promote advanced energy efficiency and related solutions in homes, buildings, industry, and communities. We do this by fostering collaboration and innovation, developing tools, and disseminating knowledge to drive market transformation. We envision the region's homes, buildings, and communities transformed into efficient, affordable, low-carbon, resilient places to live, work, and play. To learn more about NEEP, visit our website at http://www.neep.org.

Disclaimer: NEEP verified the data used for this white paper to the best of our ability. This paper reflects the opinion and judgments of the NEEP staff and does not necessarily reflect those of NEEP Board members, NEEP Sponsors, or project participants and funders.

Executive Summary

States, cities, and utilities across the region have made aggressive commitments to deep carbon reductions. In our 2018 Strategic Electrification Action Plan, NEEP found that significantly decarbonizing buildings to the necessary levels will require energy efficiency, a number of distributed energy resources including distributed generation and energy storage, and a less-recognized pathway known as strategic electrification. This combination also calls for new smart technologies to control and manage the interplay between these new building-based solutions and the electric grid.

Stakeholders throughout the Northeast and Mid-Atlantic must start now to transition towards smart energy homes of the future, and many consumers are already engaged in that transition through enthusiastic adoption of a variety of smart home technologies. But smart technologies can and must be more than just fun gadgets. In the residential sector, smart energy homes have the opportunity to drive the region towards building decarbonization by: 1) building the connection between the home's loads and the grid; 2) decreasing total residential energy use; and 3) enabling load shifting across as many end uses as possible. Smart home technologies and home energy management systems (HEMS) can integrate decarbonized distributed energy resources (DERs) and strategically-electrified technologies, such as air-source heat pumps (ASHPs) and heat pump water heaters (HPWHs). ES Figure 1 below outlines the steps.

ES Figure 1: Step-by-step Process Describing How HEMS Meets Objectives of Decarbonized Future

Home electric loads will grow because of strategic electrification; stark contrast to traditional load reduction goals of energy efficiency.

With electric space and water heat, we may face new winter peaks, potentially larger than current summer capacity. Many homes may have two heating systems operating in parallel.	Thermal efficiency, energy storage, and strategic load shifting enabled by smart energy homes can help avoid large new system peaks. HEMS can assist in managing optimal operation of two heating systems.

In an electric home, many end-uses have loads that can be **shifted** to strategically beneficial times, especially for load-storing end-uses such as battery storage or water heaters.

Nearly all end uses will be connected and may be responsive to grid needs. Managing every end use will be very challenging for utilities and grid operator.	HEMS can play the "air traffic controller" or brain in the home, working to manage the signals between all the unique systems within the home and the grid.

Simultaneously, **renewable generation** for electricity is growing. Renewables by their nature are variable. External conditions, such as clouds and wind, can have a major impact on their generation.

While low carbon, more renewables means managing the stability of the grid is more complicated compared to predictable baseload generation.	Flexible end uses can absorb the clean, low-carbon electricity when it is available, and can shift use away from system capacity peak times

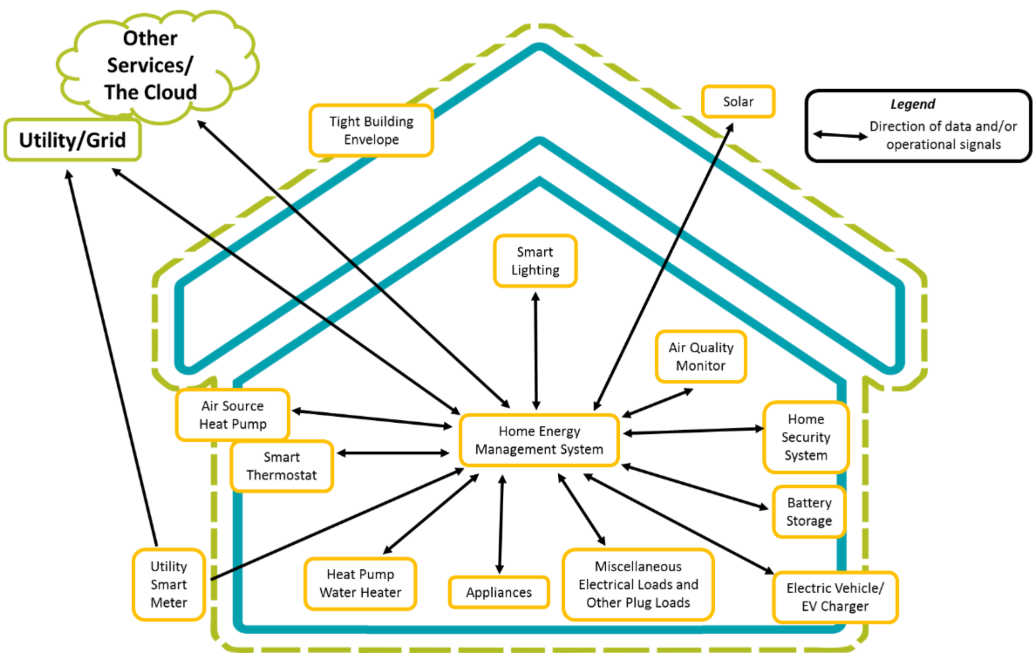
"Smart" technologies that can send and receive signs, coupled with a home energy management system, can manage this "generation-to-load" matching.

For example, EV onboard batteries present an opportunity to offer power at times of need directly to the building or grid.	HEMS can manage beneficial times to charge and discharge and ensure the electrical signals are optimized.

As these steps are implemented, the end goal of comprehensive smart energy homes of the future becomes clearer. The ideal smart energy home would be:

- Highly efficient, both for building envelope and with regard to individual technologies within
- Equipped with DERs, including rooftop solar, battery storage, and electric vehicles
- Feature strategically-electric technologies including ASHP and HPWH
- Include end uses that are smart, including appliances, various electronics and plug loads, lighting, air quality monitors, home security systems, and the aforementioned HVAC and water heating; and
- Include some sort of HEMS at the center to act as the "air traffic controller" between these different elements, exchanging data, information, and in some cases directing energy flow.

ES Figure 2: The Decarbonized Smart Energy Home of the Future



Individual technology markets that pertain to this future smart energy home—such as those for smart thermostats, residential solar, electric vehicles, ASHPs, or HPWHs—are developing at their own speeds. Some policies are in place to enable and spur investment in smart technologies. Though progress has been made on individual market and technology basis, there is work to be done on integrating these efforts into a broad infrastructure for decarbonizing residential buildings. Broader opportunities for infrastructure, enabled by smart meters, to further enhance these developments through establishing dynamic pricing are available. Several case studies of ongoing efforts in the Northeast, Mid-Atlantic, and far beyond are integrating the interrelated priorities of smart technology, distributed energy resources, and electrified water and space heating. These pilots are testing the viability of comprehensive smart energy homes, and providing insights into what combinations are ready for mass adoption and where research and development is still needed.

Ultimately, there are common barriers—such as unclear value propositions, flat utility rates, high costs, and unsupportive regulations and policies—but also common opportunities—such as technologies serving a customer amenity role, rebates and incentives, a wide diversity of products, and the grid benefits that many of them offer—between these markets. The goal is to create smart energy homes that provide better customer amenities, grid benefits, and substantial carbon reductions. The areas of focus and some short-term steps to get there are:

- ***Policy and Carbon:*** Policies must evolve to recognize and value carbon reductions as a critical consideration and motivator for decision making so that a decarbonized residential building stock may be fully appreciated and incentivized.
- ***Utility Regulatory Structure:*** Utility programs of the future will serve as a “one-stop-shop” for smart energy homes, including HEMS, DERs, and strategic electrification technologies. These programs will account for carbon reductions, promote lower-carbon strategic electrification activities, and have dynamic pricing.
- ***Smart Energy Homes Drive Smart Home Performance:*** As the grid decarbonizes and strategic electrification efforts increase, peak events will likely move towards the winter. Tight, low-load homes are critical to the success of strategic electrification and broader residential decarbonization. Low electric loads will be reinforced by smart energy home efforts that increase performance of existing homes.
- ***Quality Assurance and Transparency in Technology:*** Installed products in smart energy homes of the future are high quality, easy to find, and work well together to enable a low-carbon residential sector.
- ***Focus on the Locational Value of Smart Energy Homes and Energy Efficiency:*** A modernized grid that can account for a range of grid constraints when sending and receiving demand signals, particularly around location of savings, is critical.
- ***New Construction and Smart Energy Home Integration with Building Codes:*** New buildings are built to meet the future vision of flexible, low-load, electric homes.

Ultimately, smart energy homes, distributed energy resources, and strategically-electrified technologies are gaining market adoption footholds throughout the Northeast and Mid-Atlantic. Several smart technology markets are healthy and thriving today, and there is a need to expand their functionality and interoperability with the DERs and strategically-electric technologies to ensure we reach our residential decarbonization goals. Through focus and collaboration, and with a continued eye on equity and justice, regional actors can transform the residential sector with the smart energy homes at the center. Together, we will meet our decarbonization goals as the smart energy home works to optimize the what, when, and where of home energy use for decades to come.

Introduction and Context Setting

The 2018 International Panel on Climate Change made clear in its 2018 report that "ambitious mitigation actions are indispensable to limit [global] warming." The organization established a new target of 45 percent emissions reduction (from 2010 levels) by 2030, and net zero by 2050 in order to keep global warming to 1.5 degrees Celsius.[1] Throughout the Northeast and Mid-Atlantic, states have already established their own carbon savings goals, typically circling around the long-term 80 percent carbon reduction (from 2001 levels) by 2050, and the short term 40 percent reduction by 2030. In a thorough analysis of the pathways possible to reach these decarbonization goals, NEEP found even aggressive energy efficiency efforts for the next 30 years will not be enough to achieve either the short- or the long-term carbon reduction goals.[2] Moving forward, the region and country needs to reframe the focus from just energy efficiency to a strong push towards strategic electrification, prioritizing dynamic and flexible low-carbon loads to take advantage of clean generation at the time and location it exists. Within the residential sector, this means focusing on three concurrent efforts:

- building up the connection between a home's loads and the grid;
- decreasing total residential energy use; and
- enabling load shifting across as many end uses as possible.

Home energy management systems (HEMS) and smart energy home technologies are key components to advancing regional residential building decarbonization. In addition to making loads in a home flexible, smart energy homes can both enable and help to grow the residential distributed energy resource (DER) market. Since consumers are adopting smart home technology at rates far faster than other low-carbon solutions, smart energy homes can also ease the shift towards strategic electrification.

This report will outline how smart energy homes can achieve these multiple goals. Through market analysis, best practice exploration, and an examination of barriers and opportunities, this report will address how to make smart energy homes a reality. This report focuses on residential buildings, and while not explicitly limited to single family homes, many of the recommendations are aimed at replacement of major electric end-uses such as HVAC and water heating. Before diving into the analysis, we establish the foundation for the terminology critical to this report.

Technological Definitions

The Smart Energy Home

NEEP has been leading work in the smart energy home space since 2014 and has published several resources on the subject.[3] For the purposes of this paper, NEEP will use the following definition for home energy management systems (HEMS) and the smart energy home, as defined in a 2016 report.[4]

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[1] Intergovernmental Panel on Climate Change, 2018 report "G*lobal Warming of 1.5 °C* http://www.ipcc.ch/report/sr15/

[2] Conclusions from NEEP's 2017 report, *Northeastern Regional Assessment of Strategic Electrification* https://neep.org/strategic-electrification-regional-assessment

[3] Reports and resources available from: https://neep.org/initiatives/integrated-advanced-efficiency-solutions/home-energy-management-systems

[4] NEEP 2016, *The Smart Energy Home: Strategies to Transform the* Region https://neep.org/smart-energy-home-strategies-transform-region

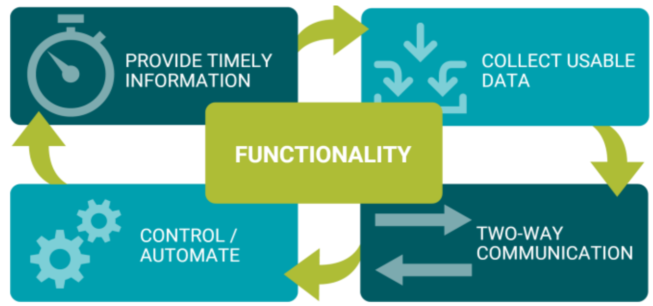
"*Home energy management systems*" refer to:

> *any hardware and/or software system that can: Monitor and provide feedback about a home's energy usage, and/or enable advanced control of energy-using systems and devices in the home.*

HEMS can have interoperability between devices, "outeroperability" (where the connection can be made to the utility)[5], and energy efficiency, whereby a smart product is not just connected, but works as efficiently as possible[6].

As defined by NEEP in the same 2016 report,[7] "*smart*" devices have the functionality detailed in Figure 1. Most importantly, they can send data and signals about their operations as well as receive and interpret signals dictating their operations.

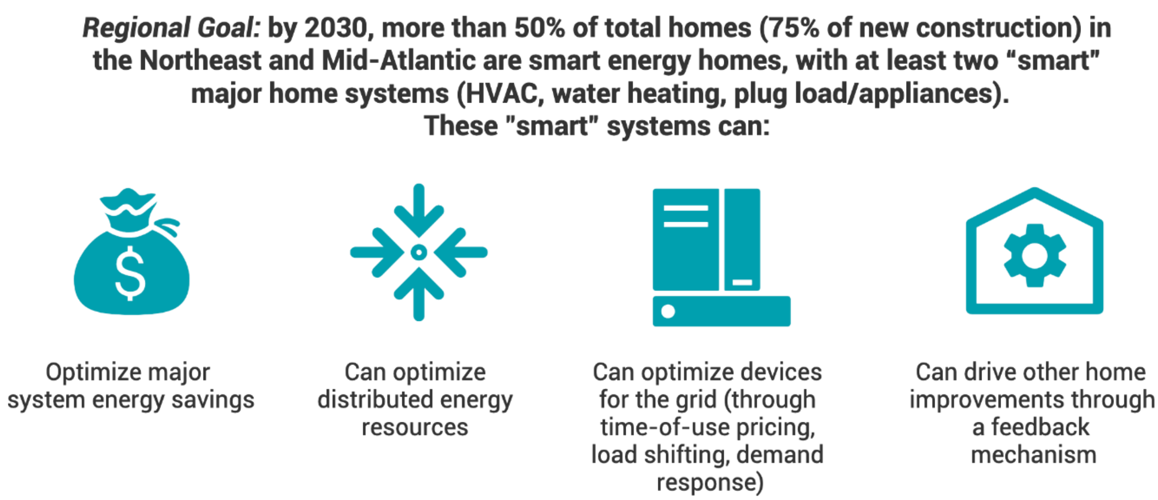
Figure 1: Functionality for a device to be "Smart", Image recreated from NEEP's 2016 Smart Energy Home report



Finally, the "*smart energy home*" takes a step beyond the gadget-filled smart home to focus on bringing smart functionality to major household energy-using systems: HVAC, water heating, and plug loads (including appliances and electronics).[8] Within these definitions relating to smart homes, there may still be questions of applicability. Can a single device be considered a HEMS? What about reliance on an electric smart meter in a gas-heated home? For the purposes of this report, NEEP takes a broad angle on what fits into the definition of smart energy homes and will address both the roles of the HEMS and utility smart meter.

For smart energy homes, NEEP established and revised a regional goal reflected in Figure 2.[9]

Figure 2: Regional Market Transformation Goal for Smart Energy Homes, from NEEP 2016



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[5] Term established by Kevin Johnson, National Grid

[6] A 2017 Lockheed Martin Energy report for NYSERDA showed energy savings potential from several smart home devices at a maximum energy savings potential of up to 16%. https://www.nyserda.ny.gov/-/media/Files/Publications/Energy-Analysis/Home-Energy-Management-System-Savings-Validation-Pilot.pdf

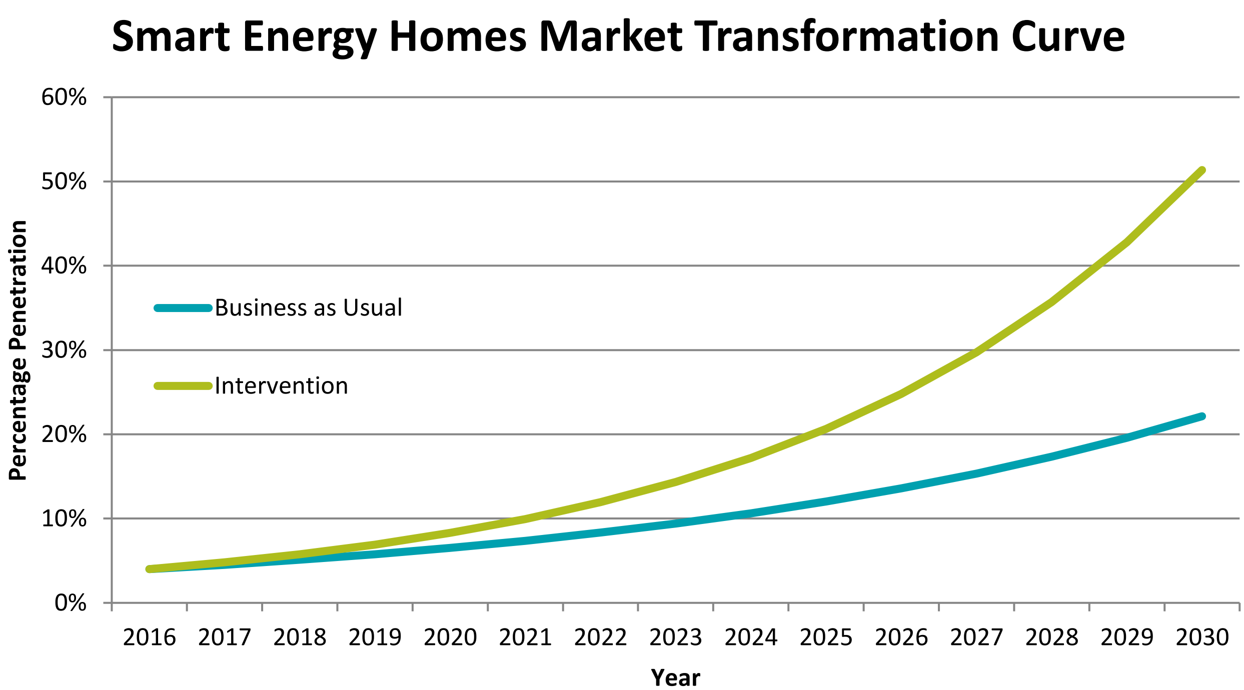
[7] Ibid.

[8] As identified in EIA RECS data, 2009 https://www.eia.gov/consumption/residential/

[9] Ibid.

In our 2016 report, NEEP also created a market transformation curve recreated in Figure 3 to show the potential trajectory to meet our 50 percent adoption by 2030. Since 2016, the rubber is starting to meet the road and we're seeing the beginnings of market change through interventions and strategic shifts.

Figure 3: Market Transformation Curve for Smart Energy Homes, from NEEP 2016



Distributed Energy Resources

While there are no shortages of definitions for distributed energy resources (DERs),[10] the National Association of Regulatory Utility Commissioners (NARUC) uses a comprehensive definition, cited here with NEEP emphasis added:

> A DER is a resource sited close to customers that can provide all or some of their immediate electric and power needs and can also be used by the system to either reduce demand (such as energy efficiency) or provide supply to satisfy the energy, capacity, or ancillary service needs of the distribution grid. The resources, if providing electricity or thermal energy, are *small in scale*, *connected* to the distribution system, and *close to load*. Examples of different types of DER include solar photovoltaic (PV), wind, combined heat and power (CHP), energy storage, demand response (DR), electric vehicles (EVs), microgrids, and energy efficiency (EE).

This is a comprehensive definition, but for the purposes of this report, we will focus on DERs that are more likely to be relevant on the residential level, such as photovoltaic, battery storage, demand response, and electric vehicles.

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[10] NARUC lists 5 definitions from other sources before defining their own. https://pubs.naruc.org/pub/19FDF48B-AA57-5160-DBA1-BE2E9C2F7EA0

Strategic Electrification

The final pillar of this report is residential building decarbonization with a focus on strategic or beneficial electrification. NEEP has published multiple resources on strategic electrification focused on opportunities in the Northeast, and has landed on the following definition:

> "Strategic electrification" means powering end uses with electricity instead of fossil fuels in a way that increases energy efficiency and reduces pollution, while lowering costs to customers and society, as part of an integrated approach to deep decarbonization.[11]

As NEEP's research has identified and is outlined in Figure 4, strategic electrification in the built environmental must be coupled with advanced efficient technologies, deep energy efficiency, and grid integration.

Figure 4: Strategy to Achieve Decarbonization[12]

Strategic electrification is not the end goal, but is rather a means towards an end that, when coupled with clean generation and lower energy use overall, will lead to decarbonization. As this report will explore, grid integration through flexibility in load management is critical in making this decarbonization goal a reality. This report will also focus on a few key electrification end uses, namely HVAC and water heating, which are beginning to shift in consumer's minds as more sustainable solutions.[13] Moving forward, these technologies not only need to be "smart" as identified in the smart energy homes goals, but also strategically shifting towards electric power.

The State of the Market

This section seeks to summarize the technologies and their associated markets that impact this report. Further analysis of markets is referenced in the appendices. Most of the referenced technologies would be applicable for a residence that had control over major end-uses such as HVAC, water heating, and rooftop solar, though for some homes without access to their own roof, community solar may be a solution. Many multi-family applications that do not fit this criteria could still have some pieces of the smart energy home, but that would require further research to outline.

The two smart energy home devices with the biggest consumer adoption thus far are smart thermostats and smart speakers. Though not a consumer product, utility smart meters have a significant share of the meter market as well and will be addressed in the Demand Response, Dynamic Rates, and the Role of a Smart Meter

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[11] NEEP 2017, *Northeastern Regional Assessment of Strategic Electrification* https://neep.org/strategic-electrification-regional-assessment

[12] NEEP 2018, *Action Plan To Accelerate Strategic Electrification in the* Northeast https://neep.org/reports/strategic-electrification-action-plan

[13] Examples outlined in Suzanne Shelton's presentation, https://neep.org/sites/default/files/5%20-%20Suzanne%20Shelton_Power%20Talk.pdf

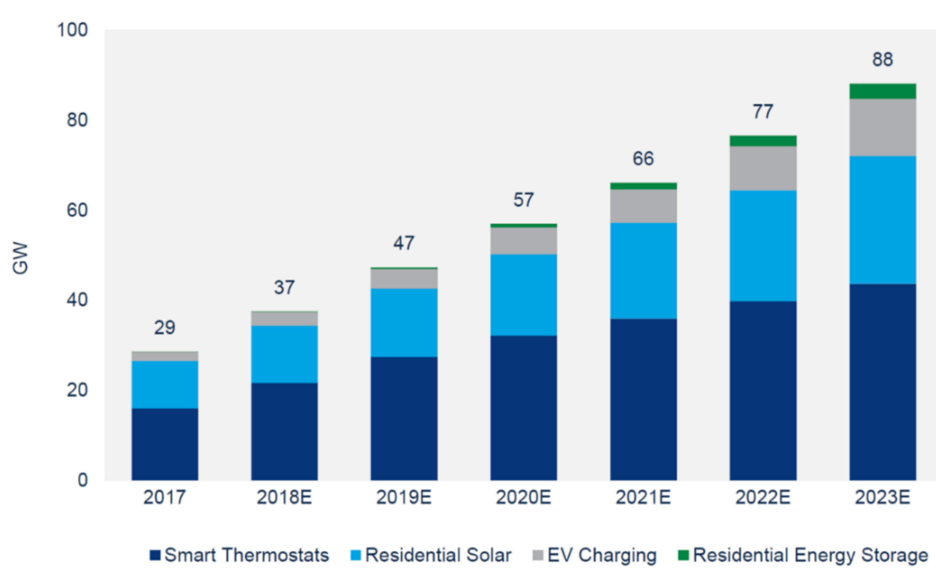
section. By 2020, US ownership of smart thermostats is estimated at nearly 40 million, with smart speaker ownership estimated at nearly 140 million. Within the smart energy home market, there are several other developments of note, including NEEP-led efforts and those from our partners such as U.S. Environmental Protection Agency (U.S. EPA) and the Home Performance Coalition. These are detailed further in Appendix A: Smart Energy Home Market Characterization Details.

Smart thermostats have gained popularity because of their sleek hardware, easy-to-use apps, and relatively easy installation. Their typical uses are to control traditional heating and cooling technology and turn a legacy non-connected large end-use into a controllable load. The latter use put that equipment on the path towards decarbonization.

Within the distributed energy resources market, most residential distributed energy resources (DERs) are currently being adopted for customer amenity or preference. In other words, most people adopt use of them as an individual investment and not as part of a comprehensive smart energy home strategy. As penetration of DERs grows, however, collective distributed resources will become more important and powerful grid assets. As such, integration of DERs with HEMS is necessary to ensure that they deliver their full value as grid assets and not become liabilities. For example, a HEMS could, in theory, forecast the expected solar PV production based on weather conditions and determine when to use that energy, when to store it, or when to sell it back to the grid. Similarly, a HEMS could determine the best charging behavior between different DERS (such as battery storage systems, HPWH, and electric vehicles) to optimize their use.

Historically, when consumer DERs have interacted with the grid, it has been through a **Distributed Energy Resources Management System (DERMS)**. DERMS can be considered "grid edge" systems, helping utilities by being an accessible resources at the end of the distribution line. HEMS, on the other hand, are most often working for the consumer to provide optimization and benefit. In an ideal scenario, both HEMS and DERMS are using advanced algorithms, learning behaviors, and in some cases artificial intelligence, to optimize performance for both the grid and consumer and ultimately resulting in carbon reductions. When coupled together, however, a HEMS could incorporate the functionality of the DERMS to help turn more end uses into grid assets and ensure the DERs are optimize for the consumer. This vision may not yet be reality, but as the technologies evolve and become more commonplace, the target should be integration to optimize the range of residential resources for the consumer, the grid, and ultimately for carbon reductions.

Figure 5: From Wood Mackenzie Power & Renewables, Projected Cumulative US Potential for Behind-the-Meter Residential Flexibility



The need for this type of integration is growing, with projected 88GW of residential flexibility in the U.S. from a range of sources by 2023.[14] The most notable sources are smart thermostats and residential solar, but also EV and energy storage at a growing rate. Figure 5 depicts this projected market growth.

Regarding current levels of penetration, residential solar is catching its footing and is slightly in the lead of DER technology adoption. Electric vehicle ownership in the U.S. has grown from 0.9 percent of car sales in 2016 to nearly two percent in 2018, and is projected to be over 20 percent by 2025.[15] Finally, the residential scale battery storage market is still in the very early days of mass adoption, with relatively high prices compared to gasoline generators, fairly limited options,[16] and little residential battery storage deployed to date.[17] Appendix B: Distributed Energy Resources Market Characterization Details has addition market details.

As discussed in Introduction and Context Setting, energy efficiency is only one of the critical strategies needed to achieve broader residential sector decarbonization goals that Northeast states have established. Strategic electrification of certain end uses—primarily space and water heating in the residential building sector—is also critical to reach these goals. The highly efficient electric technologies that are of particular focus for this report are air source heat pumps (ASHPs)[18] and heat pump water heaters (HPWH).[19] Geothermal heat pumps (GHP) also have a role to play in this market, but at present have more constraints around installation and a higher first cost than ASHPs.

Detailed further in Appendix C: Strategically Electrified Space, Water Heating, and Home Performance Market Characterization Details, the adoption of high-performing ASHPs is increasing throughout the NEEP region and beyond. One lingering barrier still to overcome is the lack of built-in connected functionality on most air source heat pumps, making them incompatible with smart thermostats or other remote control for potential load shifting. On the other hand, heat pump water heaters continue to be a very slow-growing market category. While their carbon and strategic electrification benefits are tremendous, the market penetration of heat pump water heaters is still under two percent, even after years of high utility incentives. Connectivity and decarbonization benefits[20] of heat pump water heaters, however, is a growing area of interest and there have been several market solutions developed in the past few years.

The last key element of the decarbonized residential market is the building envelope, largely addressed through home performance improvements. Shrinking the total need for energy use within a home will go very far to achieve decarbonization goals. While the home performance industry is not new, there have been additional developments and opportunities for the smart home to help drive deeper home performance. These are detailed further in Appendix C: Strategically Electrified Space, Water Heating, and Home Performance Market Characterization Details As is true for all technologies explored in this report, there is consistent need to build workforce and installation skill sets that ideally can work across technologies.

[14] Image recreated from: https://www.woodmac.com/news/editorial/residential-flexibility-88GW/
[15] Auto Sales Data: GoodCarBadCar.net, InsideEVs, HIS Marit projections, EVAdoption.com
[16] https://news.energysage.com/battery-backup-power-vs-generators-which-is-right-for-you/
[17] http://energystorage.org/
[18] NEEP ASHP Resources at https://neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp
[19] NEEP HPWH Resources at https://neep.org/initiatives/high-efficiency-products/emerging-technologies/hpwh
[20] https://www.raponline.org/knowledge-center/beneficial-electrification-of-water-heating/

The Smart Energy Home: Driving Residential Decarbonization

Most efforts in energy efficiency have been focused on load reduction. As we move towards a broader, more integrated efficiency future -especially with the shift towards time- and location-specific energy efficiency—we are starting to see different drivers. HEMS and smart technologies pay a key role in this transition, as detailed in Figure 6.

Figure 6: Step-By-Step Process Describing How HEMS Meets Objectives of Decarbonized Future

Step 1
- With strategic electrification, home electric loads are expected to **grow**, which is a contrast to the traditional load-reduction goals of energy efficiency.

Step 2
- In electric homes, many end-uses have loads that can be **shifted** at strategically beneficial times. This is especially true for load-storing end-uses such as battery storage or water heaters. In well-insulated houses with an ASHP, there is also a huge opportunity to pre-heat or pre-cool homes to avoid system peaks.

Step 3
- At the same time, **renewable generation** for electricity is growing both in large and small scale. These renewables, however, are by their nature variable. External conditions, such as clouds and wind, can have a major impact on their generation.

Step 4
- **Flexible end uses** that can absorb clean, low-carbon electricity when available, and can be shifted away from system capacity at peak times, are critical to managing this growing electric need.

Step 5
- **"Smart" technologies** that send and receive signs coupled with home energy management systems can manage this **"generation-to-load"** matching.

HEMS, acting as the "air-traffic controller" for major electric end-uses in the home, have the potential to manage new and existing electric loads and optimize their use for both individual homes and the broader grid. The growth of smart energy homes will support advancements in DERs and strategic electrification technologies, and drive towards decarbonized residential buildings.

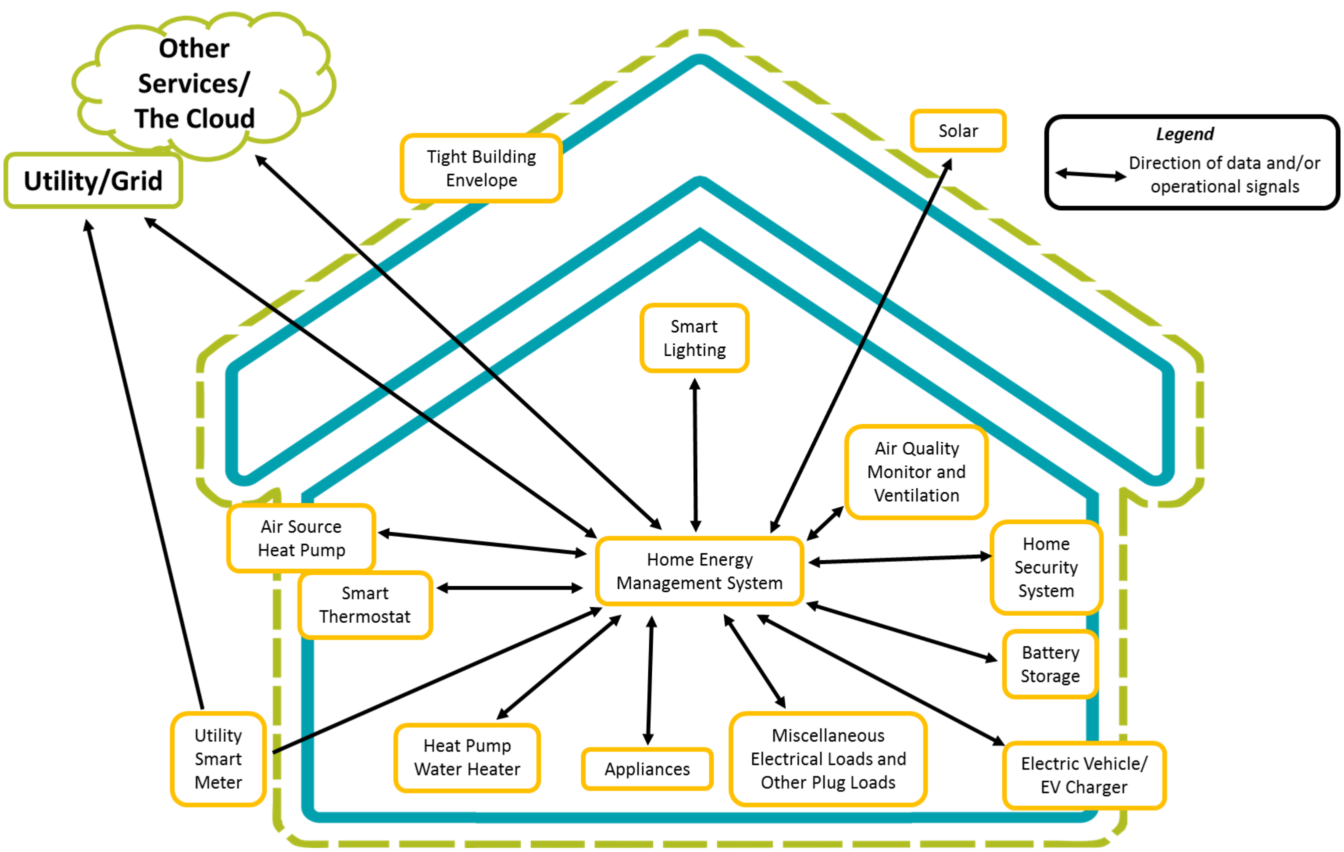
A "Collective" Vision

In an effort to consolidate our research and bring together multiple technologies, we have developed an "end goal" vision as a road map. As demonstrated in Figure 7, we are building towards an idealized smart energy home that:

- Is highly efficient, both for building envelope and with regards to the individual technologies within;
- Is equipped with DERs, including rooftop solar, battery storage, and electric vehicles;
- Features strategically-electric technologies including electric heat pumps, HVAC, depicted as an air-source heat pump (ASHP) and heat pump water heater (HPWH);
- Has end uses that are smart, including appliances, various electronics and plug loads, lighting, air quality monitors, home security systems, and the aforementioned HVAC and water heating; and
- Has some sort of HEMS at the center to act as the "air-traffic controller" between these different elements, exchanging data and information and, in some cases, directing energy flow.

In this depiction, there is also a utility smart meter that, while measuring electricity used in the whole home (and not receiving data directly from the HEMS), can send that information to both the HEMS and the utility. This step is likely critical to enable dynamic pricing and give bill credit for load shifting within the home. It is addressed further in Demand Response, Dynamic Rates, and the Role of a Smart Meter. In this ideal future home, the HEMS would also have the ability to interface with the utility and send and receive grid signals to optimize end uses based on the lowest carbon scenario, as well as potentially interfacing with other services represented as the cloud.

Figure 7: The Decarbonized Smart Energy Home of the Future



Where does the HEMS sit in the home?

In Figure 7, we show a HEMS at the center of things, both sending and receiving signals to optimize operations of various connected end-uses. In reality, much of the current market development of smart homes is on individual devices or one device and one interface. For example, a smart thermostat that is controlled both through the manufacturer app or connected to a smart speaker or a hub. In order for many smart home devices to be operational, a physical hub may be necessary to receive and translate signals and bring that information to a more accessible location, such as a smartphone app. Common logic in today's world is optimizing most smart home controls based on consumer preference alone. Moving forward, decisions on more smart devices in a home and more communication between centralized HEMS units and those smart end-uses should take into account the lowest carbon strategy to manage a home.

For the subset of homes that already have some sort of distributed energy resource, a distributed energy resource management system (DERMS) may already exist that works to optimize DERs for the grid. For homes with smart thermostats, there may already be a demand response element that is communicating directly with a utility. In NEEP's collective vision, the functionality of a present day DERMS would marry with that of a hub to yield a HEMS. This locally controlled and optimized unit would send and receive grid signals, distributing them appropriately amongst the connected end uses.

> The functionality of a present day DERMS would marry with that of a hub to yield a HEMS, with both localized control and optimization within the home and the ability to send and receive grid signals and distribute them appropriately amongst the connected end uses.

What this HEMS would look like, however, is quite flexible. The HEMS need not be a physical device nor a stand-alone app or cloud system. The HEMS of the future may very well be housed within another smart device. In many ways, it does not matter where the HEMS is located or what it looks like, as long as it has the necessary functionalities, identified in the Technological Definitions section, to connect to many different smart end-uses and bring in DER and strategic electrification functionality.

As a few smart home technologies appear to lead in consumer popularity, namely s*mart thermostats* and *smart speakers*. They are also the top choice for interfacing with the rest of the smart home and utilities.[21] If smart speakers connect to other smart devices within a home and send/receive signals to optimize their use, they are acting as the HEMS in those homes. Whether the connection is in the cloud or using a local network signal, if signals work to optimize operation, the signaler is the HEMS. This is also true for smart thermostats or any other smart device, app, or cloud-based interface within the home—the HEMS is defined by its functionality, not its physical or virtual space.

HEMS Operating Scenarios in the Collective Vision Home

As we grow towards the idealized future in Figure 7, we are likely to find parts of this picture developing more quickly than others. We may end up in a situation where smart versions of major end-uses within a home—such as HVAC, water heating, battery storage and EV charging—begin to interface directly with utilities, sending and receiving optimization signals based on grid needs. This should be considered great progress, but is not the sustainable long-term solution outlined in this report. In the big picture, a grid operator does not want to account for individual end-uses to achieve demand management goals since end-uses do not tell the whole picture.

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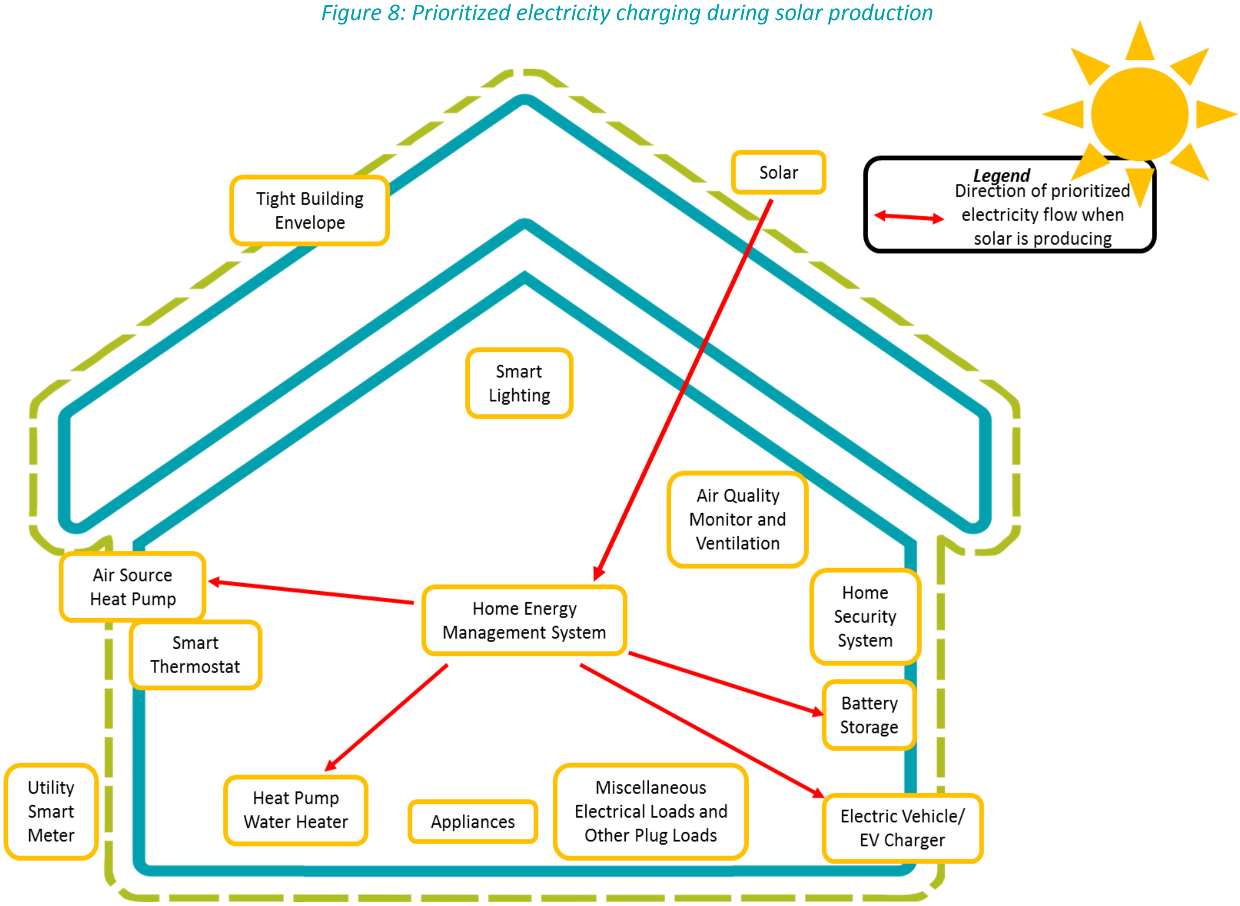
[21] E Source 2018, *Voice Control Changes Everything: Why Utilities Should Care About Virtual Assistants.* https://www.esource.com/10059-001/3/voice-control-changes-everything-why-utilities-should-care-about-virtual-assistants. Additionally ENERGY STAR lists utilities supporting ENERGY STAR Smart Thermostats, https://www.energystar.gov/products/heating_cooling/smart_thermostats

For example, a scenario could exist where a water heater is being dispatched to manage peak. The water heater may be "charged" or heated before an expected peak event, but if the "heat up" signal is sent to an electric water heater in a home with solar, the water heater may divert energy from solar that otherwise may have been used to condition air with an ASHP or run the clothes dryer or any number of other electrical end-uses. When the peak event actually happens, the home might need more electricity to balance those loads than if left unattended, and may even end up drawing additional electricity from the grid during the worst times. If a utility or grid is only interfacing with one piece of the system, there may be unintended consequences. The smart meter read at the end of a peak event may show little to no impact of the curtailment effort. If that scenario had instead interfaced with a HEMS, the HEMS would have better information on all smart end-uses within a home and would understand the need to avoid usage during a peak event. The HEMS could work to orchestrate when to charge what in order to keep the user, technologies, and grid balanced.

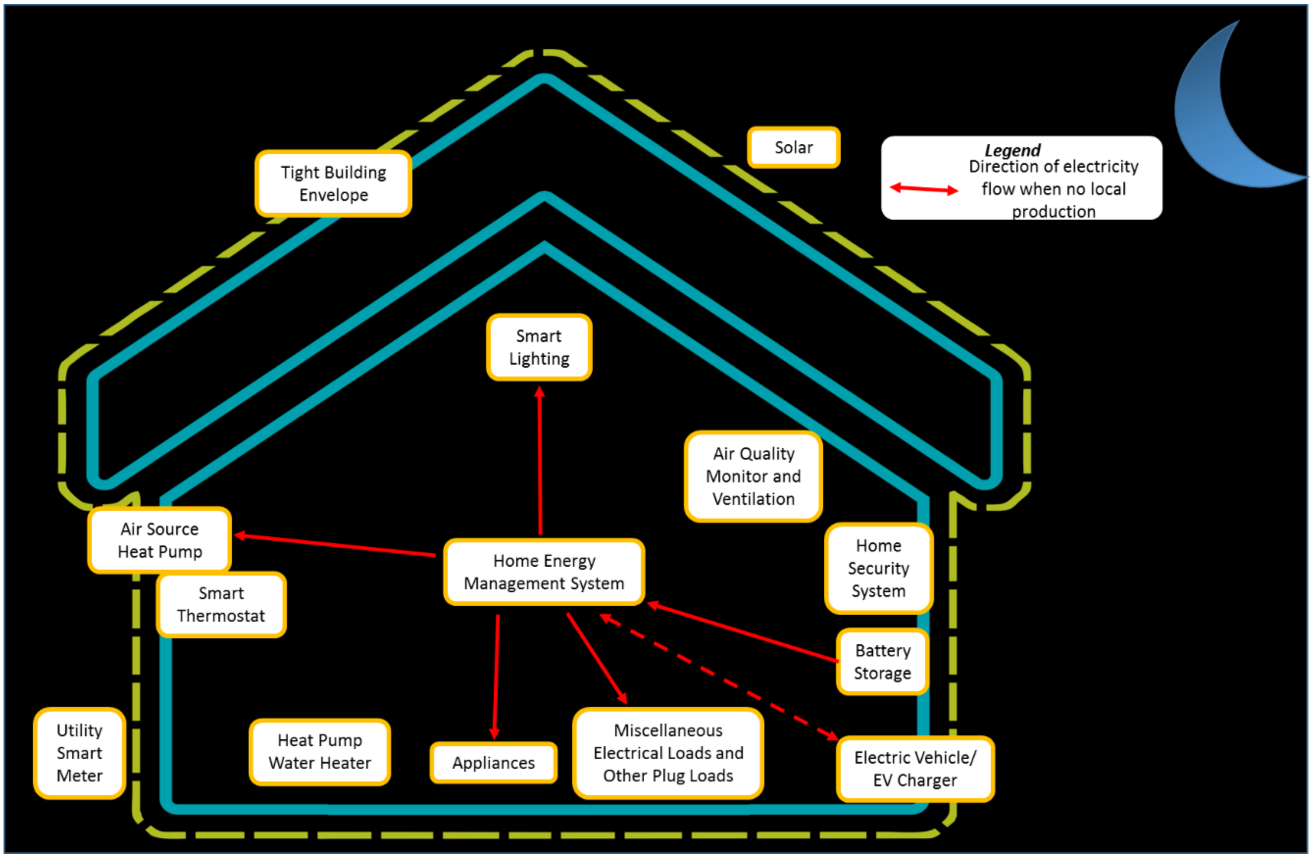
As such, while the HEMS serves a role in directing energy signals and usage traffic, the individual smart devices need to be designed with the ability to receive, interpret, and act based on the meaning of these signals. When no signal has been sent, individual devices should have their default efficient optimization. However, they need to reactive to other signals that may come in based on other needs within the home or from the utility (e.g. solar production, demand response event, or cheap rates in middle of the night).This vision may take some of the pressure off individual end-uses that may expect to be grid-responsive as long as the smart devices themselves can report their usage forecast and respond to control requests from the HEMS. If a HEMS is sending appropriate signals, individual end-uses need not connect directly to a utility.

Figure 8: Prioritized electricity charging during solar production



In the next two figures, we explore the flow of electricity in a home with HEMS and DERs, taking out the greater utility or grid needs. Figure 8 shows how a HEMS could prioritize charging when solar production is high, and Figure 9 shows the corresponding possible electricity flow in the middle of the night with no solar production. In Figure 9, EV charging is shown with a dashed line as, in the future, an EV battery could be discharged to power other end-uses in the home. At present, it is most likely to be in “charging” or “do not charge now” modes. These scenarios could be made more complex if the HEMS received additional grid signals.

Figure 9: Nighttime electricity flow when no production



Impacts, Trends, and Policies

There are several trends and policy considerations that will be impacting this space and the larger goals for residential building decarbonization driven by smart energy homes. This section explores a few of the most pressing policy considerations.

Load Shaping: Teaching the Duck to Fly

Throughout the region, we are seeing growth in smart products, distributed energy resources, and strategic use of electric technologies. That said, each individual technology is on its own market adoption curve. The comprehensive smart energy home depicted in A "Collective" Vision will not happen overnight. More likely, the elements in the home will see adoption at different rates over the course of years. It is important to keep a comprehensive end goal in mind, while also providing a pathway for technologies to grow together.

In the NEEP region, which experiences significant cold temperatures during winter, the need for a comprehensive and deliberate smart energy home is growing. Imagine a scenario where space and water heating have shifted towards electric-powered, but in the cold, cloudy, short days of New England winter, solar distributed generation is very limited. This scenario could cause a new overnight peak crisis in home heating needs. In occasions like this, it is paramount to have both battery storage and clean generation from non-solar sources (like wind) to meet the evolving needs of the grid. A central HEMS will be critical to best manage the loads within a home to meet the needs of the future.

When looking at future daytime demand curves, especially days with a large amount of mid-day renewable, the depiction is often referred to as the "duck curve" because the shape of the load resembles an outline of the bird. Taming this curve to ensure load use during the day when solar production is highest (and avoiding loads when the sun sets) has been compared to "teaching the duck to fly" in a flattened demand curve. In its 2016 paper, the Regulatory Assistance Project (RAP) outlines load shifting options to smooth the duck curve, [22] and walks through the importance of a flatter curve in accommodating a decarbonized grid. Taking it a step further, the Rocky Mountain Institute (RMI) in a 2018 analysis actually modeled the individual load sources that could be shifted to flatten the duck curve, as recreated in Figure 10.[23]

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[22] Regulatory Assistance Project, 2016 *Teaching the Duck to Fly* http://www.raponline.org/wp-content/uploads/2016/05/rap-lazar-teachingducktofly-2014-jan.pdf

[23] Rocky Mountain Institute, 2018, *Demand Flexibility: The Key to Enabling a Low-Cost, Low-Carbon Grid* https://rmi.org/demand-flexibility-can-grow-market-renewable-energy/

Figure 10: A "Flying Duck" Net load and changes from demand flexibility for an average day. Recreated from RMI 2018

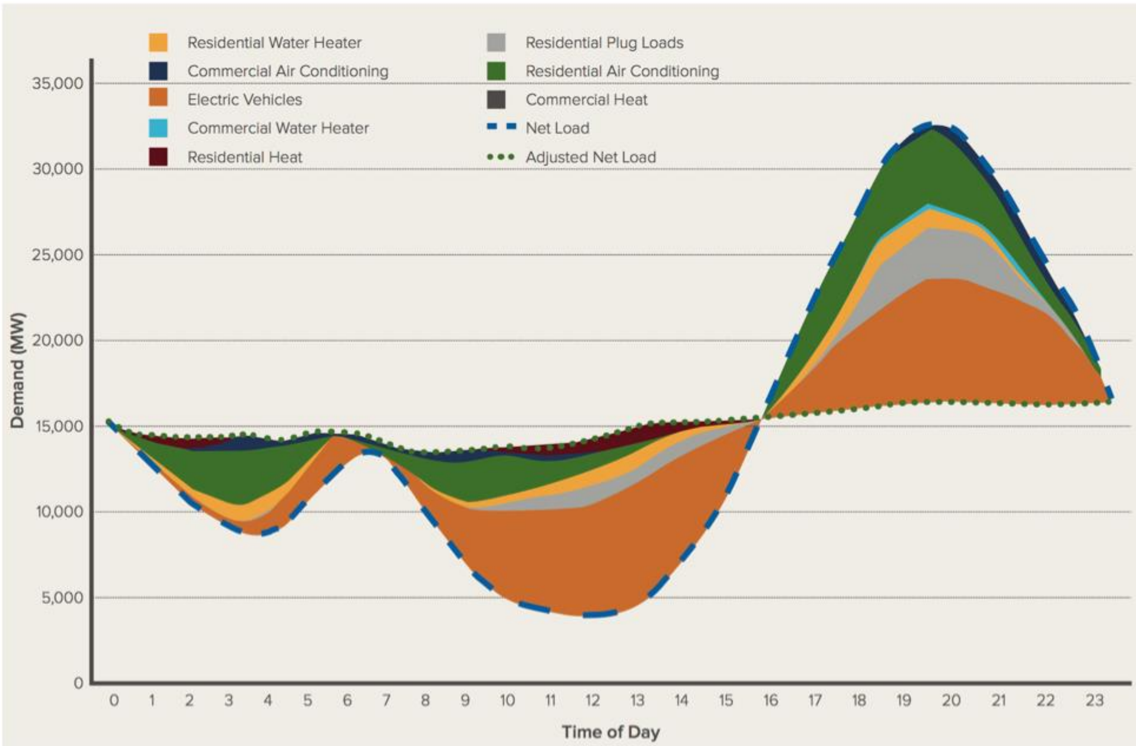
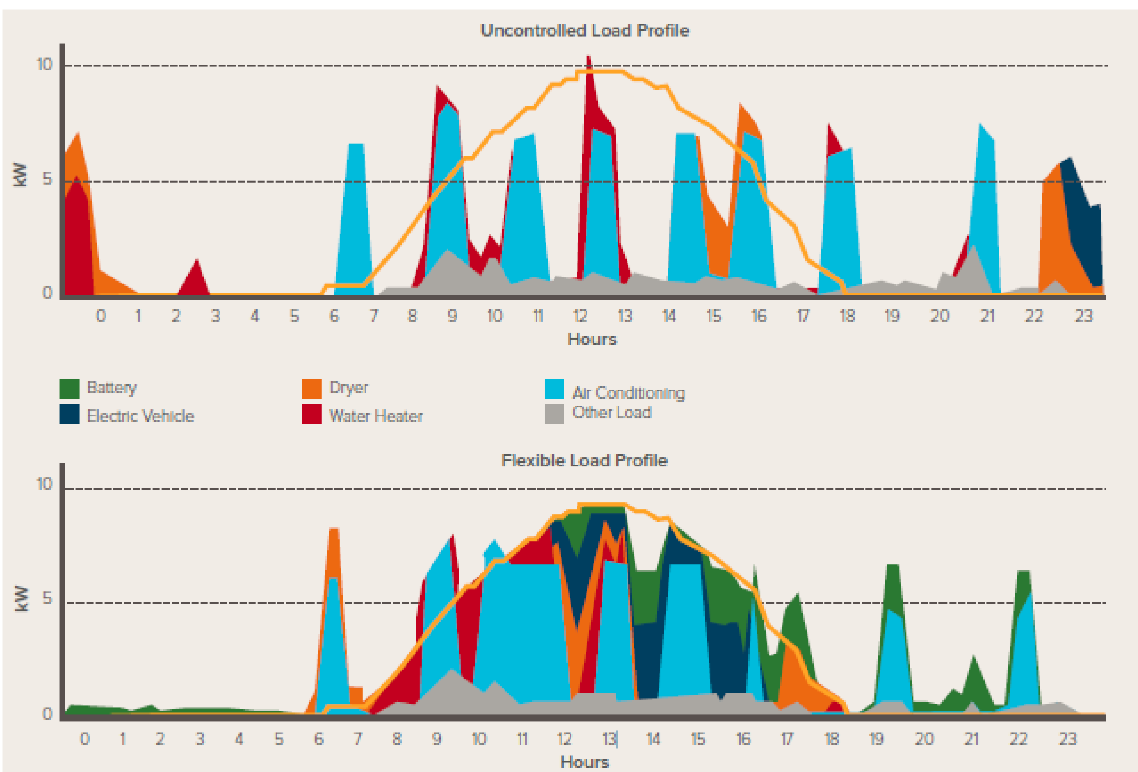


Figure 11: Impact of demand flexibility on residential load profile, from RMI 2018



While Figure 10 shows both residential and commercial end uses, the resources outlined in this report—residential water heating, electric vehicles, residential HVAC, and other connected end loads— make the largest impact in flattening the demand curve for a more reliable, and ultimately cleaner grid. At present and as depicted, residential heat is a much lower electrical load than NEEP anticipates with the growth of ASHPs.

Taking a step further, the RMI 2018 report[24] also modeled individual residential load profile, as recreated in Figure 11. This model While Figure 10 shows both residential and commercial end uses, the resources outlined in this report—residential water heating, electric vehicles, residential HVAC, and other connected end loads—make the largest impact in flattening the demand curve for a more reliable, and ultimately cleaner grid. At present and as depicted, residential heat is a much lower electrical load than NEEP anticipates with the growth of ASHPs.compares load-shifting potential of a home's "uncontrolled" load to a "flexible" load. Though this depiction is from a Hawaii model with solar production (yellow line) and air conditioning, it can be compared to a winter day in the Northeast taking electric heat into consideration. This ability to shift loads to address energy demand and pair it with the cleanest energy supply is the role of the HEMS.

State of Related Policies in the Market

In order to help support the growth of residential building decarbonization, several states in the Northeast and Mid-Atlantic have adopted or proposed policy changes. Within the 2017 strategic electrification report,[25] NEEP identified several significant policies that are enabling decarbonization, with several additions added to Figure 12.

Figure 12: Policies relating to DERs and Strategic Electrification through the Northeast and Mid-Atlantic

State	Policy
CT	Addition of a residential new construction (RNC) smart home incentive, an all-electric RNC package tied to a 50% reduction in propane rebates, and an EV-readiness criteria for the most efficient tiers. Rebates for PHEVs and BEVs (CHEAPR) Heat pump rebates available through EnergizeCT Grid modernization docket under way in PURA is addressing smart home interoperability
DE	Renewable energy assistance through utilities by way of grants through the Green Energy Program ASHP, HPWH, and smart thermostat rebates available through Energize Delaware statewide program
DC	Initiated grid modernization efforts facilitated by the Smart Electric Power Alliance (SEPA) Rebates in strategic electric and smart home technologies administered through the DC-SEU City council passes 100% clean power by 2032
ME	Significant uptake in residential ASHP and HPWH through Efficiency Maine rebate and financing programs (over 20,000 rebates FY14-FY16)
MD	Public Service Commission order 88514 includes mandate for MD utilities to do smart home pilots

[24] Ibid. Page 2, figure 1
[25] Ibid. page 35

MA	Heat pumps and other renewable thermal energy integrated into Alternative Portfolio Standard Utility three-year Energy Efficiency Plan for 2019-2021 includes reference to strategic electrification and plans for carbon reductions Robust rebates for small and large-scale ASHPs through both Mass Clean Energy Center and Mass Save Expansion of Solarize Mass program to include heat pumps, EVs, and storage (Solarize Mass Plus) Rebates for PHEVs and BEVs (MOR-EV)
NH	Residential ASHP and HPWH rebates from individual utilities Time-of-use rate, with low nighttime EV pricing, through Liberty Utilities
NJ	PSEG, NJ's largest utility, has proposed a six-year Clean Energy Future program that includes focus on carbon emissions, EV infrastructure buildout, energy storage, and smart meters.
NY	Drive Clean rebates for PHEVs and BEVs EV incentives, such as the free use of certain HOV lanes and discounted EZ-Pass toll fees Residential time-of-use rate for EV charging through ConEd EV Charger Rebate Program (EVSE installation) Smart home rates offered by utilities through REV
PA	PA Department of Environmental Protection drafted plan to boost solar (loans, carbon pricing, and tax exemptions through PA Solar Future)
RI	Rebates for PHEVs and BEVs (DRIVE) 43,000 zero-emissions EV target by 2025
VT	Utilities offering plug-in hybrid (PHEV) and battery electric vehicle (BEV) rebates as part of their Renewable Energy Standards (RES) compliance Utilities provide incentives and leasing for ASHPs and HPWHs as part of meeting their energy efficiency and RES obligations
WV	Utility efficiency efforts starting to move forward as a result of case 09-0177. West Virginia University Energy Institute conducts research focused on efficient vehicles

Demand Response, Dynamic Rates, and the Role of a Smart Meter

The Limits of Current Demand Response

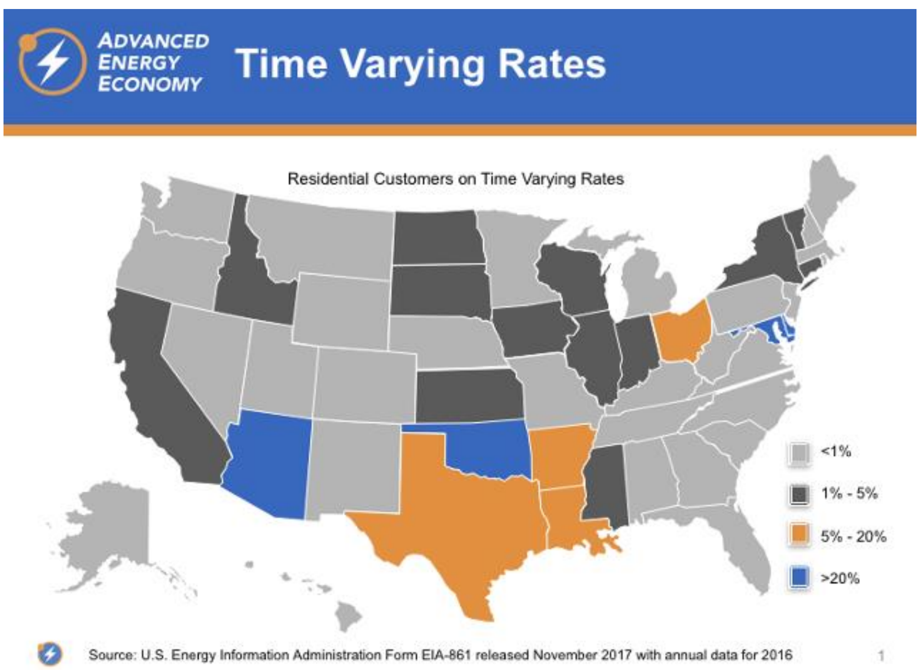
Customers receive a range of benefits from smart energy homes—such as improved comfort, security, convenience, and reduced carbon footprint—but unless homes are operating completely off the grid, utilities are being impacted by these homes as well. Most utilities have a flat residential rate structure, charging one price per kWh to their customers even though the actual price paid by the utility can vary widely throughout the day and year. More and more utilities are introducing residential demand response (DR) programs and compensating participants who voluntarily curtail their energy use during peak periods when the electric grid is especially constrained. Some direct load control demand response events have been in place for decades, however, residential demand response programs that work with one or more smart devices within the home is a newer utility trend. [26] Current residential demand response incentives are large enough to compel customers to enroll in a program, but DR incentives alone are unlikely to be enough to motivate homeowners to invest in some of the more costly technologies like battery storage, HPWH, or ASHP. While customers making one of these purchases may already be happy to also enroll in DR programs, demand response alone is not enough to drive adoption of these technologies.

Dynamic Rates

While the introduction of residential DR in the 1970s[27] starts to address the issue of electricity having different costs or values at different times, there is opportunity to go much further. The economics of dynamic or time-of-use (TOU) rates that sets up a schedule for when electricity is in highest demand (and thus most expensive) can start to tip the scales for smart devices that can be responsive to those pricing signals. This move from signal-event demand response towards constant-reward dynamic pricing is an important shift. A HEMS or other smart technology that can manage this demand response scheme behind the scenes becomes very valuable. Think of it as similar to when customers are financially motivated to adjust everyday electricity usage based on price signals.

As electric-powered technologies like EVs, storage, ASHPs, and HPWHs gain market share, they may add more stress to the grid – especially in the winter – without the ability to send and receive signals.[28] Flexible loads coupled with deep energy efficiency offer a path to mitigate this issue before it becomes a problem, and dynamic or time-of-use rates can motivate growth of smart versions of these electric technologies. A HEMS or otherwise smart-functioning technology will enable these new large electric loads to shift to off-peak times and can work to match electricity demand to supply. In theory, time-of-use rates should benefit consumers and reward them for their investment in HEMS and smart systems that can optimize energy use based on pricing signals. In the future, built-

Figure 13: Time Varying Rates in US from AEE



[26] https://www.navigantresearch.com/reports/navigant-research-leaderboard-residential-demand-response
[27] Capehart, B. (1982). Survey of costs and benefits of residential load management. Energy Systems Policy: 6:2, 28pp.;
[28] NEEP 2017, *Northeastern Regional Assessment of Strategic Electrification* https://neep.org/strategic-electrification-regional-assessment

in connected functionality, which may have a mild cost premium, may become a feature that is understood to pay for itself. Smart rate design could help bring together these value propositions for comprehensive smart energy homes.[29]

According to Advanced Energy Economy,[30] there were 7.95 million customers in the U.S. on some type of time-varying rate (see Figure 13) at the end of 2016. Maryland leads the nation with more than 75 percent of its residential customers participate in time-differentiated rates. In California, the leader in both residential solar and ownership rates of electric vehicles, residential TOU rates will be the default option starting in 2019. Because of the large presence of DERS on the California grid, the consumer benefit for a HEMS that can manage various loads and pair them with low rates is very significant.

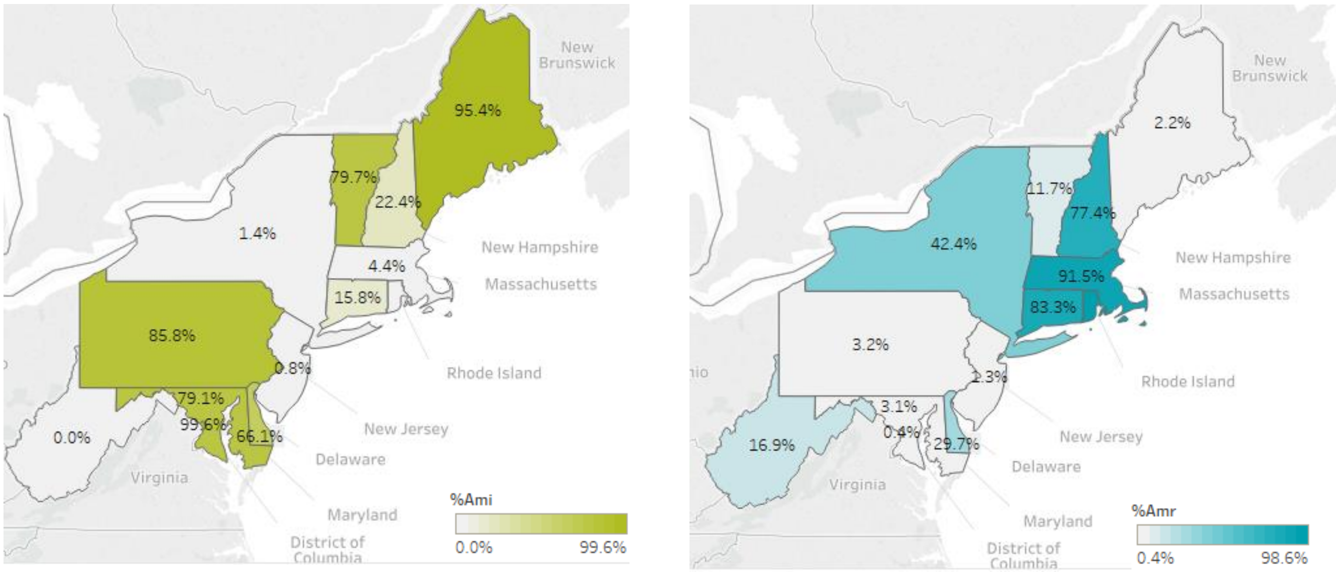
The Smart Meter

A final technological consideration that brings together smart energy homes, dynamic rates, and truly creates the motivation for a flexible residential building sector, is the smart meter. Advanced metering infrastructure (AMI) is a complex but critical consideration for smart energy homes. As depicted in A "Collective" Vision, the smart meter is an interface at the end of the home that reports back to the utility. The smart meter is necessary to show exactly when and how much energy is used in a home, and therefore charges customers accordingly based on varying prices. While there are some smart technologies, such as smart thermostats, that may have portals to communicate directly with utilities without AMI, building AMI infrastructure is ultimately necessary to enact dynamic rate structures that will help drive deeper adoption of the smart energy home. Without AMI, dynamic pricing and more widespread demand response are not possible at scale.

Within the Northeast and Mid-Atlantic, there is inconsistent penetration of smart meters. While some states and utilities elected to use one-time American Recovery and Reinvestment Act (ARRA)[31] funding to build out advanced metering infrastructure, several others did not. In those states, there is still low rates of smart meter adoption. In states that do not have AMI, most utilities have advanced meter readers (AMR), which have largely displaced the need for individual meter reading. This allows for close-range, drive-by meter reading.

[29] https://www.raponline.org/blog/timing-is-everything-how-smart-rate-design-helps-make-electrification-beneficial/
[30] https://blog.aee.net/the-state-of-advanced-metering-infrastructure-and-time-varying-rates-in-three-maps-and-one-graph.-the-leaders-and-laggards-may-surprise-you
[31] NEEP, 2017, *Advanced Metering Infrastructure - Utility Trends and Cost-Benefit Analyses in the NEEP Region* https://neep.org/advanced-metering-infrastructure-utility-trends-and-cost-benefit-analyses-neep-region

Figure 14: Comparison of Residential rate of AMI (green) and AMR (blue) in the Northeast and Mid-Atlantic, Source EIA 2017[32]



As Figure 14 depicts, several states with high rates of AMI penetration are depicted in green (Maine, Vermont, Pennsylvania, Maryland, Delaware, and DC). Of the remaining states, most at least have high rates of AMR as depicted in blue (New Hampshire, Massachusetts, Rhode Island, Connecticut). Notably, New York, New Jersey, and West Virginia have relatively low penetration (<50 percent) of either AMI or AMR.

For some of the states that have not made the investment in AMI, there remains an uphill battle to justify ratepayer expense.[33] New smart device companies, such as Copper Labs,[34] are emerging to address this issue by developing a widget that can read the data signal from an AMR meter and connect, through the customer's Wi-Fi, to a utility portal where it can send that data in real-time intervals. This essentially transforms an AMR meter into an AMI meter and may be a bridge technology to address the need for more real-time metering without building out the complete infrastructure. It is important to keep in mind that this is an after-market solution relying on Wi-Fi and may not be a good comprehensive answer to this problem.

AMI is not only necessary for billing dynamic rates but also for new utility programs such as pay-for-performance and new evaluation, measurement, and verification techniques, often referred to as M&V 2.0. While more data is not always better, in the case of dynamic rates, interval data is critical to show the change in usage. AMI seems to be the most reliable way to get there.

Location-Focused Efforts

Once AMI is in place to account for specific actions in homes at specific times, the focus will evolve to the *location* part of "time and location" efficiency. In order to have a decarbonized, improved grid, the region needs a more locational-focused approach through geographical targeting or "geo-targeting.[35]"

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[32] Images compiled from the Energy Information Agency and From EIA-861 responses, https://www.eia.gov/electricity/data/eia861/
[33] https://www.greentechmedia.com/articles/read/massachusetts-rejects-smart-meter-rollouts-as-competitive-energy-undermines
[34] https://www.copperlabs.com/
[35] More details from NEEP's 2015 report, *Energy Efficiency as a Transmission and Distribution Resource Using Geotargeting,* https://neep.org/energy-efficiency-transmission-and-distribution-resource-using-geotargeting

Optimization through smart energy homes should be beneficial to the consumer as well as to the grid. In reality, however, the grid as a whole doesn't need to be optimized from specific homes. Grid optimization achieved through smart energy homes is most useful somewhere between the home level and service territory level. In other words, at the feeder, sub-station, or neighborhood scale. While utilities have historically made their energy efficiency offerings available to everyone, there are some homes with efficiency and load-shifting abilities where the benefit is more valuable to a utility. Utilities need to account for this, potentially through changes in the cost/benefit equation or by adjusting how to recognize revenue if they are promoting behind-the-meter assets that provide grid benefits.

Technology included in smart energy homes would ideally allow for automated load shifting in response to utility signals such as price or maybe carbon. This would be done via HEMS and would include an opt-out option for customers. Homes attached to overly-stressed feeders may be primary targets for this type of comprehensive smart energy home approach, especially if customers are also low-income customers.

Real World Examples and Case Studies

In this section, we will explore several examples, both in the field and in the lab, that are showing progress towards smart energy homes of the future as referenced in the A "Collective" Vision. While comprehensive smart energy homes are still far from being realized, pieces of them are being piloted. These short case studies describe projects that are loosely organized by the origin for the case study. They offer perspectives from the smart home space, the DER space, or the strategic electrification space. That being said, all case studies are relevant and cross-cutting. While many of these examples are very new, it is promising and noteworthy to see the concepts of smart energy homes leading to residential building decarbonization currently practiced.

Real World Examples with Roots in the Smart Home

REV Pilots

As part of the Reforming the Energy Vision (REV) proceedings, New York utilities are demonstrating several cross-cutting smart home projects. Consolidated Edison (ConEd) and Orange and Rockland Utilities are piloting new "smart home" rate designs to test the impact of dynamic rates on single-family customers with central air conditioning as well as homes with rooftop solar. The pilot is limited to homes with smart meters and a participant pool of about 850 participants between the two groups.[36]

Additionally, ConEd is piloting a connected homes platform aimed at animating the DERs market by matching customer usage data and advanced analytics with vetted DER products.[37] These are in addition to two New York State Energy Research and Development Authority (NYSERDA) HEMS pilots that were field test of smart home technologies to measure their energy savings potential; one pilot was concluded in 2017 by Lockheed Martin Energy[38] and the other which was finished in in 2018 by NREL.[39] Other REV pilots of note include ConEd's Clean Virtual Power Plant, CONnectED Homes Platform, [40] Storage on Demand pilots, and National Grid's Demand Reduction Demonstration Project in Clifton Park.

Smart Thermostat Data to Drive Home Performance

Multiple efforts rooted in smart thermostat data collected are looking to use this data to better understand the performance and thermal envelope of a home. The hope is that this data could potentially be used to connect the dots between smart thermostat insights and home performance upgrades. Efficiency Vermont has developed a Smart Thermostat Analytics Toolkit (STAT)[41] that pulls in several data sources, including weather, thermostat, smart meter, and other household information, and runs an iterative analysis to, among other things, help identify homes that may be a good fit for additional Efficiency Vermont home retrofit programs.

Another effort led by the Fraunhofer Center for Sustainable Energy Systems includes working with over 600 homes to assess the feasibility of using smart thermostat data to perform a remote audit. Recent findings have

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[36] Smart Home Rate REV Demonstration Project Implementation Plan (summaries at http://www3.dps.ny.gov/W/PSCWeb.nsf/All/B2D9D834B0D307C685257F3F006FF1D9?OpenDocument)
[37] http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BD48F0B30-A8EE-4E2B-A6B9-8AEA815807E0%7D
[38] *Lockheed Martin, 2018, Home Energy Management System Savings Validation Pilot Final Report* https://www.nyserda.ny.gov/-/media/Files/Publications/Energy-Analysis/Home-Energy-Management-System-Savings-Validation-Pilot.pdf
[39] https://www.nrel.gov/news/program/2017/nrel-nyserda-conedison-partner-hems.html
[40] http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B55C8C39F-C75D-4E9E-BA92-5E02D1BE581F%7D
[41] http://www.veic.org/resource-library/smart-thermostat-analytics-toolkit

concluded that for homes with one smart thermostat, the whole-home R-value - which captures insulation level, separate insulation from air sealing opportunities-can be classified and the ACH50, which measures airflow, can be estimated.[42]

Wisconsin Energy Conservation Corporation (WECC) is leading another study in Michigan that is similarly focused on using smart thermostat data to identify homes in need of efficiency measures and to improve the targeting and marketing of energy efficiency upgrades to specific homeowners.[43]

Finally, ICF implemented a Smart Thermostat Pilot for Southern Maryland Electric Cooperative (SMECO) that ran from 2015 through 2017. ICF used its Sightline Analytics Engine to leverage thermostat and weather data to conduct “virtual audits” to identify homes with a large potential for energy savings and provide tailored recommendations on how customers could decrease energy use. The virtual audits were emailed to customers and recommendations included insulation, air sealing, HVAC tune-up, window shading, and/or thermostat setting adjustments. A survey found that 48 percent of customers self-reported some type of change as a result of the virtual audits, and an analysis showed reduced runtimes (weather normalized) between 1.1 and 23.1 percent for customers who self-reported making changes. As a result of the SMECO pilot, ICF expanded it into 2018 virtual audit programs for the four major Maryland utilities: SMECO, BGE, Pepco, and Delmarva Power.[44]

foresee, NREL

Researchers at the National Renewable Energy Lab (NREL) are working with industry stakeholders to pilot **foresee**™, a HEMS designed with goals to meet the needs of a user, to achieve energy efficiency, and to deliver grid services based on signals from the utility.[45] **foresee** is built on a predictive control framework where the model can be based on the different objectives of optimizing energy cost, thermal comfort, user preferences, and carbon emissions. **foresee** learns user preferences based on these objectives and works to operate connected elements of homes accordingly. NREL is testing the integration of home appliances, solar, and battery storage in its Golden, CO home-simulating test lab.[46] As the name implies, **foresee** seeks to use machine learning to predict the home's future energy consumption. Simulation studies of **foresee** were performed using residential field data from the Pacific Northwest, and results indicated a 7.6 percent whole-home energy savings, without requiring substantial behavioral change. In reply to a demand response signal, **foresee** was able to both provide load forecasts and deliver the committed demand response services in 90 percent of attempts. To achieve this, **foresee** deployed battery storage and shifted controllable building loads.

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[42] Zeifman et al, ACEEE Summer Study 2018 Proceedings, Residential retrofits at scale: opportunity identification, saving estimation and personalized messaging based on communicating thermostat data

[43] Goldman et al, ACEEE Summary Study 2018 Proceedings, Free X-Ray Specs—Just Send in Your Smart Thermostat Data for an Automated Peek Inside Your Home’s Envelope!

[44] Project described in http://remagazine.coop/virtual-energy-audit/ and http://conference2017.resnet.us/data/energymeetings/presentations/Smart%20Thermostats%20Building%20Science%20the%20Connected%20Home.pdf

[45] https://www.osti.gov/pages/biblio/1395097-foresee-user-centric-home-energy-management-system-energy-efficiency-demand-response

[46] In a BPA pilot using foresee, products included in the testing included Bosch appliances, ecobee thermostats, AO Smith water heater, and an Eguana battery, page 35: https://neep.org/sites/default/files/StorageEVPV.pdf

Smart Neighborhoods, Southern Company

Taking an approach beyond homes, Southern Company collaborated with Electric Power Research Institute (EPRI) and Oak Ridge National Lab to work through its Georgia Power[47] and Alabama Power[48] subsidiaries to pilot Smart Neighborhood projects.[49] The stated goals of these projects are to simplify the lives of homeowners and give them more control over their energy use. These neighborhoods, located in Atlanta and suburban Birmingham, consist of community-scale microgrids that incorporate solar, battery storage, smart appliances, energy efficient building envelopes, ASHPs, smart thermostats, voice-activated security, and other smart devices. These features are being built into new construction projects, with these two efforts taking a slightly different approach. In Birmingham, the smart neighborhood consists of mostly single-family homes with shared solar and storage resources, while in Atlanta the neighborhood consists of luxury condos with their own PV and battery storage. As of 2018, the first homes have been inhabited and the neighborhoods will remain a test bed for the integration of HEMS and DERs in new construction.

Real World Examples with Roots in Distributed Energy Resources

Residential Battery Storage Pilot, Green Mountain Power

Green Mountain Power[50], the largest electricity provider in Vermont, is working on a behind-the-meter battery storage effort by installing 2,000 Tesla Powerwalls. In this pilot, customers pay a one-time fee of $1500 (or a monthly fee of $15) to be involved. Liberty Utilities in New Hampshire is also proposing a similar pilot. These storage pilots seek to have dispatchable storage which will benefit both the utility and the customer.

Zero Energy Now, Vermont

The Zero Energy Now (ZEN) program ran as a pilot in 2016[51] and focused on deep, comprehensive home retrofits that included solar and heat pump installation. The pilot also set aside a "savings guarantee pool" of $50,000 to back a one-year savings guarantee for program participants. Through successful implementation of the program, customers saved an average of $3,700 per year with comprehensive retrofits. Notably, no customers submitted a claim for the reimbursement, leaving the entire $50,000 in tact.

Smart Cities, Columbus Ohio

The city of Columbus, Ohio won the U.S. Department of Transportation Smart Cities Challenge and associated award of $50 million to "accelerate human progress through open mobility."[52] This project seeks to drive economic growth, improve quality of life, foster sustainability, and improve safety in Columbus. This project is funded by a revolving loan that builds out comprehensive electric vehicle charging infrastructure while connecting Columbus residents to broader goals of sustainability.

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[47] https://southerncompany.mediaroom.com/2018-01-09-Georgia-Power-and-PulteGroup-partner-for-first-Smart-Neighborhood-TM-in-Atlanta

[48] https://www.smartneighbor.com/pages/neighborhood

[49] https://www.poweronline.com/doc/southern-company-subsidiaries-alabama-power-innovative-smart-neighborhood-projects-0001

[50] https://greenmountainpower.com/press/gmp-launches-new-comprehensive-energy-home-solution-tesla-lower-costs-customers/

[51] https://publicservice.vermont.gov/sites/dps/files/documents/Renewable_Energy/CEDF/Reports/Vt._Clean_Energy_Finance_Rpt_2018.pdf

[52] http://www.columbuspartnership.com/community-impact/smart-cities/

Power.House, Alectra Utilities

In 2015, Alectra Utilities started a residential solar storage pilot known as Power.House[53] to "evaluate the economic and grid benefits that residential solar storage can contribute to electricity customers and the electricity system in Ontario." Alectra Utilities is working in 10 homes to incorporate HEMS devices alongside solar panels and battery storage to help manage load on the basis of real-time carbon emissions. A feasibility study[54] of Power.House found that the program could be expanded to 30,000 homes in 2018.

Canadian Government Electric Vehicles Efforts

New approaches are being considered for how to use electric vehicles for grid services. While mostly marketed as replacements for gasoline-powered cars, EVs have the potential to become grid and building assets right out of the lot. The Canadian government is investing in EV research, and is currently funding five projects focused on EV integration through the Smart Grid Fund.[55] These projects range from peer-to-peer charging networks and testing of load shaping with dynamic price signals. A project by FleetCarma, a clean tech firm based in Waterloo, tested the amount of charge EV owners needed in the morning, but allowed a local distribution company (LDC) to control charging to minimize the impact on its network while also guaranteeing the morning charge requirement of customers. Burlington and Oakville Hydro are testing how to do this same thing by offering smart chargers at a reduced cost in exchange for some control of the charging activity.[56]

Newmotion, Vehicle-to-Grid

Newmotion, a British subsidiary of Shell, is piloting vehicle-to-grid (V2G) technology through a partnership with Mitsubishi Motors, grid operator TenneT, Enel, and Nuvve.[57] The goal of this pilot is to test the viability of discharging electric vehicles to balance the electric grid and explore consumer applications and potential benefits. V2G technology uses bi-directional charging stations that both charge and discharge EV batteries. The Mitsubishi Outlander PHEV battery has been built with V2G capabilities and is being used for grid balancing within the Netherlands. The focused use-case for V2G is to charge EVs during midday when solar output is abundant, and balancing the evening peak challenges.

Nissan Energy Solar

Another effort rooted in EVs is Nissan's recently-launched integrated home energy solution, Nissan Energy Solar.[58] This offering, available within the UK, includes a solar setup of six panels and an optional 'xStorageHome' battery storage. The setup is designed to integrate with Nissan's electric vehicle lines and is an early commercial offering of this sort.

SunShot program, Austin Energy

Austin Energy in Texas is working through the U.S. DOE's SunShot program to study how to best manage costs and load shifting with a high penetration of distributed solar. Austin Energy is creating a distributed energy

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[53] https://www.powerstream.ca/innovation/power-house.html
[54] https://www.powerstream.ca/attachments/POWER_HOUSE_Feasibility_Study.pdf
[55] https://www.ontario.ca/document/projects-funded-smart-grid-fund/electric-vehicle-integration#section-0
[56] https://www.ontario.ca/document/2017-long-term-energy-plan/chapter-3-innovating-meet-future
[57] https://newmotion.com/en_GB/drive-electric/the-future-of-ev-charging-with-v2g-technology
[58] https://www.carscoops.com/2018/01/nissan-follows-tesla-solar-panels-battery-storage/

resources management (DERM) platform to maintain grid reliability while enabling load delivery at the lowest possible cost when solar output is high. The company is working to deliver distributed storage, smart solar inverters, a DERMS, and other enabling technologies.[59] In addition to the technological outputs of a DERMS platform and the results of its study, Austin Energy is looking into new business models to capitalize on the low cost of energy during high solar output times. This is a three-year project which kicked off in 2016.

Real World Examples with Roots in Strategic Electrification

eSmartWaterProgram, Green Mountain Power

Green Mountain Power in Vermont established an eSmartWater Program[60] which, for $.99/month will provide customers with an Aquanta hot water heater controller and a Nest smart thermostat. This is a forward-looking program model to achieve residential energy savings through deployment of smart technologies on existing home end uses of HVAC and water heating. Behind the scenes, there is coordination between the Nest and the Aquanta to optimize energy savings.

Air Source Heat Pump Integration with Smart Thermostats

As the penetration of ASHPs grows, so too do their features and partners. Mitsubishi, for example, has developed the kumo cloud application for several models and remotely controls ASHPs from a mobile app.[61] Another study on the potential contributions of ASHPs for demand response found that controlled ASHPs that adjusted to price signals were largely effective at responding to the signals and maintaining comfort in the home.[62]

Heat Pump Water Heater Controls Studies

HPWH controls are being studied for their potential to shift load and help with both large scale demand response and "teaching the duck to fly." As it relates to flattening the duck curve, analysis by National Resources Defense Council (NRDC)[63] found that HPWH demand flexibility had a great amount of potential, shifting on-peak coincident energy use from 15 percent to only one percent. The report encouraged manufacturers to continue investment in HPWH technology, including connected and load management capabilities. Findings from research led by Pacific Northwest National Labs (PNNL)[64] found that HPWHs could cover about 62 percent of energy shifting capabilities that an electric resistance tank could have. As these products use much less energy at all times, they have great potential for both load reduction and load shifting.

Electrifying Boulder, Boulder Colorado

Boulder, Colorado is one of four city pilots with electrification efforts. The "Electrifying Boulder" initiative to transform the city is set out in several stages.[65] The first target includes looking at residential applications for

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59 https://www.energy.gov/sites/prod/files/2016/06/f32/SHINES_TKM_Austin_Energy.pdf
60 https://greenmountainpower.com/product/esmartwater/
61 One example is https://www.mitsubishicomfort.com/press/press-releases/new-residential-app-from-mitsubishi-electric-controls-operational-efficiency-of-cooling-heating-wireless-control
62 https://sciencetrends.com/contributions-of-heat-pumps-to-demand-response-a-case-study-of-a-plus-energy-dwelling/
63 http://aceee.org/files/proceedings/2018/node_modules/pdfjs-dist-viewer-min/build/minified/web/viewer.html?file=../../../../assets/attachments/0194_0286_000088.pdf#search=%22delforge%20vukovich%22
64 http://aceee.org/files/proceedings/2018/node_modules/pdfjs-dist-viewer-min/build/minified/web/viewer.html?file=../../../../assets/attachments/0194_0286_000318.pdf#search=%22portland%20general%20electric%22
65 https://sustainablebuildingsandcommunities.weebly.com/boulder-electrification-plan.html

ASHPs and HPWHs and providing incentives for electric vehicles. The city is taking a comprehensive approach to electrification and including its citizens in the process. Boulder has hosted several stakeholder discussions to understand the needs of residents and to determine how best to meet both citizen needs and city-wide carbon reductions goals.

Barriers and Opportunities Analysis

While the previous section explored some elements of the broader smart energy home vision, they are pilots and small-scale examples. Transforming the smart energy home market and moving from pilots to the mainstream to decarbonized is still a challenge. In this section we identify the key barriers and opportunities to broader adoption of smart energy homes, DERs, associated technologies and strategic electrification. In some cases, the barriers or opportunities are shared across all three areas of focus, as is shown in Figure 15 and Figure 16. By grouping together the barriers and opportunities between smart energy homes, DERs, associated technologies and broader strategic electrification and decarbonization, a roadmap begins to emerge on the first order priorities. These serve as the foundation for our analysis of short- and long-term strategies for successful transformation to the A “Collective” Vision.

Figure 15: Venn Diagram of Common Barriers

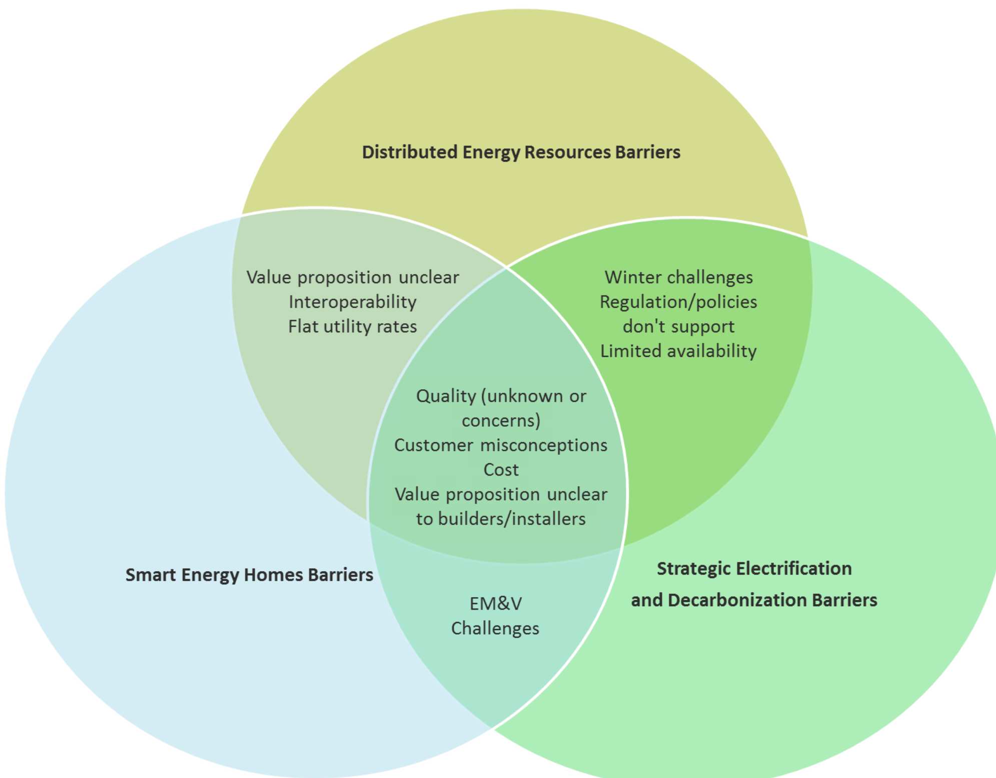
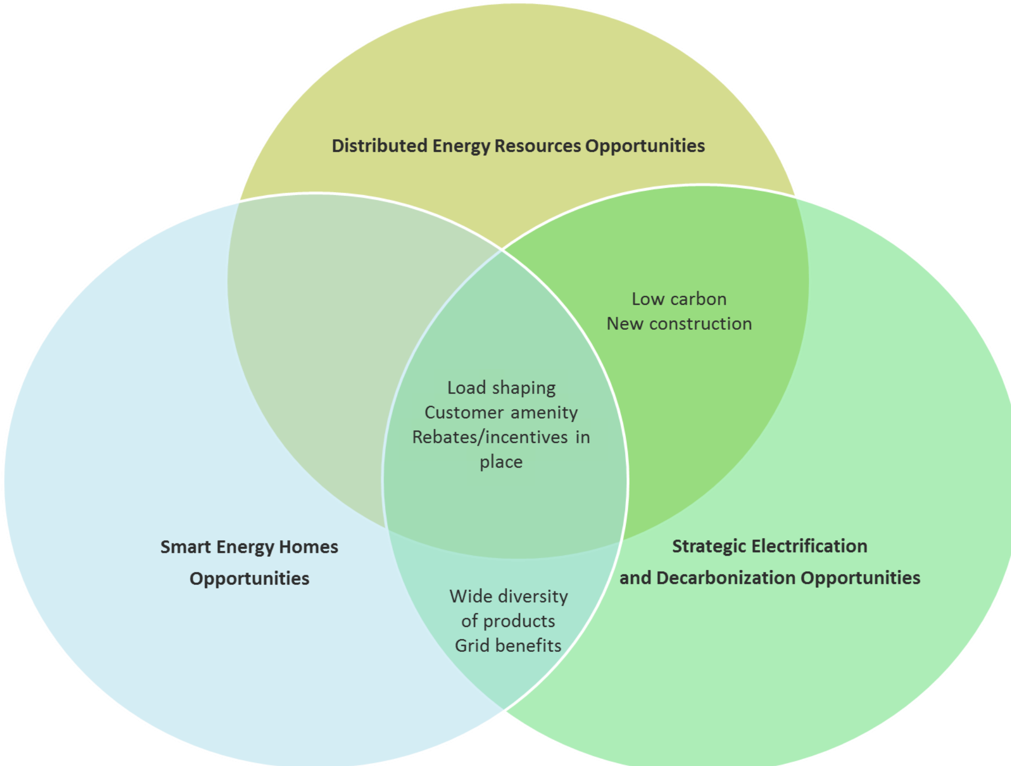


Figure 16: Venn Diagram of Common Opportunities



Barriers and Opportunities: Smart Energy Homes

Smart Energy Homes		
	Barriers	**Opportunities**
Policy and Program	• Flat utility rates • EM&V challenges for program administrator, as there may not be a baseline, variable energy savings, hard to justifying ratepayer investment • Security concerns: cyber, data, and personal	• Some program rebates already in place, with potential for further incentives • High quality data from smart home technologies with potential for more granular program EM&V and better program design • Some TOU rates already in place with an opportunity to structure rates to allow HEMS to provide more value • Potential significant cost reduction of residential DR/load management • Load shifting potential of smart products to optimize based on various signals, including price, demand, and carbon

Technology and Best Practices	• Unknown, untested, unregulated product quality often based on manufacturer claims, especially for products for which there is not an ENERGY STAR label • Lack of understanding and unclear value proposition for builders and system installers • Lack of field pilots demonstrating value of whole-home HEMS controller • Perceived and real installation, compatibility, and interoperability challenges • Lack of standardized, common data-sharing formats	• Some products have home-security benefits • Technologies have potential to generate granular data for a variety of uses (occurring now for smart thermostats) • ENERGY STAR involvement in broader smart energy home market • Wide diversity of products currently available
Consumer and Markets	• Disconnect between customer benefits (safety, convenience, money savings), utility benefits (load shifting, rate benefits), and broader decarbonization benefits • Unclear customer value proposition • Preconceived customer notions of the smart home being fully automated and comprehensive (lack of understanding that today's "smart homes" typically contain several stand-alone smart devices) • Market confusion on best product for the application (too many smart home devices, but too few whole home solutions) • Many products are expensive, considered luxury, and have high first cost	• Attractive comfort and convenience features • Opportunity to educate and engage customers about energy use and other issues (such as retrofits) through technology • Technology is easy to use for customers ("set it and forget it") • Market momentum as many customers are voluntarily buying smart home products

Barriers and Opportunities: Distributed Energy Resources

Distributed Energy Resources		
	Barriers	**Opportunities**
Policy and Program	• Lack of systemic EV charging (infrastructure and consistency between systems) • Flat utility rates • Lack of policies that value and encourage distributed generation	• Federal and some state tax incentives • DERs can help shift and shape load for better grid management • DERs are low-carbon solutions
Technology and Best Practices	• Lack of wide availability of storage systems • Unknown product quality (storage, PV) • Lack of understanding and unclear value proposition for builders and system installers • DERs are often not integrated with each other or other parts of the home	• Storage, EV, and PV can be built into new construction
Consumer and Markets	• High cost for solar, batteries, and many EVs, especially without subsidies • Preconceived notions about expense and quality of solar, EVs, and storage,	• Significantly decreased cost of solar • Value proposition for EVs is improving (better range, lower costs, more options) • Storage can provide backup power with great benefits (convenience in a small outage, critical

	especially as the value propositions are improving year over year • Most Northeast homes heated by gas or fuel oil aren't helped by electricity generation and storage in winter • Unclear value proposition for battery storage (primarily beneficial when coupled with grid considerations)	resilience in a larger outage, potential for financial benefit from load shifting under new rate designs) • Peer pressure drives investment, especially PV and EV. • Leasing options for EV reduces risk

Barriers and Opportunities: Strategic Electrification and Decarbonization

Strategic Electrification and Decarbonization		
	Barriers	**Opportunities**
Policy and Program	• EM&V challenges (baseline, time and location granular data, justifying ratepayer investment) • Regulatory challenges (lack of promotion around strategic electrification) • Potential to strain the distribution grid • Fuel switching is an explicit challenge for many utility/state programs (can only claim credit for the energy savings of electric to electric (CT, NH) • Lack of state and local policies • No step-by-step guide for implementation • Potential to shift peaks to winter	• Attractive technology for utilities (combination of EE and grid services benefits) • Utility rebates, especially for ASHP and HPWH (loans and incentives can go further) • Opportunity to change rate structure to encourage SE, including taking cost of carbon into consideration • Opportunity to replace oil and propane fueled end uses in the short term (longer term move towards conversion of gas boilers) • Opportunity for ASHP to shape electric load through pre-cooling and pre-heating, especially using variable capacities to maintain comfort in homes with tight envelopes. • The adoption of broad decarbonization goals by many Northeast and Mid-Atlantic states (converging around 40% carbon reductions by 2030 and 80% reductions by 2050)[66]
Technology and Best Practices	• ASHP quality concerns based on legacy system poor performance in cold temperature and issues with test procedure and systems not performing as expected • Leaky homes in the region likely means larger ASHPs necessary to meet load (need	• Rapid improvement and diversification of available HPWHs and ASHPs • Easier adoption of systems when part of new construction • Improvement to provide effective/efficient zonal heating through ductless ASHPs • A quality product list for cold climate ASHPs (maintained by NEEP)

[66] SE report

	deeper envelope efficiency for right-sized and right-priced units) • Improved performance and tighter homes necessary for improved ASHP performance and cost-effectiveness • Lack of understanding of appropriate applications from builders and installers • Limited product availability • Unengaged installer base, especially around HPWHs	
Consumer and Markets	• High cost for new heat pump installation (economies of scale not yet reached) • Not cost competitive with natural gas for space and water heating • Lack of knowledge and preconceived notions about heat pumps (don't work in winter, are loud, are expensive to operate) • Preconceived notions about electricity (it is coal generated, expensive, and no cleaner than other fuel sources) • Lack of understanding on actual grid mix.[67] • Customer preference (aesthetics, operation, spacing, noise) • Improper operation of ASHPs • Low awareness	• Rise in customer demand for air conditioning driving ASHP adoption • Compelling rebates for ASHP and HPWH

[67] For example, according to the ISO-New England's electricity production mix, https://www.iso-ne.com/about/key-stats/resource-mix/, Oil and Coal have shrunk from a combined 40% of the production mix in 2000 to just 2.7% of the mix in 2017. An out-of-date understanding of the grid can mean decisions are misguided.

Recommendations, Strategies, and Next Steps

Our analysis of the state of the market, pilots and other exploratory activities, A "Collective" Vision of the future, and the barriers and opportunities identified to get there, found several key areas of focus for regional efforts to use smart energy homes as a driver for residential decarbonization. Each focus includes big changes we seek and near-term actions to help get there. When possible, we identify who would lead or be most critical to advance specific efforts.

Key

All stakeholders | Regulators | Utility / Program administrators | Evaluators | Industry / Technology providers | Government | Consumer advocates

Area of Focus #1: Policy and Carbon

In order for a decarbonized residential building stock to be fully appreciated, incentivized, and realized, public policies must evolve to recognize and value carbon reductions as a critical consideration and motivator for decision making.

Short-term Actions

Address Fuel-Switching

- Focus on electrification of space and water heating. Some state plans (i.e. Connecticut) have made an official policy on fuel switching; other states can follow by encouraging low-carbon electricity.[68]
- Strategic electrification through fuel switching as a concrete

Build Grassroots Support for Carbon Reduction

- Make information about the impacts and emissions of carbon more and more readily available.[70]
- Enable carbon-based actions on a voluntary basis, based on

Pathways to the Future

- Move forward to prove the concept of carbon-based decision making.
- Leverage carbon taxes as an important tool to ensure that the real value of carbon is appreciated.[72]

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[68] http://www.synapse-energy.com/sites/default/files/New-Englands-Shrinking-Need-for-Natural-Gas-16-109.pdf
[70] Rocky Mountain Institute's WattTime subsidiary, for example, has created a business turning the marginal emissions data into usable, actionable information. http://watttime.org/
[72] https://neep.org/blog/put-price-it

policy and direct solution to address carbon, especially in areas with lower-carbon electricity generation. [69]

- Target homes based on likelihood of success, cost effectiveness, and carbon. Fuel oil and propane heated homes first, followed by those looking to add central AC. Include low-income housing where fuel-switching is coupled with comprehensive weatherization.
- Target, in the short term, residential new construction as all-electric homes.

transparency and actionability of carbon information.

- Grow capacity of smart device manufacturers to build algorithms set to optimize systems behaviors based on carbon signals, much the same way they would for pricing signals when available.[71]
- Provide tools to consumers and industry that allow for more active prioritization of carbon decisions based on more readily available data instead of policy changes.

Area of Focus #2: Utility Regulatory Structure

Future utility programs will take into account carbon reductions, promote lower-carbon strategic electrification activities, have dynamic pricing, and serve as a "one-stop-shop" for smart energy homes and their associated components.

Short term-Actions

Incorporate Smart Home and Decarb Measures into Programs

- Develop new metrics for clean energy programs (including energy efficiency, demand management, electrification, energy storage, and renewable energy) that include the value of carbon reduction, other environmental benefits, economic impacts,

Regulatory Shift Towards Carbon

- Update cost-effectiveness testing to encourage growth of smart energy homes. [75]
- Create regulatory frameworks that encourage utilities to develop and pilot more innovative

[69] While the US as a whole has 63% of generation still from fossil fuels (32% natural gas, 30% coal), the Northeast and Mid-Atlantic grids operated by PJM (32% coal, 32% natural gas, 30% nuclear, 4% hydro, 1% other renewables), NYISO (39% natural gas/dual fuels, 33% nuclear, 3% wind, 23% hydro, 2% other renewables) and ISO-NE (48% natural gas, 2% coal/oil, 31% nuclear, 11% renewables, 8% hydro) trends average or below average in terms of carbon intensive fuel sources.

[71] Ecobee has begun to build transparency here through publishing of carbon-rooted charts

[75] Case Study example of Rhode Island using the National Standards Practice Manual to account for DERs in their updated cost-effectiveness screen: https://nationalefficiencyscreening.org/wp-content/uploads/2018/12/Rhode-Island_NSPM_Case-Study-12-3-18.pdf

and benefits to the grid. Determination of cost-effectiveness to guide program efforts, especially program administrator efforts, has been limited by narrowly-defined economic alternatives.[73]

- Bring in carbon reduction (not just kW/kWh) as a trackable metric to set the foundation for future carbon-based goals and the ability to manage what is measured.[74]
- Combine smart energy homes promotions with strategic electrification and load growth conversations, highlighting HEMS as provider of residential load flexibility. Incorporate appropriate role for good load growth through EVs and storage. Conversations may evolve to determine continued support of gas equipment, if those incentives are shown to impede strategic electrification.
- Continue to conduct pilots and testing of smart energy home technology integration.
- Focus on residential new construction for shaping future homes and consider efforts such as code-readiness programs. Accelerate early adoption of codes to pave the way for potential mandatory standards for new and existing building standards.

programs to meet energy efficiency ***and*** carbon goals.

- Build on existing efforts, such as those through Regulatory Assistance Project (RAP), looking at "emissions efficiency,"[76] potentially over the lifetime of a product. While an end use might not save emissions at the time of installation, it may save emissions over its lifetime as the grid continues to decarbonize.
- Begin conversations to build regulatory support for geo-targeting efforts and explore ways it can be coupled with other utility objectives such as serving low-income customers. Provide focused incentives for storage and other smart energy home elements to avoid location-specific distribution upgrades. Develop location-based value models that can be used to target and/or compensate customers that adopt needed technology in particular areas.
- Determine appropriate ways for utilities to capture revenue from new initiatives.[77]
- Develop metrics that take emissions into account and can be useful for policymakers.

Grow Existing Program Support for Lower-carbon Technologies

- Build up and promote base of installed smart products,[78]

Use Existing AMI Data (i.e. Dynamic Pricing) and Advance Penetration of AMI Overall

- Demonstrate the need and benefits for dynamic pricing in

Adjust Planning and EM&V Efforts

- Better integrate EM&V planning and forecasting with

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[73] NEEP 2018 Strategic Electrification Action Plan, strategy 1

[74] More details in Looking Towards Future Integration of Energy Efficiency, Clean Energy, and Strategic Electrification, NEEP 2018, available from 2018 ACEEE Summer Study Proceedings

[76] https://www.sciencedirect.com/science/article/pii/S1040619016301075

[77] Existing Utility business models are based on capitalizing large assets, and this doesn't work for encouraging behind the meter assets that could help manage grid needs.

[78] NEEP 2016 *The Smart Energy Home: Strategies to Transform the Region*, strategies 2 (All stakeholders work to smarten water heating), 3 (Adjust savings expectations for smart thermostats, then put into permanent programs), and 4 (Smart appliances, water heaters, and lighting should be promoted in existing products programs)

including smart DERs such as storage and EVs. Start with ENERGY STAR certified smart products including EVSEs.

- Grow already-existing programs for ASHPs and HPWHs. Focus on fuel switching policies and creative program design such as mid- and up-stream interventions.[79]
- Bolster efforts towards offering a comprehensive customer-facing strategy for building a "one-stop shop" towards the smart home, with HEMS, strategically electric technologies, and eventually DERs.
- This includes developing customer-facing electrification education, awareness, and marketing.

order to build the case for AMI in states without it.

- Make a compelling base to support the need for AMI and dynamic pricing by documenting efforts like **foresee**.
- Shift towards dynamic rates through variable or time-of use pricing, expanded demand response, and strategic load shifting to optimize low-carbon generation.
- Increase access to utility data through efforts such as Green Button Connect to increase transparency and ownership of energy use.
- Continue to invest in modernization of the distribution network to enable two-way communication and two-way flows of energy.
- Pursue smart rate design.[80]

transmission and distribution (T&D) planning. Consider smart energy homes as non-wires alternatives to T&D upgrades.

- Shift away from Technical Reference Manuals (TRMs) towards a pay-for-performance approach to claim savings.[81] At present, TRMs are not reflective of consumption realities at a given time and location. Pay-for-performance models provide more reliability and confirmation of the right type of savings from energy efficiency and smart energy homes with load shifting.
- Pull device-level data into M&V 2.0 applications to confirm energy savings and inform program implementation, design, and planning.
- Pilot use of smart homes data for M&V and fault detection purposes

79 https://aceee.org/files/proceedings/2016/data/papers/7_888.pdf
80 https://www.raponline.org/blog/timing-is-everything-how-smart-rate-design-helps-make-electrification-beneficial/
81 Details on Pay-for-Performance activities in the Northeast here: https://neep.org/events/pay-performance-primer

Area of Focus #3: Smart Energy Homes Drive Smart Home Performance

As the grid decarbonizes and strategic electrification efforts increase, peak events are likely to move towards the winter; tight, low-load homes are critical to the success of strategic electrification and broader residential decarbonization. Low home electric loads will be reinforced by smart energy home efforts that increase the performance of existing homes.[82]

Short-term Actions

Bundle and Improve Smart Energy Home Offerings

- Better integrate existing home performance practices and existing smart home offerings, such as smart thermostats offered with weatherization efforts.
- Add approvals for some measures, such as ASHPs, that are contingent upon some level of home performance.
- Bolster the rate of home performance upgrades through combination of home performance efforts and other more cost-effective measures.

Push Home Performance Through Smart Technology

- Leverage HEMS and smart technologies that use customer engagement tools to encourage home performance upgrades and help recruit potential customers.
- Bring additional efficiency, such as demonstrating the ability for smart products to help assess the thermal performance of the home, into offerings.
- Promote existing efficiency information and remind customers of their energy scores through smart home technology.[83]
- Provide additional education and training to empower home performance contractors to serve as ambassadors for smart energy homes.[84]

Raise Awareness of and Promote Smart Home Performance Across all Customers

- Bring value to home performance through supporting efforts such as home energy labeling, building energy standards, and real estate transparency in home performance[85] for existing buildings.
- Increase integration between smart home offerings and smart home performance.[86]
- Support home energy rating through smart technologies to help consumers understand the efficiency and carbon profile of a home.

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82 Home Performance Coalition 2018, *Redefining Home Performance in the 21st Century* http://www.homeperformance.org/sites/default/files/HPC_Smart-Home-Report_201810.pdf
83 NEEP 2017, *The Smart Home Interface* https://neep.org/smart-home-interface-brief
84 NEEP 2017, *The Contractors Guide to the Smart Home* https://neep.org/contractors-guide-smart-home
85 One such effort is the Home Energy Labeling and Information eXchange (HELIX) https://neep.org/initiatives/energy-efficient-buildings/green-real-estate-resources/helix
86 NEEP 2017, *The Smart Energy Home and Cross-Promotion* https://neep.org/smart-energy-home-cross-promotional-opportunities

Area of Focus #4: Quality Assurance and Transparency in Technology

Products installed in smart energy homes of the future are high quality, easy to find, and work well together to enable a low-carbon residential sector.

Short-term Actions

Expand Qualified Products

- Design specification around residential storage, either ENERGY STAR or other entity.
- ENERGY STAR continues to update and integrate connected criteria into specifications, especially those attached to major loads in the home such as water heating. Keep an eye towards greater appeal to market actors.
- Public entity work to develop clear voluntary smart home security standards that vendors can meet in order to be eligible for utility DSM or electrification programs. Look to the Canadian Standards Association (CSA) who is working on such an effort which may be transferable to the U.S.
- Promote open protocols that allow interoperability between products from different manufacturers and yield broader customer choice.
- NEEP work to promote smart functionality in the ASHP specification.

Improve Interoperability Between Products

- Product manufacturers begin to test and label their "works with" capability, especially integration between DERs, HEMS, ASHPs, and HPWHs.
- Offer consumer transparency on cybersecurity of smart devices through ratings or certifications.
- Manufacturers and service providers certify all smart products to ENERGY STAR when possible.
- Collaboratively work to create data-sharing specifications and standardized data formats. Look to HPXML as an analogous effort in home performance
- Develop legal protections for customers and utilities in the case of data breaches or hacking. Potentially push for new laws such as the European General Data Protection Regulation (GDRP).
- HEMS/ASHPs manufacturers bring control solutions that optimize operation between ductless systems and existing heating systems to market.

Increase Information Transparency and Awareness

- Bring visibility to information on daily grid mixes.
- Utilities and public entities work to share and spread available information on all smart energy home elements, such as EnergySage for solar information.

Area of Focus #5: Focus on the Locational Value of Smart Energy Homes and Energy Efficiency

A modernized grid that can take into account a range of grid constraints when sending and receiving demand signals, particularly around location and geo-targeting of savings.

Short-term Actions

Expand Upon Existing, While Keeping Grid Modernization in Sight

- For utilities who already have geo-targeting[87] and non-wires alternative programs,[88] look for opportunities to expand these efforts, especially in areas with grid constraints.
- Look into new pilots that take into account locational constraints, needs, and objectives.
- Localize existing demand response efforts to provide more value where peak reduction is needed (and less where it is not needed), including offering DR incentives based on the location of savings.
- Analyze economic benefits from home performance efforts in target locations to improve cost-effectiveness of work.

Support Development of Geo-targeting Programs

- Work to identity “pre-approved constraints” for customers fit into a smart home rate program, such as “have car fully charged by X time” or “temperature cannot rise above Y degrees for Z hours” that allow the multiple devices in the same sub-level to optimize together.
- Integrate the range of smart home, DER, and strategic electrification technologies into same platform.
- Map grid weaknesses, anticipated load changes, and pair with smart energy home promotions. Include an assessment of “candidate” targets with expected load-changing trends.[89]

Ensure Equity in Locational Efforts

- Ensure there is equity across location-based promotions, perhaps driven by consumer advocates.
- Improve existing low-income targeted efficiency efforts for more comprehensive consumer and grid benefits through thoughtful planning.

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[87] NEEP: https://neep.org/blog/look-inside-region%E2%80%99s-latest-non-wires-alternative-projects-and-policies

[88] Several case studies explored in E4theFuture’s 2018 resource, *Non-Wires Alternatives Case Studies from Leading US Projects* https://e4thefuture.org/wp-content/uploads/2018/11/2018-Non-Wires-Alternatives-Report_FINAL.pdf

[89] One example could be low-income homes with a stressed feeder. Another could be clustered homes where there is EV and PV from neighbor-to-neighbor peer pressure creating a potential distribution challenge.

Area of Focus #6: New Construction and Smart Energy Home Integration with Building Codes

New buildings are built to meet the future vision of flexible, low-load, electric homes.

Short-term Actions

Evolve New Construction Programs

- Shift focus of residential new construction programs to promote electric homes that are DER-ready with installed HPWHs and ASHPs.
- Program administrators align incentives around promotion of low-carbon options, potentially couching efforts as "code readiness."

Embrace the Smart Energy Home in Residential Labeling/Code Efforts

- Award HERS points for HEMS that have been shown to be effective
- Open line of dialogue between home raters such as HERS, zero energy efforts, and smart energy homes.
- Engage builders on this effort.
- Pursue stretch codes that would be better aligned with the vision of smart energy homes.

Enable Success Through Codes and Building Energy Standards

- Establish "HEMS-Ready" or "DER-ready" electric homes, similar to how California is using its zero energy codes efforts.
- Pick low-hanging fruit: include 240V in an EV garage, make homes solar-ready, put in enough electrical infrastructure for the house to be all-electric, even if the grid is not yet fully renewable.

Conclusion

Smart energy homes sit at the center of residential building decarbonization success. Through dedicated focus and collaboration, smart energy homes as an integral strategy to building decarbonization will become a reality. These homes will assist the region in achieving carbon reductions goals, push the market transformation curve along, and reach 50 percent penetration by 2030.

An evolution in efficiency program structure and changes in policies will go a long way towards helping the markets grow, but it is also incumbent on customers and industry players to create interconnection between smart technology and other residential products such as electric vehicles, solar, battery storage, ASHPs, and HPWHs. Home energy management systems (HEMS) that are tested today are showing potential to manage a home full of smart end uses and pairing with a grid full of renewable energy. Those commercially-available products must integrate further to achieve this reality.

For many elements of thisA “Collective” Vision, markets are in the beginning stages and may have prohibitive costs for many customers. As markets evolve and grow, however, economies of scale will bring technologies to the mass market. Utilities, state, and others investing in these technologies must keep a long-term perspective to ensure that market animation efforts and program spending are appropriately benefiting all stakeholders. Dynamic pricing and additional focus on location-specific efforts will help ensure more equitable growth of these markets. Several smart technology markets are healthy and thriving today, but there is need to expand their functionality and interoperability with distributed energy resources (DERs) and strategically-electric technologies to ensure we reach our residential decarbonization goal. Ultimately, decarbonization of our building stock is necessary to benefit all, but will especially benefit those without the means to adapt to climate change.

Through continued coordination and collaboration of the HEMS working group and broader educational efforts, NEEP is committed to helping evolve this space and work towards the bigger end goal. NEEP’s ASHP initiative is expanding to incorporate smart controls. Smart technologies along with a home energy management system as a hub to direct traffic in the “home of the future” will be critical to transforming the residential sector and decarbonizing homes through the region. As we collectively work through the barriers and begin to leverage the opportunities for growth of DER, smart technology, and strategically-electrified major end uses, the near-term steps identified in Recommendations, Strategies, and Next Steps should pave the way towards the ultimate smart energy home end goal. Smart energy homes will drive residential building decarbonization.

Appendix A: Smart Energy Home Market Characterization Details

Smart Device Characterization

The two smart energy home devices with the biggest adoption thus far are smart thermostats and smart speakers. Utility smart meters have a significant share of the meter market as well, but they are not a consumer product and were addressed in the State of Related Policies in the Market section.

Smart thermostats have gained popularity with sleek hardware, easy-to-use apps, and relatively easy installation. They are typically installed to control traditional heating and cooling technology and turn a legacy non-connected large end-use into a controllable load, putting that equipment on the path towards enabling residential decarbonization.

Smart speakers or other voice-based devices are controlled via spoken commands and connect, typically via home Wi-Fi network, to the internet and potentially any other smart devices within a home. These products have gained significant popularity in a short timeframe and have largely created their own markets. Through their mass adoption, smart speakers have greatly increased the number of homes with an installed smart device, creating a potential platform for HEMS.

Figure 17: Smart Speaker and Smart Thermostat projected market adoption, Data compiled through E Source Surveys and projections from Voicebot AI and Parks Associates

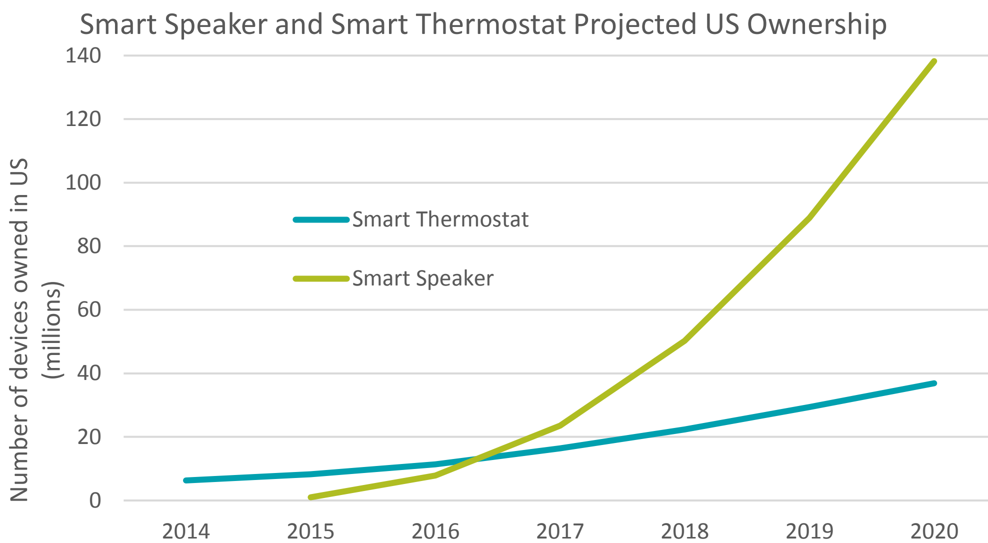


Figure 17 demonstrates the historic and projected growth of smart speakers and smart thermostats through 2020. With approximately 126 million household in the US, the ownership rates of both smart speakers and smart thermostats are expected to be significant. The projections for smart speaker ownership anticipate the technology to be almost ubiquitous by 2020. Smart thermostats, however, are expected to be popular but not quite as common.[90] One consideration with this market is households who own more than one device—these homes are not separated out in Figure 17—and market research project about 19 percent of smart speaker owners own two of them, about eight percent own three devices, and another seven percent own four or more.[91]

[90] Data compiled and assembled through E Source Surveys, projections from Voicebot AI (https://voicebot.ai/2017/04/14/gartner-predicts-75-us-households-will-smart-speakers-2020/), and Parks Associates https://www.parksassociates.com
[91] Data from Voicebot.ai, collected from Tech Crunch article, https://techcrunch.com/2018/03/07/47-3-million-u-s-adults-have-access-to-a-smart-speaker-report-says/.

Other Developments in the Smart Home Space

There are several efforts currently tracking the smart home market with an eye towards energy, including the NEEP-facilitated HEMS working group[92] and the Home Performance Coalition (HPC) since 2014.

Another entity working in the smart home space is the U.S. Environmental Protection Agency's (EPA) ENERGY STAR program. Introduced in 1992, ENERGY STAR is a voluntary program that certifies high-efficiency products in the marketplace to help customer support of energy efficiency. ENERGY STAR has included an optional "connected" criteria for some of its product categories for several years, but the number of ENERGY STAR products certifying as connected has grown slowly.[93] Most product categories have 0.5-4 percent of their products certify as "connected," with some categories such—as pool pumps—still without a single connected product. The Electric Vehicle Supply Equipment (EVSE) is one outlier with nearly 40 percent of certified products being connected. This is promising, given the significant opportunity for EV charging to be controlled through a HEMS.

Table 1: ENERGY STAR Connected Products Growth

Product Category	# connected models May 2017	# connected models October 2017	# connected models November 2018	% connected models November 2018
Clothes Dryers	3	2	9	3.7%
Clothes Washers	0	3	3	1.6%
Dishwashers	0	0	5	0.7%
Electric Vehicle Supply Equipment	3	6	7	29%
Freezers	4	5	6	2.5%
Light bulbs	7	13	35	0.4%
Light Fixtures	180	190	203	1.2%
Refrigerator	44	49	74	3.4%
Room Air Conditioners	7	7	11	1.9%

In addition to the optional connected criteria for a range of products, ENERGY STAR developed a smart thermostat specification, incorporating a field-data based metric to address their performance.[94] Connectivity is a mandatory requirement for this specification, which has 36 models certifying to it as of November 2018. Finally, in 2018 ENERGY STAR embarked on a new effort to develop a program for smart home energy

[92] This is a quarterly convening utilities, government, industry, researchers, states, non-profits, and others focused on advancing the HEMS space with energy efficiency and decarbonization and a key consideration.
[93] Data pulled from analysis of ENERGY STAR Qualified Products list in May 2017, October 2017, and November 2018, https://www.energystar.gov/products
[94] https://www.energystar.gov/products/heating_cooling/smart_thermostats

management systems (SHEMS),[95] looking to certify a bundle of smart home products that would be installed by home security and service providers, many of whom already have smart home offerings. This is an ambitious effort to work with a channel of the smart home market that has largely gone unchecked.[96] As part of the SHEMS process, ENERGY STAR and partners have convened working groups focused on specific areas of interest, including DER and demand response.

[95] https://www.energystar.gov/shems

[96] In NEEP 2016 (Ibid) Strategy 5 recommended that stakeholders seriously engage with service providers in the IoT space, especially home security

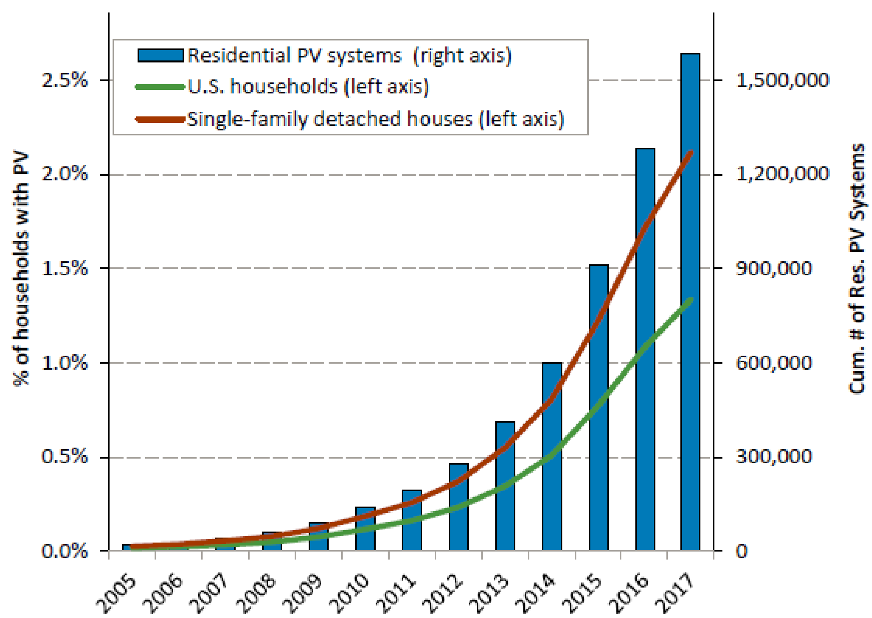
Appendix B: Distributed Energy Resources Market Characterization Details

Currently, most residential DERs are adopted for customer amenity or preference as individual investments and not as part of a comprehensive smart home effort. As their penetration grows, however, the collective distributed resources will become more powerful and important grid assets; DER integration with HEMS can ensure that DERs deliver full value as grid assets, not liabilities. For example, a HEMS could, in theory, forecast the expected solar PV production based on weather conditions and determine when to use that energy, store it, or sell it back to the grid. Similarly, a HEMS could determine the best charging behavior between different DERS such as battery storage systems, HPWHs, and electric vehicles to optimize their use.

Residential Solar Market

In the residential solar market, prices have fallen drastically over the past several decades and continue to fall, even as much as seven percent from 2016 to 2017.[97] Meanwhile, the number of homes with residential PV continues to grow near exponentially, as is shown in Figure 18.[98] California is the true U.S. leader in solar adoption with 25 percent of all U.S. PV installations; the Northeast trails behind with 13 percent of PV installations, with Massachusetts, Vermont, New Jersey, New York, Maryland, and Connecticut leading within the region. Residential solar is claiming its share of the market and, thus far, is slightly in the lead of DER technology adoption.

Figure 18: Residential Solar PV systems from NREL's Solar Industry Update



Residential Electric Vehicle Market

Electric vehicle ownership in the U.S. has grown from 0.9 percent of car sales in 2016 to nearly two percent in 2018 and is projected to be over 20 percent by 2025.[99] Once again, this overall growth is largely led by California, which accounts for 48 percent of all EV purchases.[100] Outside of California, several states in the Northeast have higher than average rates of both ownership and sales, with Vermont, DC, Connecticut, New York, Massachusetts, and Maryland as most notable for both electric and plug in hybrid rates.[101] Table 2 shows a

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[97] Data cited from EnergySage, taken from https://www.nrel.gov/docs/fy18osti/71493.pdf

[98] Image recreated from https://www.nrel.gov/docs/fy18osti/71493.pdf, with data sources: Res. PV Installations: 2000-2009, IREC 2010 Solar Market Trends Report; 2010-2017, SEIA/GTM Solar Market Insight 2017 Year-in-Review; U.S. Households U.S. Census Bureau, 2015 American Housing Survey; state percentages based on 2000 survey.

[99] Auto Sales Data: GoodCarBadCar.net, InsideEVs, HIS Marit projections, EVAdoption.com

[100] http://evadoption.com/california-evs-by-the-numbers-20-statistics-that-might-surprise-you/

[101] State breakdowns from: https://autoalliance.org/in-your-state/

state-by-state breakdown of full battery electric (BEV) and plug-in hybrid (PHEV) vehicle ownership, demonstrated by the percentage of registered vehicles, as well as the 2017 sales rates. While California is the leader in all metrics, there are bright spots throughout the Northeast.

Table 2: Northeast rates of EV ownership (% of registered vehicles) and 2017 sale, compared to CA[102]

State	CT	DE	DC	ME	MD	MA	NH	NJ	NY	PA	RI	VT	WV	CA
% Electric registered	**.09**	**.05**	**.22**	**.03**	**.09**	**.11**	**.05**	**.09**	**.08**	**.04**	**.04**	**.11**	**.01**	**.6**
% Plug-in Hybrid Registered	**.13**	**.10**	**.19**	**.1**	**.16**	**.14**	**.11**	**.11**	**.13**	**.07**	**.09**	**.26**	**.03**	**.51**
% Electric sold in 2017	**.57**	**.27**	**.88**	**.2**	**.44**	**.53**	**.22**	**.35**	**.34**	**.18**	**.34**	**.8**	**.05**	**2.59**
% Plug-in Hybrid sold in 2017	**.76**	**.54**	**.92**	**.54**	**.54**	**.76**	**.6**	**.52**	**.65**	**.33**	**.55**	**1.18**	**.09**	**2.22**

The price for EVs as a broad category has also come down in recent years while the distance they can travel on a single charge, often referred to as their “range,” has increased. Table 3 shows a snapshot of battery electric vehicle (BEV) options and prices from January 2018 with the worst (yellow) and best (purple) performances highlighted. This is a very dynamic industry, with some products such as the 2019 Nissan LEAF improving performance 40 percent in their newest models to 150-mile range with a slightly lower MSRP than reported in January 2018.[103]

[102] Data collected from: https://autoalliance.org/in-your-state/
[103] Reporting MSRP of $29,990 and range of 150 miles for 2019 model https://www.nissanusa.com/vehicles/electric-cars/leaf/range-charging.html

Table 3: January 2018 Snapshot of Electric Vehicle Options from EVAdoption.com[104]

Currently Available Battery Electric Vehicles (BEVs) in the US (January 20, 2018)							
Make/Model	**EV Type**	**Range (miles)**	**MSRP**	**Cost / Mile of Range**	**kWh Battery Pack**	**Cost per kWh**	**Availability**
BMW i3	BEV	114	$44,450	$390	33	$1,347	Unknown, likely at least all key ZEV states
Fiat 500e	BEV	87	$32,995	$379	24	$1,375	CA, OR
Ford Focus Electric	BEV	115	$29,120	$253	33	$882	EV-certified Ford dealerships throughout US
Chevrolet Bolt EV	BEV	238	$36,620	$154	60	$610	All 50 US states
Honda Clarity Electric (3)	BEV	89	$37,510	$421	25.5	$1,471	California, Oregon - by lease only
Hyundai Ioniq Electric	BEV	124	$29,500	$238	28	$1,054	California
Kia Soul EV	BEV	111	$33,950	$306	30	$1,132	CA, CT, GA, HI, MA, MD, NJ, NY, OR, RI, TX, WA
Nissan LEAF (1)	BEV	107	$30,680	$287	30	$1,023	All 50 US states
smart fortwo electric drive (1)	BEV	58	$23,900	$412	17.6	$1,358	All 50 US states
Tesla Model 3 (2)	BEV	310	$50,000	$161	78	$641	Deliveries to early reservation holders
Tesla Model S 75D	BEV	275	$74,500	$271	75	$993	Tesla stores/galleries in 26 states and D.C.
Tesla Model S 100D	BEV	351	$94,000	$268	100	$940	Tesla stores/galleries in 26 states and D.C.
Tesla Model S P100D	BEV	337	$135,000	$401	100	$1,350	Tesla stores/galleries in 26 states and D.C.
Tesla Model X 75	BEV	237	$79,500	$335	75	$1,060	Tesla stores/galleries in 26 states and D.C.
Tesla Model X 100D	BEV	295	$96,000	$325	100	$960	Tesla stores/galleries in 26 states and D.C.
Tesla Model X P100D	BEV	289	$140,000	$484	100	$1,400	Tesla stores/galleries in 26 states and D.C.
VW e-Golf	BEV	125	$30,495	$244	35.8	$852	CA, CT, ME, MD, MA, NJ, NY, OR, RI, VT, D.C.
Total / Average (Mean)	13*/17	192	$58,719	$314	55.6	$1,085	
Median	17	114.5	$37,510	$306	35.8	$1,054	
Average (Mean) - excluding Tesla	10	142	$46,092	$324	40.4	$1,144	
Median - excluding Tesla	10	112.5	$31,838	$296	30.0	$1,093	

*14 distinct BEV models, 17 when including all battery variations for Tesla Models S/X

(1) These vehciles are expected to have larger battery packs at some point 2018 in the US

(2) Tesla has not officially revealed battery pack size; various documents point to around 78 kWh https://electrek.co/2017/08/07/tesla-model-3-new-details-revealed/

(3) Honda Clarity BEV is only available by lease at $199/month (base) - MSRP shown is an estimate based on Edmunds.com data

Information as of January 20, 2018 | Research and chart: EVAdoption.com

An additional development to help foster EV adoption is the ENERGY STAR specification for electric vehicle supply equipment (EVSE).[105] Both fully-electric and plug-in hybrid vehicles that charge at home often do so using a designated EVSE or EV charger, which can include a wall outlet connector, a power supply cable, a charge stand or wall mount, a vehicle connector, and protection components. The more efficient the charging equipment, the more efficient the charging process. Eventually the EV itself may be a connected product that interfaces with a HEMS, but in the meantime, connected EVSEs can more easily create the connection between charging operations and HEMS signals. As Table 1 shows, there are already several connected EVSEs certified to ENERGY STAR.

Residential Battery Storage Market

Finally, the residential scale battery storage market is still in the very early days of mass adoption, with relatively high prices compared to gasoline generators and otherwise fairly limited options.[106] While groups such as the Energy Storage Association are working to grow this market, there is little residential battery storage deployed

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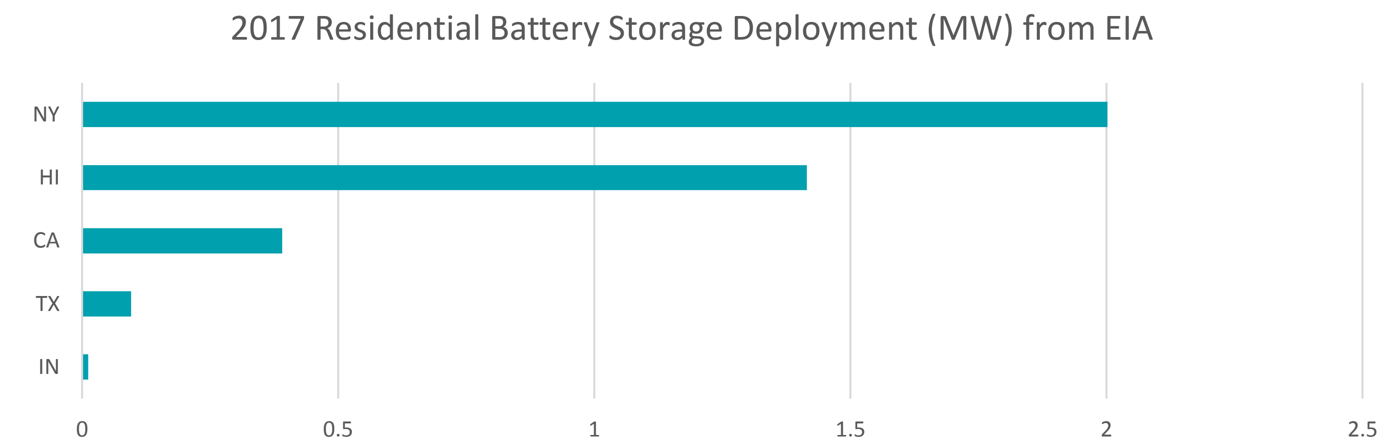
104 http://evadoption.com/ev-statistics-of-the-week-range-price-and-battery-size-of-currently-available-in-the-us-bevs/
105 https://www.energystar.gov/products/other/evse
106 https://news.energysage.com/battery-backup-power-vs-generators-which-is-right-for-you/

to date.[107] As Table 4 shows, using 2017 data from the U.S. Energy Information Administration, only five states have a notable amount of residential battery storage deployment.[108] New York is a clear leader here, though as explored in the Real World Examples with Roots in Distributed Energy Resources case studies section of this report, Vermont is also deploying innovative battery storage solutions. While ENERGY STAR has not yet developed a specification for residential battery storage, this is another product category that could greatly benefit from a qualified product list of highly performing units.

Table 4: 2017 Residential Battery Storage Deployment from EIA



	IN	TX	CA	HI	NY
MW	0.012	0.096	0.391	1.415	2.002

107 http://energystorage.org/
108 Data assembled from EIA 861 2017 data set, https://www.eia.gov/electricity/data/eia861/

Appendix C: Strategically Electrified Space, Water Heating, and Home Performance Market Characterization Details

As discussed in **Policy** and Carbon: Policies **must** evolve to recognize and value carbon reductions as a critical consideration and motivator for decision making so that a decarbonized residential building stock may be fully appreciated and incentivized.

- ***Utility Regulatory Structure:*** Utility programs of the future will serve as a "one-stop-shop" for smart energy homes, including HEMS, DERs, and strategic electrification technologies. These programs will account for carbon reductions, promote lower-carbon strategic electrification activities, and have dynamic pricing.
- ***Smart Energy Homes Drive Smart Home Performance:*** As the grid decarbonizes and strategic electrification efforts increase, peak events will likely move towards the winter. Tight, low-load homes are critical to the success of strategic electrification and broader residential decarbonization. Low electric loads will be reinforced by smart energy home efforts that increase performance of existing homes.
- ***Quality Assurance and Transparency in Technology:*** Installed products in smart energy homes of the future are high quality, easy to find, and work well together to enable a low-carbon residential sector.
- ***Focus on the Locational Value of Smart Energy Homes and Energy Efficiency:*** A modernized grid that can account for a range of grid constraints when sending and receiving demand signals, particularly around location of savings, is critical.
- ***New Construction and Smart Energy Home Integration with Building Codes:*** New buildings are built to meet the future vision of flexible, low-load, electric homes.

Ultimately, smart energy homes, distributed energy resources, and strategically-electrified technologies are gaining market adoption footholds throughout the Northeast and Mid-Atlantic. Several smart technology markets are healthy and thriving today, and there is a need to expand their functionality and interoperability with the DERs and strategically-electric technologies to ensure we reach our residential decarbonization goals. Through focus and collaboration, and with a continued eye on equity and justice, regional actors can transform the residential sector with the smart energy homes at the center. Together, we will meet our decarbonization goals as the smart energy home works to optimize the what, when, and where of home energy use for decades to come.

Introduction and Context Setting, energy efficiency is just one of the critical strategies needed to achieve broader residential sector decarbonization goals that Northeast states have established. The strategic electrification of certain end uses—in the residential building sector, that is primarily space and water heating—is also critical to reach these goals. The highly-efficiency electric technologies that are of particular focus for this report are air source heat pumps (ASHPs)[109] and heat pump water heaters (HPWHs).[110] Geothermal heat pumps (GHPs) also have a role to play in this market, but have more constraints around installation and a higher first cost than ASHPs at present.

ASHP Market

There has been a resurgence of interest in ASHPs in the past decade, especially focused on variable speed systems that can operate efficiently at high capacities even at very low outdoor temperatures and provide warmer air to counteract resident's perception of "cold blow." There is a new generation of heat pumps that have entered the market in both ductless and centrally-ducted applications. In many cases, these ASHPs are installed to meet a cooling demand from a customer who is either replacing or never before had central air conditioning. Often ASHPs can also play a significant role in heating homes and displacing legacy heating systems, be they fuel oil, propane, natural gas, or electric resistance. In some cases, this would lead to fuel switching from a fossil-fuel heating source to electricity, which would help push towards strategic electrification goals.[111]

While ASHPs are not yet common place, regional sales data from 2015 suggests residential ASHP sales in the Northeast and Mid-Atlantic were approximately 285,000,[112] with New England and upstate New York representing about 65,000 of those units and the Mid-Atlantic region[113] representing roughly 220,000. Active promotion of ASHPs in many states have boosted those numbers in more recent years. A 2015 NYSERDA study[114] found that the large majority of centrally-ducted ASHPs just met or barely exceeded minimum efficiency requirements (HSPF 8.2, SEER 13), while nearly the entire ductless market far exceed minimum efficiencies (97.5 percent of systems had SEER values of 15 or higher). These market findings are discussed further in the 2017 Update to the Northeast/Mid-Atlantic Air-Source Heat Pump Market Strategies.[115]

While demand response for electric cooling has been a popular residential program for years, winter demand response with electric heating has not been deployed as often. Modern, cold-climate ASHPs have sophisticated programming and operations to adjust their capacities to meet the needs of a home, but most ASHPs today are not "connected." This is an example of an intelligent technology that serves efficiency purposes, but doesn't

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[109] NEEP ASHP Resources at https://neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp

[110] NEEP HPWH Resources at https://neep.org/initiatives/high-efficiency-products/emerging-technologies/hpwh

[111] To support the healthy growth of the ASHP market, NEEP maintains an active ASHP initiative to address market barriers, as well as maintain a product list of ASHPs that meet high performance criteria at low temperatures. https://neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp

[112] 2015 HVAC Market in Review: Opportunities for Efficiency, D&R International, Webinar, June 22, 2016.

[113] Defined for this data set as New York Metro, Long Island, New Jersey, Eastern Pennsylvania, Delaware, District of Columbia and eastern Maryland

[114] https://www.nyserda.ny.gov/-/media/Files/...stock.../Vol-3-HVAC-Res-Baseline.pdf

[115] NEEP 2017, *Northeast/Mid-Atlantic Air-Source Heat Pump Market Strategies Report 2016 Update* https://neep.org/sites/default/files/NEEP_ASHP_2016MTStrategy_Report_FINAL.pdf

contribute to broader grid and decarbonization purposes since it is not a controllable load and therefore not "smart."

In fact, recent evaluation of heating performance of ASHPs in Massachusetts and Vermont found that in many homes where people owned ASHPs, they did not use them as a primary heating source and often reverted to their existing heat system.[116] Furthermore, many ASHPs are considered "incompatible" with smart thermostats, as the smart thermostat signal is more akin to "on/off" and ASHPs respond much better to slower ramp ups and downs. While there are some exceptions with early collaborations between ASHPs and smart thermostat manufacturers, there is still a significant opportunity to bring connected functionality into ASHPs. Smart thermostats are manufactured to not only allow customers remote control of their ASHPs, but also make them candidates for load shifting, demand response, and even optimizing their use with on-site generation such as rooftop solar.

HPWH Market

For water heating, this report is most interested in connected, high-efficiency heat pump water heaters (HPWHs). These products use nearly 60 percent less energy than their electric resistance counterparts and are a very low-carbon option. An analysis of the carbon impact of HPWHs concluded that "the greatest net climatic benefit…was predicted to be achieved when a storage natural gas water heater (the most common system for domestic hot water in the United States) fueled by shale gas was replaced with a high efficiency heat pump water heater powered by coal-generated electricity."[117] The electric mix in the Northeast and Mid-Atlantic is significantly less carbon intensive than coal-only electric generation,[118] so carbon benefits from HPWHs are even greater. Even with significant energy and carbon benefits of HPWHs, they still have reached only about 1-1.5 percent of the residential water heater market since their introduction in the 1980s.[119,120] In many states in the Northeast, large utility incentives for HPWHs have been in place for several years,[121] though there has still been very slow growth in the market. Several efficiency programs, such as Efficiency Vermont and Energize Connecticut, have seen more uptake of HPWHs when the incentive was paid midstream directly to the distributor and/or installer rather than a downstream rebate to a customer. [122]

In many configurations, water heaters have long been considered *thermal batteries*, as water can be heated at opportune times for energy generators and used at the opportune time for customers. In many ways, however, water heaters are a one-way battery. They can be "charged," but they can only shift their charge away from

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[116] Cadmus completed two evaluations on the subject, one in Massachusetts published in 2016, http://ma-eeac.org/wordpress/wp-content/uploads/Ductless-Mini-Split-Heat-Pump-Impact-Evaluation.pdf and the other in Vermont published in 2017, https://publicservice.vermont.gov/sites/dps/files/documents/Energy_Efficiency/Reports/Evaluation%20of%20Cold%20Climate%20Heat%20Pumps%20in%20Vermont.pdf.

[117] Greenhouse gas emissions from domestic hot water: heat pumps compared to most commonly used systems, from *Energy Science and Engineering* 2016; https://onlinelibrary.wiley.com/doi/pdf/10.1002/ese3.112)

[118] From the systems operators, PJM is 32% coal, NYISO is 39% natural gas/dual fuels (potentially including coal) and ISO-NE is only 2% coal/oil

[119] http://eedal2017.uci.edu/wp-content/uploads/Thursday-19-Butzbaugh-U.S.-Heat-Pump-smaller.pdf

[120] http://ma-eeac.org/wordpress/wp-content/uploads/Heat-Pump-Water-Heater-Impact-Study-Volume-1.pdf

[121] A 2016 program summary shows HPWH incentives ranging from $400 to $750 https://neep.org/sites/default/files/resources/Northeast_Appliance_Incentive_Summary.pdf

[122] Example from EnergizeCT, https://www.energystar.gov/sites/default/files/asset/document/1_Jesus%20Pernia_MythBusters%20Water%20Heater%20Edition_FINAL.pdf

other times, they cannot discharge the energy that they have stored in the hot water. Even so, the ability to take energy when it is abundant and keep that energy through more constrained periods is very beneficial towards shaping load curves to meet the needs of the grid. In rural areas, many electric cooperatives have spearheaded this work with traditional electric resistance water heaters which have an even higher energy draw and therefore the opportunity to be “charged” with a greater amount of electricity than the efficient HPWHs.[123]

While basic direct load controls of electric resistance water heaters have been in place for decades, the potential to use smart HPWHs to achieve some of the same load management ends is only just beginning. Simulation and lab testing from NRDC show that with more sophisticated controls strategies, HPWHs can both achieve load flexibility and energy efficiency.[124] Specifically, its research found that when managed well, the HPWH could shift from a California coincident peak of 15 percent to only one percent, and a solar coincident from 55 percent up to 65 percent, showing the ability to not only “charge” a HPWH to avoid the worst times for the grid, but also to take advantage of renewables through the day.

Given the low penetration of HPWHs, there is a huge opportunity for growth in this market and to integrate connected functionality with HPWHs to ensure they are not only highly efficient but also shiftable, responsive loads. Unlike ASHPs, several HPWHs are being built with embedded connected functionality. For example, the Rheem HPWH is being offered with a built-in EcoNet, which is a Wi-Fi based control that integrates with other smart home devices[125], and AO Smith water heaters are being built with a CTA-2045 port to enable them to be “connected ready.” [126] New proposed legislation in Washington State, for example, would mandate connected functionality in new electric water heaters sold in the state. This is the first legislation of its kind and will be very interesting to see how it impacts the market development of smart water heating.[127] As the HPWH market grows, there is a need for the smart functionality to grow with it.

The Need for Thermal Efficiency

Together with this shift towards electric space and water heating is the need to prioritize home performance improvements to increase the number of energy efficient, lower-load homes. This can be achieved through thermal envelop improvements—such as air sealing and insulation—and reducing the need for hot water through efficient water-using products such as faucets and showerheads. This would help ensure the capacity of water heaters could be as low as possible. Having a lower overall load in a home is not only critical from a decarbonization perspective, but can also improve the economics of both HPWHs and ASHPs by ensuring the right-sized units are installed. If a smaller and less expensive system can meet the needs of the home, the first cost will be reduced. Furthermore, as design improvements are made in the cold-climate performance of ASHPs, there may be less or even no need to have a back-up heating source in a tighter home.

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[123] The Brattle Group commissioned by NRECA, NRDC, and PLMA, 2016, *The Hidden Battery Opportunities in Electric Water Heat* http://www.electric.coop/wp-content/uploads/2016/07/The-Hidden-Battery-01-25-2016.pdf

[124] Delforge, Vukovich, NRDC, *Can Heat Pump Water Heaters Teach the California Duck to Fly?* Proceedings from 2018 ACEEE Summer Study

[125]https://www.rheem.com/econet

[126] CTA 2045 is a standard that allows multiple vendors to develop multiple communications protocols through inclusion of a common port in major end uses that can be plussed in with various compatible communications technologies. https://www.hotwater.com/water-heaters/residential/electric/grid-enabled-residential-electric-water-heater-pgt-80/

[127] http://lawfilesext.leg.wa.gov/biennium/2019-20/Pdf/Bills/House%20Bills/1444.pdf

At present, high efficiency ASHPs are likely to be a lower carbon heating option due to their high efficiency but might not be the lower cost heating option due to the lower carbon mix on most of the grid in the Northeast. This is particularly true for a home replacing gas heat, given current electricity and natural gas prices. A tighter home that will achieve better performance from a potentially smaller system, however, will maximize the bill-savings from an ASHP. As the Home Performance Coalition (HPC) describes in a recent report, "smart home performance" is needed to address the energy use of existing homes.[128] The HPC's report states, "A home can be smart and not energy efficient, and vice versa, but smart and energy efficient homes can be a utility's greatest asset."[129] HPC identifies data-sharing, behavior change, and experience as the pillars of smart home performance, which integrates more traditional home performance measures with smart devices. In addition to the fact that tighter, lower-load homes require less energy to operate comfortably, tighter homes can be better assets to demand response and load-shifting programs since they can maintain comfortable temperatures for longer periods of time. Moving forward, it will be especially important to have the ability to maintain comfort in a home during a peak event as more electric end-uses are added to the grid by ASHPs and HPWHs.

There is a strong need to prioritize home performance to achieve the full benefit and economic savings of ASHPs in existing homes, but in new construction, the economics of ASHPs are much improved. Not only would a ductless ASHP provide both heating and cooling in one unit, but it could avoid much of the infrastructure costs of piping or ductwork to transfer heat through a home. This is also true for HPWHs that have some limitations in placement within an existing home; there is no additional cost to building and designing a new home to account for a HPWH.

[128] Home Performance Coalition 2018, Redefining Home Performance in the 21st Century: How the Smart Home Could Revolutionize the Industry and Transform the Home-to-Grid Connection http://www.homeperformance.org/sites/default/files/HPC_Smart-Home-Report_201810.pdf
[129] Ibid page 8