Opportunities for Home Energy Management Systems (HEMS) in Advancing Residential Energy Efficiency Programs

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Table of Contents

Table of Figures

Table of Tables

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About NEEP

NEEP was founded in 1996 as a non-profit whose mission is to serve the Northeast and Mid-Atlantic to accelerate energy efficiency as an essential part of demand-side solutions that enable a sustainable regional energy system. Our vision is that the region will fully embrace next generation energy efficiency as a core strategy to meet energy needs in a carbon-constrained world.

Executive Summary

Home Energy Management Systems (HEMS) are an invention of the internet age; they are a 21st-century byproduct of the idea that utility smart meters can enable two-way communication with homeowners while smart consumer products can allow greater connectivity, control, and ultimately a better living. Since the earliest documented implementations of smart meters in the mid-2000's, program administrators around the world have looked for ways to use the energy information provided at the whole home level to enhance residential energy efficiency and conservation programs. In certain parts of the United States, changes in utility regulation, such as the decoupling of sales from profits, have paved the way for alternate residential program mechanisms that utilize technology to deliver more energy savings and enhance customer satisfaction. These are some of the earliest instances of programs that used home energy consumption information with the goal of influencing energy savings, a concept which evolved into what is now referred to throughout the energy efficiency industry under the umbrella term of "HEMS."

A 2010 ACEEE report[1] began to quantify the opportunities presented by feedback initiatives, many of which utilized nascent HEMS devices and technology. The paper published results showing reduced household electricity consumption of 4 percent to 12 percent on average; these results demonstrated that feedback was an effective behavioral tactic in getting customers to save energy, and the more accurate and timely the feedback, the better. This study and its findings formed the basis for an accelerated interest in energy efficiency programs that used direct feedback as a savings mechanism, often with a connected, communication-capable device at the heart of the strategy. In the years since the ACEEE report, the market for technology and consumer products has changed dramatically. Major corporations have entered, and exited, the energy efficiency market, with early incarnations of consumer-facing dashboards such as Microsoft Hohm and Google PowerMeter later giving way to a plethora of products, platforms, and dashboards that offer expanded capabilities to both end-users and program administrators. These products range from pieces of hardware that monitor and control single energy end-use systems; to whole-home monitoring devices that track multiple fuel sources or that use disaggregation algorithms to parse out electric loads; to platforms that use no in-home hardware at all, but use consumer data, building characteristic information, and geographic location to conduct sophisticated data analysis and yield reasonable portfolio-level estimates.

The definition of what constitutes "HEMS" has evolved from once denoting only a monitoring system to today's more widely accepted view of HEMS as an umbrella acronym for a variety of home energy management solutions, which can involve stand-alone or combined versions of the aforementioned products and dashboards.

The definition of what constitutes a "home energy management system" has evolved, too, from once denoting only a monitoring system to today's more widely accepted view of HEMS as an umbrella acronym for a variety of home energy management *solutions*, which can involve stand-alone or combined versions of the aforementioned products and dashboards. As dynamic as the market for HEMS products has become, however, the lack of independently verified empirical data on HEMS-provided savings impacts, as well as the lag in development of standards and communication protocols, has created what some would argue is market

[1] http://aceee.org/research-report/e105.

confusion for consumers and participants in energy efficiency programs. Nevertheless, the HEMS space continues to evolve, with manufacturers and program administrators acting to address barriers to consumer uptake in the hopes of fulfilling the promise of deeper savings.

NEEP, through its work on business and consumer electronics, identified HEMS as an emerging area for programs and developed a research scope to synthesize much of the findings and results from the past several years of HEMS evolution into a discussion of opportunities for HEMS in energy efficiency programs, particularly those in the Northeast and Mid-Atlantic. The purpose of this report is to demonstrate the potential for HEMS as an evolving avenue to deeper residential energy savings, and it explains, in detail, the variations and characteristics of HEMS; what the market is and who the major market players are; what the major barriers to implementation look like; and finally, it attempts to outline potential program solutions with HEMS at the core of the strategy. NEEP contracted CLEAResult to lead the HEMS research and investigation. This report is intended to evaluate the opportunity of HEMS, NEEP is committed to continuing tracking and engagement efforts in this space and to, fueled by the research and analysis in this report, develop regional strategies to transform the HEMS market in the years to come. This report includes the following sections:

Technology Assessment. Working off of a comprehensive technology assessment put together for the Pacific Gas & Electric Company (PG&E) 2015 HEMS Market Characterization, the research team used the PG&E report's taxonomy to break HEMS into information-based and control-based products; these two functionalities include sub-categories of devices into which nearly every known HEMS device and platform can be assigned. Information-based systems refer to the direct feedback platforms envisioned in the 2010 ACEEE report, while control-based systems use programming and sophisticated technology to insert more automation into a product and remove the variability caused by human behavior. The technology assessment provided the research team several lenses through which potential opportunities for HEMS in programs were identified.

Program Activity Assessment. In support of future opportunities for HEMS in programs, the research team sought out the objectives, parameters, and any available results from completed or in-process programs that have utilized or are using HEMS. With the added benefit of the categorization laid out in the Technology Assessment, the landscape for HEMS pilots, projects, and programs expanded considerably; any programs discovered were organized into the more precise information-based and control-based device categories, which allowed for easier comparisons amongst goals and significant results. This work began to bring estimates of savings potential for HEMS-enabled programs into sharper focus, and set up the additional analysis conducted in the Opportunity Assessment.

Although initial efforts around standards and protocols in the HEMS space stalled, ENERGY STAR and PNNL, amongst others, have renewed discussions around testing devices and establishing protocols to support manufacturers in this market.

Policy Opportunities and Recommendations. The opportunities for HEMS adoption in the Northeast and Mid-Atlantic, as well as nationally, are enhanced by legislative action at the federal and state level, standards and protocol development by nationally recognized entities such as ENERGY STAR®, and efforts to revisit cost-effectiveness calculation methodologies. In this section, the NEEP HEMS research team reviewed and summarized these efforts with respect to their impact on opportunities for HEMS in energy efficiency programs. The most prominent advocacy efforts are currently helmed by Efficiency First and the Home Performance

Coalition, who recognize the value of incorporating smart home technology into residential energy efficiency programs and have directed their focus accordingly. Although initial efforts around standards and protocols in the HEMS space stalled, ENERGY STAR and the Pacific Northwest National Lab (PNNL), amongst others, have renewed discussions around testing devices and establishing protocols to support manufacturers in this market. In this section, the research team addresses several HEMS barriers and challenges put forth in the Technology Assessment and recommends policy drivers to help solve these issues going forward.

Potential of HEMS as a Measurement and Verification (M&V) Tool. In the earliest deployments of smart meters, program administrators envisioned that interval data could provide value to programs through a utility's advanced metering infrastructure (AMI). Independent of AMI, some HEMS have the capability to collect interval level data. Leveraging recent work from a May 2015 NEEA report, this section analyzes the potential opportunity to use HEMS as an M&V tool to measure and verify savings from energy efficiency measures in a home. The research team also reviewed new and ongoing efforts and potential products or systems that may unlock previously unattainable data sets for the purposes of more rigorous and quicker program M&V.

Opportunity Assessment. Through the examination of HEMS technology options available, HEMS program activities, policy drivers, and M&V considerations, the opportunities for HEMS begin to present themselves. The remaining pieces of the puzzle are those critical programmatic considerations that may be taken for granted in traditional residential energy efficiency programs, but which deserve fresh attention with the new perspective granted by the capabilities inherent in HEMS. The research team examined many variables and leveraged new HEMS-specific learnings into the opportunities and recommendations described in this paper, and found that although every program is different, the Opportunity Assessment provided strong guidance as to the direction that programs can take; following are summaries of the recommendations that have emerged from this extensive analysis.

In the earliest deployments of smart meters, program administrators envisioned that interval data could provide value to programs through a utility's advanced metering infrastructure (AMI). Independent of AMI, some HEMS have the capability to collect interval level data.

- **Energy End-Use**: Focus on space heating and cooling end-uses for the most savings potential, especially when non-electric fuels are a priority. Continue to monitor the growth of plug loads and consumer electronics, and plan for HEMS-based strategies that can facilitate electricity savings.
- **Region / Territory**: Within the Northeast region, smart thermostats and associated smart climate controls hold the most immediate promise for HEMS-enabled programs, especially when bundled with existing retrofit measures for efficient equipment upgrades. In some Northeast and Mid-Atlantic program territories, smart climate controls should offer energy and demand savings capabilities in order to take advantage of future HEMS product advancements.
- **Channel**: The DIY / self-install channel, and to a lesser degree, the qualified installer channel, are currently the paths of least resistance through which most vendors and manufacturers are moving their products. Programs should leverage these channels for cost-effective delivery while exploring other potential avenues for encouraging HEMS and connected device uptake.
- **Dwelling Type**: HEMS hold promise for nearly every dwelling type, but the nature of the systems available and desires vary widely by vintage, building type, and occupant income level. Existing homes

are the biggest opportunity by sheer volume, but the multifamily market is growing quickly in many metropolitan areas throughout the country and should be examined for new program opportunities. Additionally, using the direct install channel strategically in low income properties, manufactured homes, and in existing multifamily structures is highly recommended for any programs looking to bring HEMS into those building types.

- **Energy, Demand, and Other Resources**: The capabilities of HEMS are such that program administrators who wish deliver energy savings now and other, additional resource savings at a later time should be able to do so through product updates and add-ons. Demand response capabilities of HEMS should be available for any program that is forecasting peak load issues, whether in summer or in winter. Energy and thermal storage as well as energy balancing abilities inherent in HEMS will be critical aspects of grid resilience planning; and, to the extent possible, energy programs should begin exploring opportunities to claim savings for water and greenhouse gas emissions where these benefits can be accounted for.
- **Customer Engagement Planning**: Conduct proactive customer segmentation and employ the basic behavioral strategies when designing a program that utilizes information-based HEMS.
- **Designing Programs with M&V**: Strive for using interval data in HEMS program M&V, for both rigor and timeliness; settle on data collection protocols that allow this capability before programs are launched.

HEMS may make it possible to deliver whole-home energy usage information, long-term customer engagement, demand response savings, direct load control, more data and transparency for M&V, and ultimately more cost-effective energy savings. With the analysis conducted in this report among others, the research team concluded that program administrators should have confidence that HEMS can deliver energy and other resource savings, as well as enhanced customer satisfaction, as long as the appropriate program design considerations are taken. With the assumptions from this report in hand, programs in the Northeast, Mid-Atlantic, and beyond, could achieve space heating and cooling savings of up to 17 percent from a whole-home baseline, or smaller increments of savings across a wide variety of end uses, by pulling the appropriate program levers. The opportunity also exists for programs and regulators to reconsider the way that programs are evaluated at a portfolio level in order to encourage adoption of HEMS products that can conserve resources while providing non-energy benefits to users such as enhanced safety, health, and security.

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Recommendations. This section includes specific recommendations around:

- Best practices for using HEMS in customer engagement and program evaluation planning
- Estimated savings and discussion of cost-effectiveness variables for resource planning
- A HEMS program design framework
- Recommendations for further research and new program strategies

NEEP and the research team hope that this report will be a resource to ensure programs are better equipped to select vendors, manufacturers, and third-party service providers to deliver an advanced HEMS platform to program administrator clients. Homes will, at some point in the not-too-distant future, be filled with smart technology. With HEMS, programs have a golden opportunity to leverage the power of smart technology to accelerate progress towards sustainability goals, while engaging customers with relevant, useful, even delightful enhancements to their living environments.

1. Introduction

1.1 Project Overview

In 2013, NEEP commissioned a report on Business and Consumer Electronics[2] (BCE) which explored the potential energy savings in this category, and sought a unified regional strategy around how to access the savings. The total energy used by BCE in the United States makes up 13.2 percent of annual residential electric energy consumption, but often these loads are small and distributed, making them difficult to parse out. One of the major opportunities to emerge from the BCE report was home energy management systems (HEMS), and in accordance with the report, NEEP introduced a Working Group in early 2014 that brings together leaders from efficiency programs and manufacturers to focus on HEMS and the potential for advancing energy efficiency programs.

__Home energy monitoring or management systems and/or solutions (HEMS)__ are loosely defined as any hardware and/or software system that can monitor and provide feedback about a home's energy usage, and/or also enable advanced control of energy-using systems and devices in the home.

With the launch of the HEMS Working Group, NEEP began working in partnership with the Home Performance Coalition (HPC) to align the potential of HEMS with the goals of energy efficiency programs. NEEP's partners in the Northeast and Mid-Atlantic provide incentives to increase the adoption of energy efficiency measures; however, uptake in home energy management services and products remains low. The NEEP HEMS Working Group recently put forward a document entitled "Establishing Common Understanding for Home Energy Management Systems (HEMS) in Efficiency Programs"[3] designed to assist program administrators when they are in early conversations with HEMS vendors to illustrate what metrics and data points are most important for programs. While this document is a tool to help break down barriers to HEMS adoption, NEEP found there was much more research necessary to advance HEMS.

In an effort to further explore how NEEP could advance the adoption of smart home products amongst consumers, NEEP's Market Strategies Initiative and Regional EM&V Forum provided funding for a research project to "explore the potential of Home Energy Management Systems (HEMS) as energy-saving devices to keep the Northeast/ Mid-Atlantic region an energy efficiency leader and develop adequate resources to ease integration of HEMS into efficiency programs." To address this, the report is structured to cover the following elements:

- Technology Assessment
- Program Activity Assessment
- Policy Opportunities and Recommendations
- Potential of HEMS as a Measurement and Verification (M&V) Tool
- Opportunity Assessment
- Recommendations for Further Study

[2] http://www.neep.org/business-consumer-electronics-strategy-northeast-2013
[3] http://www.neep.org/sites/default/files/resources/HEMSCommonUnderstandingFinal7-29.pdf

CLEAResult, through its acquisition of PECI, has been tracking HEMS since early 2010. Their research conducted to date has shown that while the market for HEMS products is certainly evolving, no single vendor or energy services company has a lock on this product offering yet, due in part to the absence of industry-wide smart grid standards and a lack of uptake by program administrators. NEEP contracted CLEAResult to lead the HEMS research team and prepare this report; the research team sought to expand upon and synthesize previous research to determine appropriate recommendations for HEMS in energy efficiency programs.

The purpose of this report is to demonstrate the potential for HEMS as an evolving avenue to deeper residential energy savings, and it explains, in detail, the variations and characteristics of HEMS; what the market is and who the major market players are; what the major barriers to implementation look like; and finally, it attempts to outline potential program solutions with HEMS at the core of the strategy. The HEMS market at present is a national, if not international, market, though NEEP's perspective is focused on the opportunities HEMS can bring to the Northeast and Mid-Atlantic region. Without a previously clear path to a program strategy involving HEMS, there are several key themes, the successful integration of which could result in a program that offers long lasting, deeper energy savings. In order to continue delivering savings to program administrators on a mass scale, as well as utilize the capabilities of smart metering infrastructure once it comes online, residential pilots or programs should explore the inclusion of HEMS as not only energy-saving solutions, but as integral to the future of connected, smart homes.

1.2 General Definitions

There are many definitions for the general category of HEMS in use in the energy industry, but CLEAResult's working definition is as follows:

> **Home energy monitoring or management systems and/or solutions (HEMS)** are loosely defined as any hardware and/or software system that can monitor and provide feedback about a home's energy usage, and/or also enable advanced control of energy-using systems and devices in the home.

Other groups have put forward definitions of HEMS, including that prepared for PG&E published in February, 2015, entitled "Characterization and Potential of Home Energy Management (HEM) Technology"'[4]:

> "**HEMS** can be broadly defined as those systems (including both hardware and software linked together via a network) that enable households to manage their energy consumption. This can be done in one (or both) of two ways:
>
> - HEMS can provide energy consumers with information about how they use energy in the home and/or prompts to modify consumption.
> - HEMS can provide the household (or third parties) the ability to control energy- consuming processes in the home, either remotely via a smartphone or web service or based on a set of rules, which can be scheduled or optimized based on user behavior."

Another term important to define is Home Area Networks (HAN), which the PG&E research team defines as "a network that facilitates communication and interoperability among digital devices within a home. In the context of home energy management, the HAN acts as a communication network in a home that can connect

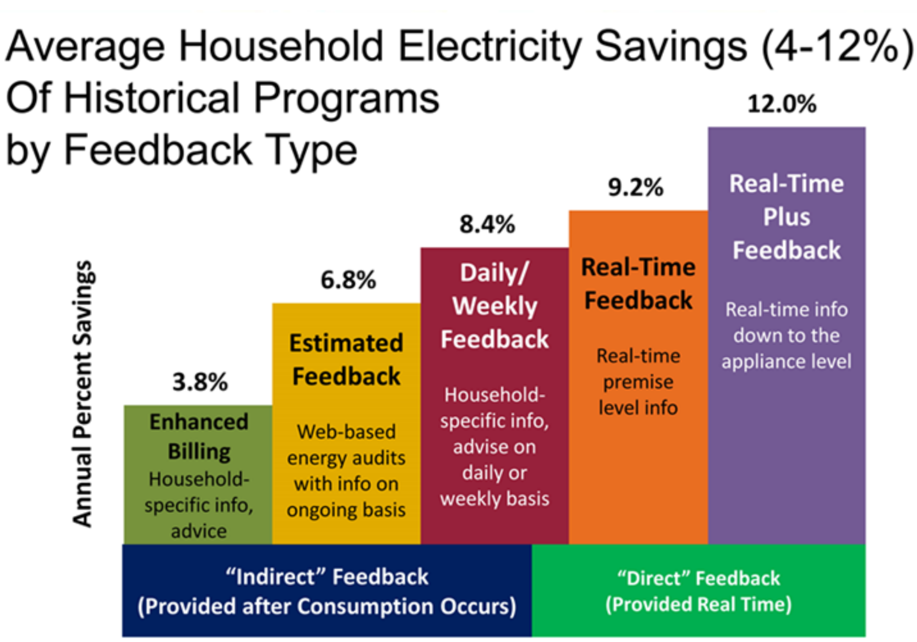
[4] http://www.cusa.uci.edu/wp-content/uploads/2015/02/PGE-HEMS-Report.pdf

components of the HEMS."[5] Finally, there is other general terminology used to describe this market, including "The Internet of Things" (IoT) which is typically used loosely and refers to similar markets and types of products as HEMS.

1.3 Background and State of the Art

Working within the stated definitions, the research team found that "HEMS" is often used as an umbrella term for the "smart home" connected products that can be part of a larger HEMS ecosystem. These products and their capabilities are not new technology, but the state of the art has advanced significantly since their introduction to the market more than a decade ago. Only a few program administrators ran pilots testing the limited capabilities of certain types of early HEMS, and published results. The pilots occurred around the same time that individuals could buy basic whole-home energy monitors such as The Owl or TED online. These instances and products, while instructive, had mixed results, thus program administrators remain reluctant to deploy HEMS on a broad scale.

Figure 1 Estimated electricity savings from a meta-analysis published by ACEEE in 2010. Source: Ehrhardt-Martinez et al., American Council for an Energy-Efficient Economy, 2010



In 2010, a report published by ACEEE, "Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Savings Opportunities"[6], began to quantify the opportunities presented by feedback initiatives, many of which utilized nascent HEMS devices and technology. The paper conducted a meta-review of 36 feedback studies implemented between 1995-2010 and found that the sample of programs across multiple continents reduced household electricity consumption by 4 percent to 12 percent on average (Figure 1). The paper also suggested that, if well-designed, "feedback programs for the residential sector might generate electricity savings that range from as little as 0.4 percent to more than 6 percent of total residential electricity consumption." One of the more revelatory conclusions from the meta-review was the observation that "indirect" feedback, such as comparative language provided in monthly billing inserts, yielded lower percent savings, while "direct" feedback, such as the two-way communication thought possible with smart meters, yielded much higher levels of potential savings when provided in "real time". These

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[5] http://www.cusa.uci.edu/wp-content/uploads/2015/02/PGE-HEMS-Report.pdf section 3.4
[6] http://aceee.org/sites/default/files/publications/researchreports/e105.pdf

results not only demonstrated that feedback was an effective behavioral tactic in getting customers to save energy, but that the more accurate and timely the feedback, the better. **This study and its published findings formed the basis for an accelerated interest in energy efficiency programs that used direct feedback as a savings mechanism**.

While the ACEEE paper was a game-changer for many researchers, manufacturers, utilities, and program administrators, enticing them to explore HEMS as an option in pilots and other program deployments, it wasn't until the introduction of commercially available smart technology, including the Nest Learning Thermostat in 2011, that consumers started to take notice of this space. Utilities and third-party program administrators alike recognized that there was potential for "smart" devices like the Nest to save energy in homes, but thus far no such device had been successfully marketed directly to homeowners. This report will cite several pilots in the years since the Nest was launched where it helped homeowners save energy.

Energy utilities and efficiency program administrators have been in a state of flux over the past several years. In 2012, Superstorm Sandy caused damage in every state on the East Coast of the United States[7], with particularly severe damage in the Northeast, where some communities were without power for several weeks. Due in part to the damage caused by Sandy to the Northeast's power infrastructure, New York launched its Reforming the Energy Vision (REV) energy modernization initiative in 2014[8] to "fundamentally transform the way that electricity is distributed and used in New York State." Along with New York, four other states – California, Hawaii, Massachusetts, and Minnesota – are actively pushing their regulated utilities towards grid transformation[9], with initiatives involving microgrids, renewables, and distribution of smart meters, amongst other goals. As discussed later in the Opportunity Assessment, HEMS could be a key to the success of these efforts by acting as an "air traffic controller" for distributed generation resources.

With earlier versions of home energy monitoring devices, vendors and program administrators alike assumed that in order to work, HEMS would piggy-back on extensive smart meter deployments in millions of existing homes throughout the country. However, with the release of products like Nest Learning Thermostats directly to consumers, and the program administrator industry reconsidering its priorities, a reliance on smart meter infrastructure to enable two-way communication with consumers may not be a safe bet. HEMS could enhance a program administrator's investment in smart meters if the advanced metering infrastructure (AMI) were open, allowing interval data to flow in such a way that a HEMS could utilize it to deliver information to homeowners, and back to the program administrator. Opening AMI networks to this type of communication has proven to be difficult for utilities, and as such, many HEMS and connected device manufacturers have developed products that do not rely on smart meters. (Further discussion of the capabilities and characteristics of HEMS will be undertaken in the Technology Assessment.)

With the technology of smart home products and platforms improving and gaining traction in the direct-to-consumer market, the research team believes that it is not a question of "if" HEMS and connected devices will make it into homes, but "when" and "how." What makes HEMS more compelling for inclusion in residential energy efficiency programs is the evolution of the technology; HEMS have transformed from early prototypes of analog, one-way communication devices to the current offerings of smart home ecosystems available through

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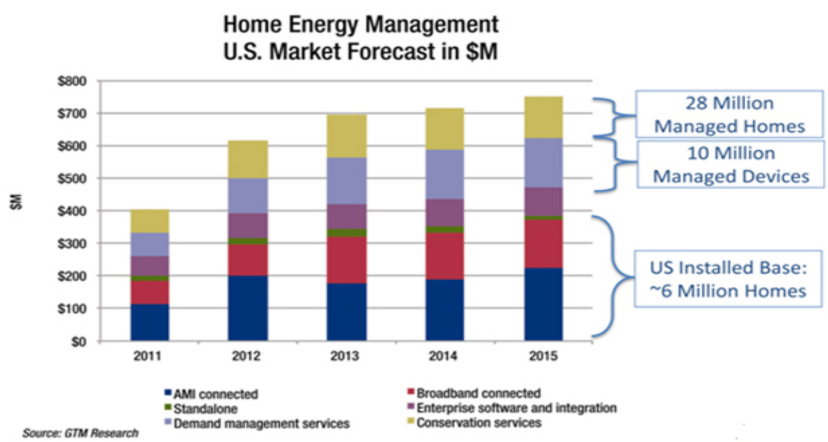
[7] https://en.wikipedia.org/wiki/Hurricane_Sandy
[8] http://www3.dps.ny.gov/W/PSCWeb.nsf/All/CC4F2EFA3A23551585257DEA007DCFE2?OpenDocument
[9] http://www.utilitydive.com/news/beyond-the-substation-how-5-proactive-states-are-transforming-the-grid-edg/369810/

retail channels, monitoring platforms that include energy feedback strategies, control devices with demand response options, and so on. HEMS no longer represent a field of devices with limited functionality. With over 240 unique products on the market, produced by venture capital-funded companies and start-ups intent on shaping the green energy economy, HEMS now represent a prime opportunity to transform the houses of today into the smart, connected, and efficient homes of tomorrow.

1.4 Industry Trends and State of the Market

With millions of customers expressing interest in home automation products, the HEMS market has room to grow and evolve. GreentechMedia (GTM), a prominent media outlet that focuses on issues affecting the energy efficiency and renewables industries, has been covering home energy management opportunities and market players since a 2013 report on the subject. Early on, GTM predicted market share of home energy management products, which can be seen in Figure 2.

Figure 2: HEMS Market share through 2015 according to GreenTechMedia.



In a consumer market already saturated with new electronics and devices, home automation products represent an entirely new opportunity for electronics manufacturers to create demand out of thin air. Manufacturers of all sizes – from small and upstart to large and very recognizable – have proven to be inventive with new types of devices, while continuing to specialize and partner. Residential renewables, electric vehicle adoption, and smart appliances also all have the potential to fuel HEMS market adoption. GTM originally forecast the HEMS market to be worth over $4 billion by 2017.[10] The market has now eclipsed this prediction: several prominent market research organizations, including Parks Associates and Navigant, have continued to track HEMS using terminology such as "home area networks" and the Internet of Things (IoT). According to a report released by Navigant Research in June 2015, "annual revenue from shipments of residential IoT devices is expected to increase from $7.3 billion in 2015 to $67.7 billion in 2025."[11]

In 2011, when the market for HEMS seemed to depend heavily on smart meter implementation, GTM held a Smart Grid HAN webinar that described what it called "tipping points", or several key conditions need to occur for HEMS to achieve wider adoption and implementation.[12] They included:

1. **Smart Meters:** The most sophisticated HEMS products are those that could communicate with a smart meter to collect and store interval meter data. HEMS are the best product available to help the utilities convert this data into feedback for the customer.

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[10] http://www.greentechmedia.com/articles/read/home-energy-management-systems-market-to-surpass-4-billion-in-the-us-by-201
[11] https://www.navigantresearch.com/newsroom/global-revenue-from-shipments-of-residential-internet-of-things-devices-is-expected-to-reach-nearly-70-billion-in-2025
[12] As indicated in GTM Research Smart Grid HAN Webinar, April 6, 2011.

2. **Idiot-Proof Installation:** HEMS are multi-part products and often have elements which need to be installed by licensed professionals. In order for homeowners to actually use them—and not just put them away, (the "kitchen drawer" effect)—they need to work out of the box and require minimal tweaking or installation by third-party vendors.
3. **Plug & Play Compatibility:** The lack of market standards, as described in the Benefits, Barriers & Challenges section, needs to be rectified in order for HEMS to achieve wider adoption. Systems should have the ability to interact with multiple meter and device types, which is currently not the case.
4. **Lower Prices:** As with all technology, HEMS devices started off as unique products but will go down in price as they reach a larger audience and mass production levels.
5. **Residential Variable (Dynamic) Pricing:** The program administrators that are using dynamic pricing—differentiating between peak and non-peak energy prices, amongst other models—are often primary drivers for the use of HEMS in electric programs. Critical peak pricing makes the home automation, demand response, and load control functions of HEMS that much more valuable to programs that are trying to achieve energy and demand savings for electric utilities.
6. **Program Direct Investment:** Many HEMS vendors started off by going directly to utilities for business, and many others have pivoted to create customer-facing devices when utilities did not respond to the market need. Program administrators may want invest more time and money into helping HEMS reach broader adoption in order to add value to their programs.
7. **Smart Appliance Mass Marketing:** While HEMS vendors are busy developing their home control and monitoring products, major appliance manufacturers have been working on their end to create products that can essentially "talk back." These appliances, which are less foreign to consumers than a completely new device such as a load control switch, will become critical to the plug & play compatibility of HEMS.

Although four years have passed and the market has expanded for HEMS devices, many of the conclusions from this webinar still ring true, especially for energy efficiency programs.

CLEAResult Home Automation Market Survey, 2014

As part of CLEAResult's ongoing primary research into new technologies and program development, an online survey was conducted with 500 Oregon residents gauging their interest in home automation and related devices in late Q4 2014. Using a margin of error of 5 percent, the results from the survey presented some very pointed insights into the market for Internet of Things (IoT) devices and where they are headed in the next several years, namely:

- 52 percent of men, versus 36 percent of women, are "Absolutely" or "Probably" investigating purchasing a HEMS device in the next 2 years
- Men were also more interested than women in comfort as well as smartphone or appliance apps
- Respondents making over $75,000 are more interested in home security than cost
- The higher wage bracket respondents are much more likely to buy home automation devices in the next 2 years
- These respondents are interested in using smartphones and wall displays

One of the biggest takeaways from this survey came from asking respondents about their top reasons for considering home automation. Respondents were permitted to select as many answers as they wished, and the top five results were as follows:

1. **Automated energy savings** (i.e. appliance knows to turn on when energy rates are cheapest, only applicable in areas with time-of-use (TOU) rates) - 53.2 percent
2. Enjoying **a more comfortable home** that "learns" heating & cooling preferences - 49.8 percent
3. Using **smart phone apps to control the home** while away (lights, heating/cooling, etc.) - 48.6 percent
4. **Improving the environment** with decreased energy use - 48.2 percent
5. **Receiving alerts** when appliances need attention (water heater, air filter, furnace, etc.) - 47.2 percent

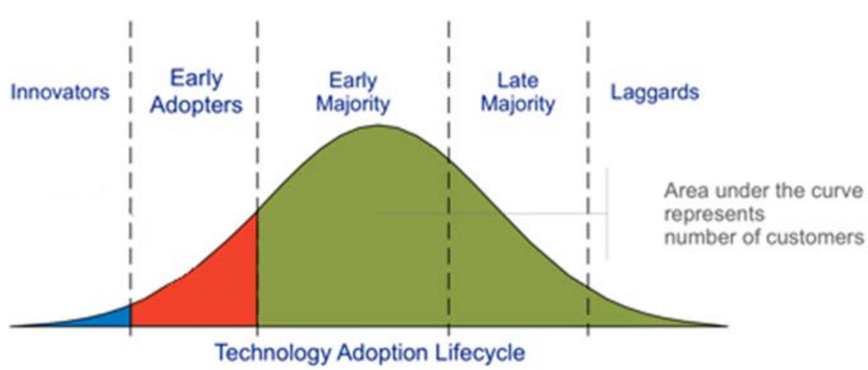
Figure 3: Consumer reasons for considering home automation products.

These and other responses to this survey question are depicted in Figure 3. Additional results are provided in Appendix B: Findings from 2014 CLEAResult Home Automation Market Survey and give further insight into consumer interest in HEMS products, for example: customers cite cost of device hardware, security and protection of personal data, and system issues (such as interoperability or rebooting errors) as their top three concerns around home automation products. The survey also showed that consumers remain interested in energy program incentives, with lighting, appliances, and HVAC incentives showing up as the most desirable; this is relevant given that HEMS may provide a platform for programs to more easily communicate program enhancements to customers.

Market Expectations: Focus on Early Adopters

While the HEMS market is rapidly evolving, new innovations are still being developed and consumers are finding them. On the Technology Adoption Lifecycle bell curve (Figure 4); some HEMS products are still in the "Innovator" or "Early Adopters" phase, primarily due to inaccessibility through traditional retail channels or because of their newness to the market and potential technical challenges.

Figure 4: Technology Adoption Lifecycle



Smart thermostats, however, have likely moved into the “Early Majority” category: according to a recent iControl survey of 1600 homeowners, 72 percent wanted a self-adjusting thermostat, but most are not looking to energy providers for these devices.[13]

In the energy efficiency industry, free-ridership is a major concern for program administrators since they cannot claim savings from those individuals who would have purchased efficient products regardless of a program. However, in an emerging market such as HEMS, early adopters and early majority participants can be “champions.” For the idea of HEMS to catch on, it must achieve market acceptance through multiple channels, and programs should take the opportunity to use early adopters to spread the word on HEMS; especially if the technology is “fun” and if social media is leveraged properly in the process.

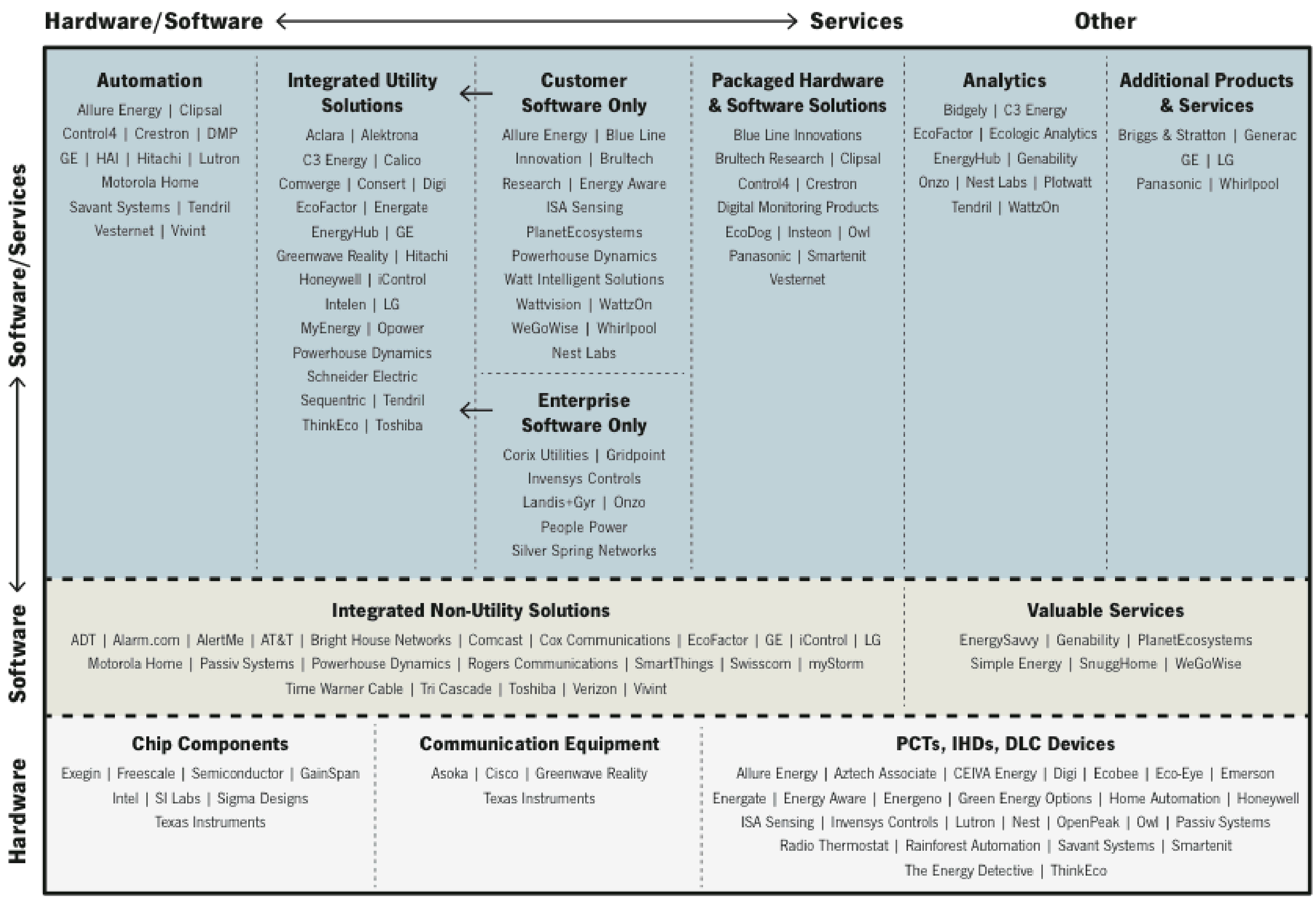
So, though new and complex, HEMS have both big and small company investment. There has been considerable traction with smart thermostats deployed through US homes, but there is still a long way to go before HEMS are widely accepted by consumers.

[13] http://www.greentechmedia.com/articles/read/smart-thermostat-is-the-most-wanted-connected-home-device

2. Technology Assessment

The Technology Assessment sets out to review and update inventories of HEMS technology from existing resources, while expanding the inventory lists and providing costs and potential linkages where appropriate. To understand how much technology has evolved, we look back to 2013, when GTM produced an extensive report on HEMS[14] which included an “HEMS Vendor Taxonomy.” This is the first instance observed by the research team in which a prominent entity attempted to qualify types of products by existing vendors, and assign hardware and software into categories, as seen in Figure 5 below.

Figure 5: GTM's HEMS Vendor Taxonomy, 2013.



This early taxonomy set the stage for several more rounds of in-depth research and characterization of HEMS technologies, including the definitions and report reviewed in this section. Through this report, the research team updated a product list based primarily off of the technology assessment prepared for the 2015 PG&E Market Characterization. The NEEP HEMS research team worked off of the existing list to add new products and include information on availability and cost (if published). This complete list is publically available at NEEP’s HEMS page and can be downloaded as a sortable workbook.[15]

[14] http://www.greentechmedia.com/research/report/home-energy-management-systems-2013-2017

[15] http://www.neep.org/initiatives/high-efficiency-products/home-energy-management-systems

2.1 Leveraging Existing Research: Key Takeaways from the PG&E HEMS Market Characterization

The 2015 PG&E report[16] provided one of the most comprehensive assessments to date of the variety and breadth of devices and software platforms that have entered the HEMS market. The report also took the important step of characterizing the diverse categories that can be found in this space, creating definitions of the categories, and slotting over 240 products into the categories, giving several of the most prominent products ample description.

Table 1 shows the major categories identified in the PG&E report as well as a count by each category. This list and additional product category information can be found in Appendix A: Master List of HEMS Products. Please note this is a live list, and will be updated in real time at neep.org.[17]

Table 1: Categories of HEMS Products from PG&E Report

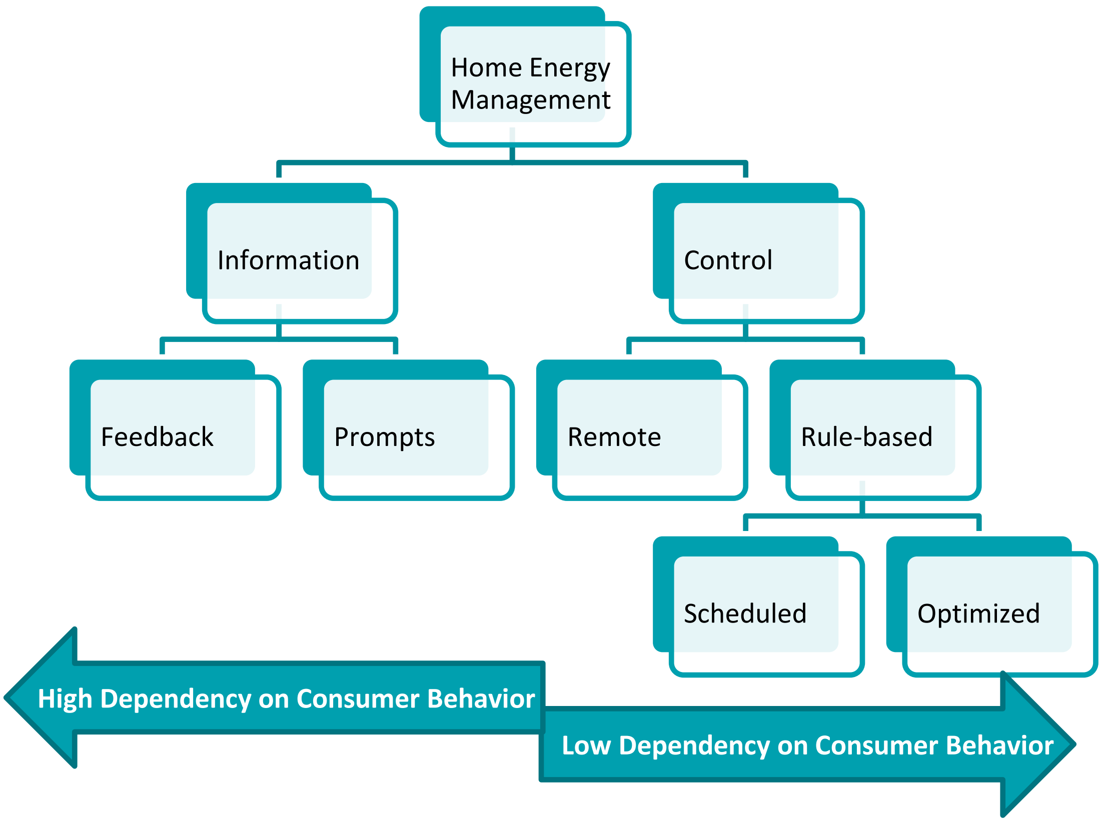
Category	Short Definition	Count of Each Category
Smart Lighting	Lighting bulbs, controls, and fixtures that have automated control functionality	12
Smart Plug	Proxy hardware piece that controls or provides feedback about connected energy consuming devices	48
Smart Hub	Device that enables and manages interaction between existing smart hardware within a single home	14
Smart Switch	Wi-Fi enabled wall switch that controls or provides feedback about connected energy consuming devices	3
Smart Appliance	Communicating appliance which can be controlled remotely via various interfaces	9
Smart Thermostat	HVAC Wi-Fi enabled control utilizing remote or rule based mechanisms	16
Energy Portal	Online dashboard that is consumer or program administrator facing	46
Data Analytics Platform	Cloud based analytics platform that analyzes large volumes of data collected from existing smart hardware	15
In-Home Display	Physical display that collects data from existing hardware and provides real time feedback and/or prompts	38
Load Monitor	Single non communicating piece of hardware that displays energy consumption data of the connected appliance or devices	18
Smart Home Platform	Software platform that enables multiple different hardware devices to operate as a home automation system	23
Web Service Platform	Cloud-based platform that focuses on more than just energy	2
Total		**244**

In addition to parsing out and defining the many categories of devices that are coming online in the HEMS space, the PG&E report took the important step of identifying and highlighting the primary functionalities of HEMS,

[16] http://www.cusa.uci.edu/wp-content/uploads/2015/02/PGE-HEMS-Report.pdf
[17] http://www.neep.org/initiatives/high-efficiency-products/home-energy-management-systems

information and **control**. As depicted in the graphic representation below (Figure 6), the Information and Control functionalities cover many specific capabilities of HEMS, and are based on the dependency on consumer behavior; an information-based HEMS, such as one that delivers feedback and counts on the homeowner to act on that feedback, will have a higher dependency on consumer behavior, while a control-based HEMS, which changes a system based on algorithms and not consumer inputs, will need to rely very little on consumer behavior.

Figure 6: Home Energy Management Functionalities, derived from the PG&E report "Characterization and Potential of Home Energy Management (HEM) Technology"



When looking at the types of devices outlined in the PG&E report and comparing them to the functionalities of “information-based” versus “control-based,” one can start to identify, and therefore assign, the categories of devices by functionality; smart lighting, plugs, and thermostats are control-based, versus energy portals and in-home displays, which are information-based. These distinctions are outlined in Table 2.

Table 2: Product types assigned by functionality: Information- versus Control-Based HEM types.

Category	Information Based	Control Based
Smart Lighting		X
Smart Plug		X
Smart Hub		X
Smart Hub + Smart Switch		X
Smart Switch		X

Category	Information Based	Control Based
Smart Appliance		X
Smart Thermostat		X
Energy Portal	X	
Data Analytics Platform	X	
In-Home Display	X	
Load Monitor	X	
Load Monitor + Smart Plug	X	X
Smart Home Platform		X
Web Service Platform	X	

2.2 Benefits, Barriers & Challenges

As referenced in the Introduction, HEMS are relatively new to the market and have both benefits as well as barriers to adoption. These challenges were discussed at length at a NEEP hosted in-person workshop on July 15, 2015 entitled "The Hidden Potential of HEMS"[18], which included members of NEEP's Regional EM&V Forum as well as participants from the NEEP HEMS Working Group. The benefits, barriers, and challenges are discussed here at length.

Benefits

While the perceived barriers are often cited as the reasoning for why HEMS programs have not yet taken off in energy efficiency programs, there are some very important benefits that HEMS can provide to homeowners and occupants as well as program administrators.

Benefits to Homeowners

Safety, Security and Comfort: There is a growing expectation by consumers that HEMS and connected devices will provide an easy and secure way to manage their smart home. Homeowners want and expect that any platform they choose will provide them with unprecedented connectivity, more visibility into their home's security, and higher levels of comfort. There is also an expectation that this advanced visibility would include instant and remote alerts for maintenance, fault diagnostics, and even the potential for auditing equipment or systems to determine optimization opportunities.

Energy and Cost Savings: As previously discussed in Industry Trends and State of the Market section, consumers are asking for automated systems that will help them save energy, and therefore money, and provide ways of "not having to do everything themselves." There is less understanding at the homeowner level of how reduction in demand can help them save money, except in territories with very high or increasing Time of Use (TOU) rates.

[18] http://www.neep.org/events/hidden-potential-hems-workshop

Information and Control: Some homeowners are motivated primarily by their interest in having greater visibility into, and therefore control over, their homes. The reasons for this range from homeowners wanting to see how much energy they are using, to managing systems remotely while on vacation or out of town, or simply for entertainment purposes.

Resilience: Homeowners are becoming increasingly interested in both renewable energy on a local scale and in energy storage, in the event that the power goes out and they need a backup. A HEMS could help manage energy balance in a home if it could tap into multiple resources to manage grid usage.

Benefits to Utilities and Third-Party Program Administrators

Enabling Demand Response: As already mentioned, while homeowners may not readily see the benefit of demand response on an individual home level, program administrators are citing the potential for demand response capabilities at a larger scale as one of their primary interests in using HEMS and connected devices.

Real-Time Usage and Measurement: HEMS could lead to enhanced usage data, which could give programs greater insight into how consumers use systems and devices, such as real hours of use in lighting. As discussed in greater detail in the following section, Potential of HEMS as a Measurement and Verification (M&V) Tool, program administrators also perceive HEMS as being able to provide the ability to better quantify savings and persistence, which could lead to real-time or near real-time M&V.

Consumer Engagement: Building HEMS into programs could make them a “gateway” for additional energy savings opportunities offered through the program, as well as a way to verify with the consumer whether or not a measure was installed after purchase.

Barriers and Challenges

The potential ability for HEMS to enable Demand Response, real-time usage metering and measurement, and automated controls is commonly overshadowed by the problems that often plague nascent technologies and systems. Many of the key barriers to HEMS becoming a part of residential energy efficiency programs stem from the rather nebulous composition of the systems themselves, suffice to say there are other critical hurdles that HEMS must overcome to achieve market adoption.

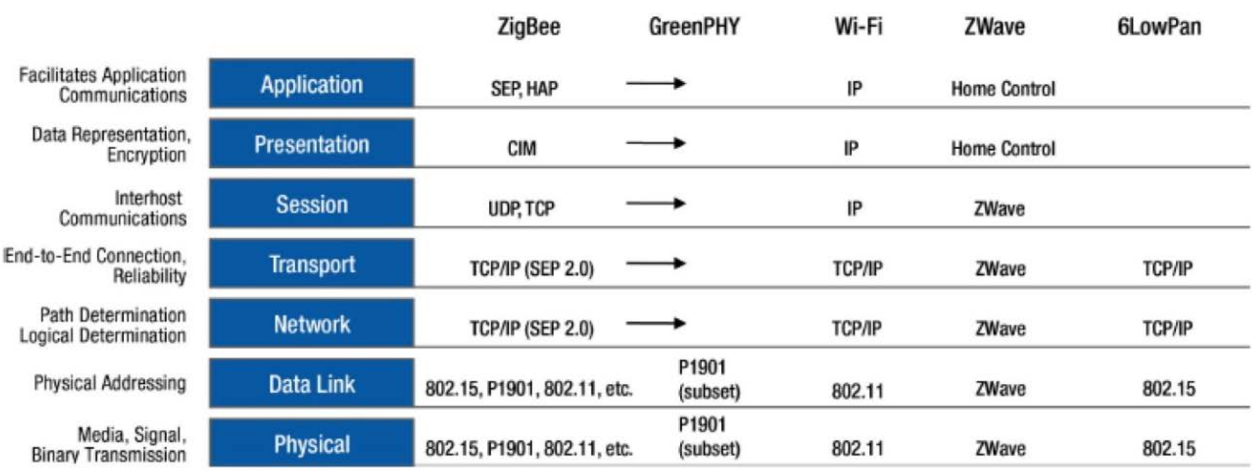
In addition to technology barriers, there are also cost, regulatory, and engagement challenges that have hindered the growth of HEMS, outlined in the sub-sections below.

Technology and Standards Barriers

Early Adopter Challenges: Many of the specific challenges facing HEMS stems from the fact that the platforms and connected devices that constitute them are all new technology that, in most cases, has been on the market for less than five years. Some of the products are released to market before they are ready and have had customer services issues as a result of trying to service what are essentially prototype devices. Additionally, almost every device has its own application interface that may or may not “play nicely” with other devices or platforms, and the notion that the “technology is not ready” is reinforced throughout the customer base and in social media.

Lack of Standards: While several manufacturers have joined together in initiatives, such as Thread,[19] to level the communication standards playing field in the HEMS market, there is currently no preferred standard for communication protocols. Even with this lack of standards and protocols, HEMS vendors are developing and launching new devices into the market without a consistent, proven communication platform, leading to market confusion and fragmentation. Figure 7 begins to describe the variations that need to be standardized for a working HEMS market. At least one national entity has announced work on standards since the inception of this project; Pacific Northwest National Lab's (PNNL) efforts will be discussed in the Policy Opportunities and Recommendations section.

Figure 7: Communication protocols and parameters according to GTM.



		ZigBee	GreenPHY	Wi-Fi	ZWave	6LowPan
Facilitates Application Communications	Application	SEP, HAP	→	IP	Home Control	
Data Representation, Encryption	Presentation	CIM	→	IP	Home Control	
Interhost Communications	Session	UDP, TCP	→	IP	ZWave	
End-to-End Connection, Reliability	Transport	TCP/IP (SEP 2.0)	→	TCP/IP	ZWave	TCP/IP
Path Determination Logical Determination	Network	TCP/IP (SEP 2.0)	→	TCP/IP	ZWave	TCP/IP
Physical Addressing	Data Link	802.15, P1901, 802.11, etc.	P1901 (subset)	802.11	ZWave	802.15
Media, Signal, Binary Transmission	Physical	802.15, P1901, 802.11, etc.	P1901 (subset)	802.11	ZWave	802.15

Incompatibility with Smart Meters: In some cases, HEMS may not be able to access the data made available through smart meters because of the many varieties of meters currently in place on homes. ZigBee and ZWave are still leading protocols for connected devices but many smart meters currently in the market are not compatible. There are hundreds of models of meters, including legacy electromechanical; Automatic Meter Reading (AMR) in which data is usually collected monthly but remotely, and advanced metering infrastructure (AMI), in which data is usually more detailed and collected in frequent intervals; allows communication between the program administrator and the customer.[20]

Cost and Distribution Barriers

Cost of Systems: There are few program administrator incentives or other opportunities to reduce initial or ongoing service costs for HEMS. Program administrators find it difficult to fund HEMS for long-term engagements with what they perceive to be questionable savings and nebulous cost-benefit analysis. There is also sometimes a significant cost in the form of monthly service fees, as well as system upgrades, which are difficult to calculate.

Cost of Energy: Not every program administrator uses dynamic pricing models, especially in the Northeast and Mid-Atlantic where electric space heating is not common. Dynamic pricing could enhance the cost-effectiveness

[19] http://threadgroup.org/
[20] The difference between AMR and AMI meters, http://news.itron.com/Pages/ami4_0808.aspx

of a HEMS-enabled program offering. Low power prices in some places are also a handicap to getting people to modify behavior with HEMS based on price alone.

Cost of Goods and Real Estate: The economy is still recovering from the Great Recession, and not everyone has discretionary income to spend money or time on a new piece of technology for which many people do not see an immediate value.

Distribution Channel Challenges: Most program administrators do not have a workable HEMS distribution strategy in their territories, and consumers would not necessarily respond well to something that came from the program administrator. Consumers much prefer to "shop" for products, and HEMS is—in their view—a product. This situation arose in 2012 with BC Hydro's decision to install nearly two million Itron OpenWay meters over the next two years, and to offer customers a rebate to buy in-home displays through stores. The "business case suggests that the choice for BC Hydro customers would be something they could go out and buy, rather than ordering it through the program administrator."[21]

Regulatory and Security Barriers

Regulatory Challenges: Federal regulations, state-level public policies, and state and local codes create innumerable "regimes" within which HEMS must find a path to operate. These are discussed more in detail in the later section, "Policy Opportunities and Recommendations."

Network Security: Recent large data breeches have left many consumers wondering how safe their private information is in "the cloud." Homeowners are also increasingly skeptical of wireless internet and cable providers and their ability to reliably deliver service.

Persistent Lack of Trust and Privacy Challenges: Many consumers feel alienated by program administrators and have security concerns about how much of their information is being transmitted electronically, and who's receiving it. Customers do not trust program administrators, regulators, or government with personal information if permission to access their data is not explicitly given. With many of the key components of HEMS residing within the Internet of Things, and the overall connectivity of these systems, one prominent challenge is the perceived "creepiness" factor that exists in how HEMS can interact with and be controlled by homeowner or occupants, as well as others outside of the home. The interconnected nature of these systems can provide great benefits to the users, however without proper feedback loops, fail safes, and network security, the potential for unwanted interaction can be considered off-putting and potentially dangerous.

Health Challenges: There is also a small but vocal segment of the population that thinks that smart meters are a source of EMF radiation. There are many who also believe that connected, communicating pieces of technology are spying on homeowners. These customers' concerns must often be satisfied before much larger segments of the population will buy into new technology.

Engagement and Usability Barriers

Out of the Box Usability: Most consumers have grown accustomed to ready-to-use devices with clear instructions. Homeowners are not receptive to complicated systems that need constant attention. Without the

[21] http://www.greentechmedia.com/articles/read/itron-cisco-win-bc-hydro/

proper engagement strategy, the HEMS might be put away and not used again. This is called the "kitchen drawer" effect.

Education and Training: Similar to the usability issue, the lack of education and training available (such as ENERGY STAR® or other customer-facing tools) to homeowners for HEMS and connected devices affects their engagement. Builders and contractors could use additional education and training should they wish to promote these devices in their businesses.

Engagement Challenges: The barriers to a customer's engagement with a system depend heavily on the behavior change techniques proposed for use. The success of a program that wishes to use HEMS relies on people engaging and being stimulated: studies have shown that behavior change will only come if there are goals, incentives, competition, and/or reasons to interact.[22]

2.3 Technology Alliances and Trends

Trends can be observed by looking at both functionalities—information and control—and then at the various categories of products. Smart home platforms and smart hardware devices often show up as control-based, whereas user interfaces such as portals, displays, and data-based dashboards show up as information-based. With this conclusion, the information is extrapolated into four "meta-categories":

1. **Smart Home Platform**: platform that enables home automation and control. These platforms do not necessarily explicitly monitor or manage energy use, but rather allow for device control
2. **Smart Hardware**: includes all connected hardware and devices that may be sold separately
3. **Customer-Facing Energy Interface**: any dashboard (often an in-home display) that could manage energy monitoring and provide energy consumption feedback to the end-user
4. **Program Administrator-Facing Energy Interface**: any dashboard which could provide territory-wide data analytics, connect to program energy savings, and/or enable demand response (DR) events to be dispatched by program administrators

Matching prominent products with these meta-categories, one can start to see a pattern: many well-known technology companies, such as Google/Nest, have pieces of a comprehensive HEMS solution, but few products have a total solution which can communicate with consumers and program administrators, while providing home automation and choice of product selection to the end-users. This leads to the conclusion that technology alliances and partnerships may play a greater part in providing comprehensive HEMS solutions that could work for energy programs.

Table 3 shows examples of prominent vendors and technology companies, and how they may align with the meta-categorization. The research team has observed that the market is crowded but converging with alliances and partnerships, and those mentioned in this table are observed or have been announced as of August 2015; these represent some of the more public products, but the team has not observed a clear leader in this space yet, nor is there any further information as to interoperability between products. But, depending on the goals of a program, a comprehensive HEMS solution using one technology company or strategic alliance could theoretically make it easier to provide data access to program administrators and to customers, and more

[22] Carroll, Ed & Brown, Mark. "Research to Inform Design of Residential Energy Use Behavior Change Pilot", Conservation Improvement Program Discussion Hosted by the Minnesota Office of Energy Security, July 21, 2009.

quickly find a solution for interoperability issues. The open squares in the table mean that there may be opportunities for additional functionalities, and therefore products, in a comprehensive HEMS platform.

Table 3: Prominent HEMS Product Families and Alignment with Functionalities

	Category	Publicly Announced Technology "Families," Alliances and Strategic Partnerships						
Control-based	Smart Home Platform (Home Automation & Control)	iControl Networks	SmartThings	Apple Homekit	Lowe's Iris			Revolv (purchased by Nest Labs)
Control-based	Smart Hardware (Lighting, Plugs, Hub, Switch, Appliances, or Thermostats)	iControl One	Samsung + SmartThings	Ecobee	Iris Smart T-stat, Iris Plugs, etc.		Energy Aware, Carrier	Nest
Information-based	Customer-Facing Energy Portal (Energy Monitoring & Feedback)	iControl				Tendril Energize	Silver Spring Networks Customer IQ	MyEnergy (a Nest Labs company)
Information-based	Program administrator-Facing Energy Portal (Energy/DR + Data Analytics)	iControl + EcoFactor				Tendril ESM	Silver Spring Networks + Bidgely	Nest Seasonal Savings / Rush Hour Rewards (Google)

2.4 Technology Assessment Takeaways

Using the excellent information and research provided in the PG&E Report to accelerate industry understanding of the device categories and functionalities of HEMS is another step in the process of discovering the potential of these systems. The perceived benefits, barriers, and challenges present us with another layer of characterization that could be useful in realizing the most appropriate applications of various types of information-based and control-based HEMS in energy efficiency programs.

3. Program Activity Assessment

In order to better understand the opportunities presented by HEMS, the research team had to first assess the programmatic activity that has taken place. First, the team conducted a survey of NEEP stakeholders as to what HEMS-related programs and pilots have been run. Second, the research team scanned prominent literature sources that catalog what efficiency programs and pilots have occurred with HEMS across North America, including any results or evaluations of these programs.

The research team focused on programs, pilots, and projects that were commenced or completed within the past five years for the Program Activity Assessment. With a few exceptions, projects completed prior to 2010 were not considered, primarily due to the large technology advancements in the last few years as well as the high implementation inconsistency of projects. Some of these early devices were either not reliable or did not have well defined platforms for engagement, contributing to variable savings results. For example, the Blue Line PowerCost Monitor is a real time electricity monitor; in the context of the larger HEMS market, this device is one of the most basic and analog options, offering limited opportunities for customer engagement. An Energy Trust of Oregon study with Blue Line monitors[23] showed no statistically significant savings. The report published in 2009 indicated significant mechanical issues, rendering the Blue Line device functionless in a number of homes, amongst other possible reasons for the lack of savings. In contrast to the Energy Trust findings, Hydro One conducted an even earlier study with Blue Line's PowerCost Monitor in 2004, over a period of two-and-a-half years and with over 400 participants, which showed a persistent 6.5 percent savings across the diverse and geographically variable pilot group.[24] The Blue Line device has since been further refined. The GroundedPower Consumer Engagement (iCES) system is another example of an early HEMS device with conflicting findings. In 2009 Cape Light Compact conducted a pilot[25] with the iCES system and found an average energy savings of 9.3 percent per participant per day. The iCES system was later purchased by Tendril, and is now fully part of the Tendril platform. A later pilot with the Tendril Energize platform yielded results ranging from 1.49 percent to 1.99 percent average savings per household.[26] The disparity in savings may be attributed to two differences about the pilots: the iCES pilot targeted high consumption users, primarily electric space heat customers, and the later Tendril Energize did not provide heavy participant training for this strictly behavior modification platform. The variability in the platforms and approaches used in these very early iterations of HEMS programs show up in the inconsistency of the results, and while they are instructive, they are difficult to qualify with the types of devices and platforms available today.

3.1 Programs Identified in Literature Scan

The research team sought to identify as many pilots, programs, and projects involving HEMS and connected devices as was feasible in the bounds of this project. The Team scanned prominent literature and publications on the subject of HEMS, including the PG&E Technology Assessment Report. The projects identified by this comprehensive report are broken out and categorized by device type in Appendix C: List of Studies, Pilots,

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[23] (Sipe and Castor) The Net impact of Home Energy Feedback Devices, 2009. http://energytrust.org/library/reports/Home_Energy_Monitors.pdf

[24] The Impact of Real-Time Feedback on Residential Electricity Consumption: The Hydro One Pilot, March 2006, Paragon Consulting.

[25] Cape Light Compact Residential Smart Energy Monitoring Pilot Final Report, March 31, 2010; PA Consulting Group.

[26] (Dougherty) MASSACHUSETTS CROSS-CUTTING BEHAVIORAL PROGRAM EVALUATION INTEGRATED REPORT, June 2013. http://www.rieermc.ri.gov/documents/2013%20Evaluation%20Studies/ODC_2013_Cross_Cutting_Behavioral_Program_Evaluation.pdf

Projects and Programs found in Program Activity Assessment, and represent the best and most up-to-date sources to the Team's knowledge. Note that Appendix C only calls out a few prominent energy portal and smart meter programs, but many utilities around the nation now offer these; there is also a notable absence of gas-specific programs since there have been very few published instances of gas programs utilizing HEMS devices to date.

During this research, the team found numerous advanced and smart power strip rebates, demand response programs, as well as smart thermostat – specifically NEST – rebates. Though they are not included in Appendix C as explained above, the team found that many of the pre-2010 pilots centered on in-home display and user behavior, reflecting the dominant state of information-based HEMS devices and technology at the time. Many of the recent pilots and programs that have come out in the last few years instead focus in on smart thermostats, following the flow of technology advancement.

Natural Gas-specific Insights: One resource that proved especially fruitful is a report commissioned by NREL in 2012 entitled "Residential Feedback Devices and Programs: Opportunities for Natural Gas"[27]. This report acknowledged that most of the research conducted on energy feedback programs to date had occurred in electricity-focused pilots, despite the fact that 43 percent of the energy used in the Residential sector in 2010 was natural gas. The researchers in this NREL project reviewed electric feedback programs in search of parallel lessons for gas programs, examined commercially available feedback options for gas, and identified three gas feedback options with strong potential. Of the three options identified, two could be achieved with the use of HEMS in gas systems: smart ("advanced") thermostats, and AMI-driven usage alerts. This report is a valuable resource for any program administrators who are considering applying HEMS in a gas-dominated region, especially in the Northeast where space heating consumes a majority of energy in the Residential sector and where natural gas is prevalent.

Two pilots that stand out from the literature scan, and which were not completed at the time of the NREL report publishing, are the Vectren and Northern Indiana Public Service Company (NIPSCO) programmable and smart thermostat pilots. The Vectren and NIPSCO pilots were conducted from 2013 to 2014 and evaluated Nest thermostats for both gas savings in the heating season and electric savings in the cooling season. These two Indiana pilots utilized randomized control trials (RCT), and also deployed programmable thermostats. Both pilots found that Nest savings were nearly twice that of the programmable thermostats. Since heating and cooling constitute the largest category for energy consumption in a home in the Northeast, this category also presents the largest opportunity for savings in that region, especially for gas consumption.

3.2 NEEP Program Activity Survey Results

In conjunction with the literature scan, a smaller sampling was done in the form of a web survey amongst NEEP partners and other program administrators throughout the United States. In the NEEP survey, there were nine questions that inquired about involvement with HEMS pilots and/or programs, technology used, fuels addressed, as well as other key factors of the HEMS work. The survey data consists of about 18 respondents' experiences with HEMS. The responses are consolidated and organized by survey question in Appendix D: Survey Responses to NEEP Program Activity Assessment Survey.

[27] http://www.nrel.gov/docs/fy13osti/55481.pdf

The survey found that many of the partners surveyed were involved with programs or pilots surrounding both gas and electricity (as seen by Question 6 in Appendix D). This follows, as the majority of the programs or pilots were based and centered upon smart thermostats. The Nest is the most common device, with the Honeywell Lyric or Wi-Fi and Ecobee thermostats as the next most common devices (Question 7, Appendix D). Most of these programs or pilots were hardware based, pointing to the hardware manufacturer's supplementary software, in-home display, dashboard or apps for further homeowner engagement. Only a select few incorporated a 3rd party software or dashboard as a part of their program or pilot.

3.3 Common Goals across Programs

In reviewing the results of the literature scan and the Program Activity Survey, one can start to see some common goals, challenges, and themes.

Goals: The majority of the pilots and projects that have been completed or are underway cite de**termination of energy savings** as the primary goal for the project, with **demand response** showing up as a strong secondary goal. Throughout many of the pilots, researchers have also shown an interest in enhancing consumer engagement, testing of AMI infrastructure, assessing the value of features of the devices being tested, and evaluating the functionality of optimization in control devices. This goal, in particular, is cited quite often in smart thermostat pilots and projects.

Challenges: Although Randomized Control Trial (RCT) is often regarded as the "gold standard" for evaluation of behavior-based programs, many projects found RCT too difficult to use, and had to employ other methodologies through which to estimate savings in their respective projects. According to the authors of PG&E's HAN pilot, one of the largest and most rigorous tests of in-home displays published, "...the impacts of the IHDs on customer electricity consumption were estimated by comparing the customers' actual electricity consumption before and after exposure to the IHDs with the energy consumption of a control group identified through propensity score matching. While we recognize the superiority of RCT in experiments involving feedback, it was not possible to employ randomization in this case because of the limited time available to recruit customers to the experiment."[28] This is mirrored by several other pilots, and reiterates the difficulty of RCT. While RCT remains the gold standard for behavior-based energy efficiency programs, the use of HEMS technology should enable programs to explore the use of interval-data based M&V practices, as described in further detail in the Potential of HEMS as a Measurement and Verification (M&V) Tool section.

Additional challenges existed in program application as well as consumer experiences of devices; this is evidenced most clearly in the Process Evaluations of the Cape Light Compact Smart Home Energy Monitoring Pilot (SHEMP) project and the differences between the Legacy (2010) and Energize (2013) cohorts[29]. In addition to the difference in savings, as observed later in Table 4, Legacy customers had a minimum electric usage to participate, versus Energize customers, who were not selected based on usage; Legacy also had a major social networking component, while Energize had none; and finally, Legacy customers also had manuals and a higher level of engagement, while Energize customers weren't provided information or training during the device installation experience.

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[28] http://www.calmac.org/publications/han_final_report_final.pdf

[29] http://www.rieermc.ri.gov/documents/2013%20Evaluation%20Studies/ODC_2013_Cross_Cutting_Behavioral_Program_Evaluation.pdf

Themes: Overall, program administrators who have incorporated HEMS and/or connected devices into a pilot, program, or project are optimistic that HEMS devices can enable energy or demand savings, while recognizing that some element of functionality testing will remain a part of the process. In several parts of the country, smart thermostat pilots and projects are finding success, delivering savings, and proving to be especially cost-effective where cooling savings are highly valued and the cost of energy is high. Several other programs have recognized the potential of behavior modification in energy users, and have attached HEMS programs to dynamic (time of use) pricing strategies.

3.4 Significant Program Activity Results and Conclusions

PG&E Meta-Analysis of Feedback Studies

Information-Based HEMS: A significant contribution of the PG&E Report and the research it built upon[30] – also leveraged in the Technology Assessment – is a discussion of the savings potential of HEMS, using the two functionalities laid out in the report and a synthesis of past findings from pilots. In regards to informational functionality, the PG&E report states that "over 100 empirical studies testing the effectiveness of providing energy information including energy portals, load monitors, and IHDs, have been conducted over the past 40 years," and reviews of several of these have appeared in literature in recent years. Four reviews mentioned from 2010 or before concluded that feedback is generally positive, but "its effectiveness is immensely variable, ranging from negative (i.e. increase in energy consumption) to up to 20 percent in energy savings." The variations in potential savings are likely attributable to research settings, methodology, and characteristics of feedback provided; to address this, the PG&E research team conducted a meta-analysis of 42 feedback studies to assess both the overall effectiveness of energy feedback as well as any "moderating effects" of specific feedback characteristics on savings outcomes. The PG&E research team reported that:

> "Previous qualitative reviews (Darby, 2006; Ehrhardt-Martinez et al., 2010; EPRI, 2009; Fischer, 2008) reported average savings of 8-12 percent, but meta-analysis results suggest the actual expected savings are closer to half of that. When taken together, the 42 studies had an unweighted mean r-effect size of .1174 (~12 percent savings). However, this effect size estimate does not take into account the variability in sizes of the studies nor does it take into account the possibility of between-study effect size variance. Therefore, we conducted both a fixed effect and random effect meta-analysis…. These analyses suggest that feedback results in statistically significant energy savings, but that the true effect is **typically in the range of 4-7 percent savings**."

From the meta-analysis and again regarding the informational functionality of HEMS devices, the PG&E team concluded that:

- Goal comparisons were the most effective informational strategy
- Combining feedback with other interventions increased savings
- "Computerized feedback" had higher effect sizes than any other medium
- When analyzed, studies of less than three months and more than one year were more effective than those that ranged from 3-12 months

[30] Karlin, B.,Ford, R., & Zinger, J., (in press). The Effects of Fe/edback on Energy Conservation: A Meta-Analysis. Psychological Bulletin

Control-Based HEMS: The PG&E research team contrasts its findings about information-based HEMS with control-based HEMS by noting that research on information-based systems significantly pre-dates that of control-based systems. Taken from a more academic perspective, the PG&E Report states that "characteristics of control functionalities, such as the controlling source (user or third party), type of control, level of intelligence, and type of loads controlled may all impact on the degree of savings achieved but empirical field studies investigating these variables are extremely rare and no conclusions can be made at this stage regarding how these variables may moderate the effectiveness of control." Despite this nuance, energy efficiency programs have enthusiastically taken to testing smart hardware in deployments across the country, with more notable efforts occurring around smart plugs (advanced power strips) and smart thermostats. Several evaluated pilots and programs utilizing smart hardware appear in the literature scan and in the Program Activity Survey, noted in the previous section and in the chart below. However, the PG&E team notes that "some manufacturers have conducted their own analyses or hired third parties to assess effectiveness" and that "systematic, comparative, replicable research is required."

Integrated Solutions: The PG&E report puts forth a third solution for HEMS technological platforms, that of "integrated solutions." Of the more notable conclusions in the PG&E Report is the postulation that HEMS savings potential is positively related to the degree of connectivity, and they point out that "companies are also involved in perpetuating the concept that integrated solutions offer greater savings than single smart hardware/user interface solutions." Using estimates based on assumptions about household behavior and inefficiencies derived from the US Department of Energy (DOE)'s Residential Energy Consumption Survey (RECS), Williams and Matthews estimated that programmable thermostats could save around 3 percent whereas "an integrated system that includes monitoring and control of appliances, plus zone heating/cooling" could save as much as 26 percent."[31] These are the types of systems alluded to in Table 3 of the Technology Assessment; integrated systems that provide both information and control functionalities may deliver more savings than a system that provided only one or the other.

Connecting the Dots

One of the most relevant takeaways in this task is in connecting the dots amongst the findings of the PG&E Technology Assessment Report and statistically significant savings identified in both the literature scan and Program Activity Survey, with the device categories of HEMS products as laid out in the PG&E report. Table 4 lists the information gleaned from the literature scanning and Program Activity Survey under these device categories, and shows savings estimates by functionality. Although, as the literature scanning exercise shows, there have been many programs that involved HEMS or connected devices in some way, fewer programs and projects have published savings, and some of the projects are still running and have no savings yet to show.

[31] Williams, E. D., & Matthews, H. S. Scoping the potential of monitoring and control technologies to reduce energy use in homes. 2007. http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=4222890&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D4222890

Table 4: Significant results in prominent HEMS and connected device pilots and projects.

Program, Pilot, or Project	Year	Location	Device Category	Functionality	Savings Results
Omaha Pricing & Behavior Pilot	2008	NE	In-home Display	Information-Based	Energy: 12%
Cape Light Compact SHEMP Legacy Cohort	2010	MA	In-home Display / Energy Portal	Information-Based	Energy: 7.8-8.8%
Stanford Google PowerMeter Study	2010	CA	Energy Portal	Information-Based	Energy: 5.7%
United Illuminating & UE3 Pricing & In Home Display Pilot	2011	CT	In-home Display (+ Pricing)	Information-Based	Energy: 8-22%
Energate - Oklahoma Gas and Electric Company Demand Response Pioneer Smart Thermostats Pilot	2011	OK	Smart Thermostat (+ Pricing)	Information-Based / Control-Based	Up to 50% during on-peak periods
Ecobee Mass. Residential Wi-Fi Programmable Controllable Thermostat Pilot	2011	MA	Smart Thermostat	Control-Based	Electric: 16% (cooling season); Gas: 11%
PG&E Home Area Network Pilot	2012	CA	In-home Display / Energy Portal	Information-Based	Energy: 5.5%
WeatherBug Home e5 DR Pilot	2012	TX	Smart Thermostat	Control-Based	Energy: 3.85%
Honeywell Total Comfort Connect T-Stat Study	2012	US	Smart Thermostat	Control-Based	Energy: 2-3%
ConEd Room and Central AC Demand Response Program	2012	NY	Smart Plug / Smart Thermostat	Control-Based	*Demand*: 0.716 kW per customer (Room ACs) 1.0 kW per customer (Central ACs)
Cape Light Compact SHEMP Energize Cohort	2013	MA	In-home Display / Energy Portal	Information-Based	Energy: 1.49-1.99%
Centerpoint Energy - WeatherBug Pilot	2013	TX	Smart Thermostat	Control-Based	Energy: 4%
Liberty Utilities: Venstar Colortouch T5800	2013	NH	Smart Thermostat	Control-Based	Energy: Gas = 69 therms (8% of heating)
California Bidgely Behavior Pilot	2013	CA	In-home Display / Energy Portal	Information-Based	Energy: 4.67 -7.43%
PSE Honeywell VisionPro Wi-Fi Thermostat	2013	WA	Smart Thermostat	Control-Based	Energy: 8%

Program, Pilot, or Project	Year	Location	Device Category	Functionality	Savings Results
PG&E Opower/ Honeywell Smart Thermostat Field Assessment	2014	CA	Energy Portal (mobile app) / Smart Thermostat	Information-Based / Control-Based	Energy: no significant savings observed
Alameda County Residential Behavior Pilot	2014	CA	Energy Portal	Information-Based	Electricity: 7.4%, Gas: 13%
Energy Trust of Oregon Nest Heat Pump Pilot	2014	OR	Smart Thermostat	Control-Based	Energy: 781 kWh/yr (4.7% average annual electric savings = 3.8% in Site Built homes, and 8.7% in Manufactured Homes)
South Central US Time-of-Use Pricing Pilot† (Demand Response Pilot)	2015	South Central US state	In-home Display / Energy Portal / Smart Thermostat / (+ Pricing / DR)	Information-Based / Control-Based	*Demand*: up to 60% during on-peak periods
Vectren Nest Smart Thermostat Pilot	2015	IN	Smart Thermostat	Control-Based	Energy: Gas = 69 therms/yr (12.5% of heating gas usage), Electric = 429 kWh/yr (13.9% of cooling electric usage)
NIPSCO Nest Smart Thermostat Pilot	2015	IN	Smart Thermostat	Control-Based	Energy: Gas = 106 therms/yr (13.4% of heating gas usage), Electric = 388 kWh/yr (16.1% of cooling electric usage)
Entergy Smart Power Strip Program	Ongoing	LA	Smart Plug	Control-Based	Energy: 85kwh/year
†Note preliminary results: authors request permission before citation (Harding and Lamarche)					

Given these results from prominent information- and control-based HEMS device programs across the country, savings ranges can be surmised for a few critical HEMS device-based programs as seen in Figure 8. All ranges are based on total energy consumed by that fuel type, and these ranges are used in further analysis for savings estimation later in the Savings Estimates for Planning section of the Opportunity Assessment.

Figure 8: Savings Ranges for Prominent HEMS Devices based on Program Results.

In-Home Displays	•Electric Savings Range: 5% - 22% •Gas Savings Range: 5% - 22%
Energy Portals	•Electric Savings Range: 5.7% - 7.4% •Gas Savings Range: 5.7% - 13%
Smart Thermostats	•Electric Savings Range: 2% - 16% •Gas Savings Range: 8% - 12.5%
Smart Plugs	•Demand Savings Range: 0.5 -1.0 kW per customer •Energy Savings Range: 1% - 4.58%

4. HEMS in Policy

The objective of this section is to identify opportunities and recommendations for policies that could help support the adoption of HEMS. This includes updates from Efficiency First as well as discussions with Kara Saul-Rinaldi, a leading expert in smart home policy and Vice President of the Home Performance Coalition. Topics include communications protocols, interoperability barriers, and data sharing considerations; as well as customer-facing data and security concerns for HEMS and connected devices; and finally, regulatory stances and opportunities for driving policy. Some of the research, conclusions, and recommendations in this section are based on the white paper "Making Sense of the Smart Home: Applications of Smart Grid and Smart Home Technologies for the Home Performance Industry", which was published in May 2014 by the National Home Performance Council[32] (now Home Performance Coalition, HPC), and which set the stage for constructive discussion around the policy drivers that can enable smart home technologies such as HEMS.

4.1 Standards, Transparency, and Security

As discussed in the Technology Assessment, lack of standards and protocols are perceived to be barriers to implementing HEMS and connected devices in energy efficiency programs. The lack of standards around **communications protocols** has been a challenge for both technology companies that wish to receive and analyze energy usage data, and program administrators that wish to use that data to enhance programs. In 2012, the National Institute of Standards and Technology (NIST) undertook an initiative to "identify opportunities to tailor communication protocols that have been designed for network traffic control to provide quality of service (QoS) to smart grid applications and to manage power flows in the smart grid between traditional and renewable generation sources and between program administrator-owned and customer-owned assets."[33] No usable standards for communication came out of this project to date.

However, recent efforts have commenced by the Pacific Northwest National Lab (PNNL) to validate and confirm the accuracy of non-intrusive load monitoring (NILM) technology[34]. This effort is hoping to establish the tools necessary to compare energy monitoring products. PNNL states that, "in the past, it has been challenging to acquire energy performance data from a building and from its individual appliances because of cost, complexity, and intrusiveness of the measurement and verification equipment and process… Despite these challenges, the data are valuable to utilities, researchers, and homeowners who want to conserve energy." PNNL is conducting this research in lab homes and Northwest Testbed Homes with a particular focus on NILM technology's ability to differentiate and measure loads in real test homes. The objectives of this project are:

- A compilation of the current state of commercially available (or nearly available) NILM technologies
- A laboratory testing protocol to provide a consistent benchmark for evaluating the efficacy of NILM technologies
- A field installation guide (or best practice guide)
- A consistent and repeatable analytical method for comparing NILM technologies to field monitored data

[32] Saul-Rinaldi, K., LeBaron, R., & Caracino, J. 2014. 'Making Sense of the Smart Home: Applications of Smart Grid and Smart Home Technologies for the Home Performance Industry.' http://www.homeperformance.org/sites/default/files/nhpc_white-paper-making-sense-of-smart-home-final_20140425.pdf.
[33] http://www.nist.gov/el/smartgrid/sgcnet.cfm
[34] http://labhomes.pnnl.gov/experiments/nilm.stm

- A comparison of the efficacy and performance of NILM technologies, as compared to actual monitored loads.

The PNNL project may be the most promising effort by any lab or entity attempting to establish standards for home energy monitoring technology to date.

The Green Button Initiative[35] is an industry-led effort to respond to a White House call-to-action to improve accessibility of energy usage data for customers. It was launched in 2012 to provide a standardized electronic format for transferring energy consumption data. In participating utility service areas, customers can download their data directly from their utility's website via a literal green button and presents a significant opportunity in **data sharing** to enable customers and program administrators more access to energy usage information, even if the program administrators themselves do not have open AMI systems. However, although this initiative was well-received when it was announced, Green Button it has not substantially increased its adopting utilities since its early days. One element of Green Button is the "Connect My Data" capability which does not presently have much support or recognition amongst programs or customers, but could be enabling for HEMS and efficiency programs.

Despite challenges on multiple fronts in establishing standards, the residential energy efficiency industry has found momentum in the **HPXML** initiative[36], which was born out of necessity in multiple programs and has evolved into a data sharing standard that is backed by both BPI and ANSI. HPXML is officially known as the "Standard for Home Performance-Related Data Transfer,"[37] and it has seen wide acceptance and usage in the industry. Its stated purpose is to "facilitate smooth communication between home performance program tracking systems and energy upgrade analysis software", which means that many of the critical home characteristic data points that are necessary for implementation of residential programs are able to be used by multiple software platforms, vendors, and dashboards. Although currently viewed solely as a solution for program portfolio and administration, the success of the HPXML standard may resolve additional **interoperability barriers** across software platforms, including the transmission of critical data points on a home-to-device level.

Another effort which may prove useful to electric utilities for dealing with interoperability issues is the development of the open automated demand response standard known as **OpenADR**.[38] The OpenADR Alliance refers to the protocol as "an open and standardized way for electricity providers and system operators to communicate DR signals with each other and with their customers using a common language over any existing IP-based communications network, such as the Internet." While specific to demand response programs and electric utilities, this effort has proved useful in breaking down barriers between utilities, manufacturers, and stakeholders at the federal level including the U.S. Department of Energy (DOE) and the Federal Energy Regulatory Commissions (FERC). The process for launching OpenADR as well as the list of certified products could prove instructive to HEMS device and product manufacturers and vendors looking to establish basic protocols for energy efficiency programs. NEEP's HEMS Working Group and its substantial list of stakeholders could be a launch pad for such an effort.

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35 http://www.greenbuttondata.org/
36 http://hpxmlonline.com/
37 http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_innovations_4-3-11_nrel_hpxml.pdf
38 http://www.openadr.org/overview

While homeowner privacy and data security is a concern and potential consumer barrier for HEMS, California is leading the nation in addressing customer data privacy. In 2010 the state passed a law that prohibits utilities from selling or disclosing personally identifiable data as well as energy usage data to third parties.[39] A program administrator is required to receive prior consent from customers in order to disclose this information. However, the law does allow a program administrator to use this consumption information in aggregate form if there is not personally identifiable information. This rule of aggregate data has been adopted by other entities as a best practice. For example, the EPA's ENERGY STAR Connected Thermostats specification looks to validate product savings by requiring manufacturers or providers to submit actual metered usage data periodically. In order to ensure customer privacy, the EPA specification will require that data is submitted in aggregate with no identifying information[40].

Internationally, a German based collaboration is looking to address customer privacy with smart devices in Europe. With recent rising concerns over European data privacy, there has been more focus on ensuring data stays within Europe and not through US based servers. Mozaiq, a collaboration of Bosch, ABB, and Cisco, will provide an open source smart home platform for 3rd party devices to share information with each other. Moziaq plans to host the data in Germany and states that it will not own or mine the customer data in order to provide a neutral and safe platform for device communication.[41]

4.2 Cost-Effectiveness of HEMS

In many ways current, and in some cases increasing, spending on energy efficiency programs is coming under scrutiny. Several recent articles have vocally questioned program spending on energy efficiency, including a recently released study on a Weatherization Assistance Program in Michigan[42]. Additionally, current cost-effectiveness rules and testing procedures, while mandated by regulators across the country, do not easily allow for the measurement of "non-energy benefits" such as health, comfort, and safety, even though program administrators realize that these are important to homeowners (as described in the Introduction). Programs and commissions alike are beginning to realize that through the strict application of cost-effectiveness testing, they may be implementing policies that unnecessarily limit demand side management opportunities.

Cost-effectiveness screening can be challenging for measures such as HEMS as they do not necessarily include all of the benefits, especially non-energy benefits (discussed further in Savings Estimates for Planning). To that end, stakeholders in residential energy efficiency programs have found an opportunity to dialogue with regulators around the Home Performance Coalition's Resource Value Framework (RVF)[43], which may be an opportunity to reset the process for cost-effectiveness testing. The RVF advocates adhering to six principles in designing energy efficiency screening tests that may make advanced technology or previously non-cost-effective measures workable for future energy efficiency programs. HEMS has the potential to play a significant role with the increasing focus on efficiency as a tool to reach a widening range of policy goals, including air quality and carbon emissions. The framework to appropriately recognize and measure the value provided by HEMS needs to be put in place.

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[39] http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200920100SB1476
[40] http://www.energystar.gov/products/spec/connected_thermostats_specification_v1_0_pd
[41] http://www.greentechmedia.com/articles/read/a-smart-home-platform-built-to-keep-european-data-within-european-borders
[42] http://econresearch.uchicago.edu/content/do-energy-efficiency-investments-deliver-evidence-weatherization-assistance-program
[43] http://www.homeperformance.org/policy-research/advocacy/about-resource-value-framework

4.3 Policy Drivers

With Efficiency First and the Home Performance Coalition (HPC), the home performance industry has strong partners who provide great clarity around policies that could impact energy efficiency programs and home performance businesses alike. According to Efficiency First, a prominent advocacy group for the home performance industry, there are three primary areas of focus in policy currently[44]:

- Protect and expand investment in energy efficiency as a resource with energy efficiency policies, to help companies in today's industry be more successful
- Leverage public investment to attract large scale investment into the building performance sector
- Drive innovation and competition to deliver value for customers and other stakeholders

In particular, the Clean Power Plan is likely to drive energy efficiency actions. Historically one of the biggest hurdles with counting carbon reduction from energy efficiency has been from policymakers who are hesitant to count these the opportunity to capture the data behind these savings and perhaps, finally, measure carbon reductions. savings. The concern arises from the standard measurement of these savings as only estimated, and not metered. The data collection capabilities, EM&V, and savings potential of HEMS on end-use energy efficiency may help some states as they determine their compliance path for the Clean Power Plan, and more generally HEMS offer

A pending state grant program, the Residential Energy Efficiency Valuation Act (REEVA), has been put together focused on the concept of using measured savings to validate energy efficiency. If passed, REEVA would provide funding for pay-for-performance home energy retrofit pilot programs that require metering in order to account for projected savings. The measured savings approach provides more accurate savings with improved measurement and verification over time and also allows regulators to pay out on defensible savings as the market drives further energy efficiency innovation[45]. This act could develop the market for energy savings.

Measured savings can play a key role in the Portman-Shaheen Bill, or the Energy Savings and Industrial Competitiveness Act, as well. This legislation includes the Sensible Accounting to Value Energy (SAVE) Act, intending to ensure mortgage appraisals account for home energy efficiency and the resulting future energy bill savings. Section 25E provides incentives to deep home retrofits on a pay-for-performance basis (an alternative to the prescriptive approach of 25C). Efficiency First is recommending adding metering after completion to measure actual energy savings for the payment.[46]

4.4 Policy Conclusions and Recommendations

With innovation as a priority for national policy organizations such as Efficiency First, and with 111(d) on the horizon, HEMS may provide the opportunity that residential energy efficiency programs are looking for to bridge the gap to real savings. Pending legislation like REEVA and RVF reflect the need and shift in focus to hold energy savings accountable with metering in order to validate energy efficiency as a legitimate energy and emissions reduction resource. While most of the conclusions and recommendations provided in the NHPC’s Smart Home

[44] Efficiency First Quarterly Home Performance Policy Briefing, July 1, 2015.
[45] http://www.efficiencyfirst.org/static/files/ENR%20Statement.pdf
[46] http://www.efficiencyfirst.org/static/files/ENR%20Statement.pdf

paper still ring true, the NEEP HEMS research team recommends additional steps to move the industry forward on policy issues:

- **Educate national stakeholders, such as Efficiency First, on potential of HEMS as an M&V tool** (discussed further in Potential of HEMS as a Measurement and Verification (M&V) Tool). Incorporate details of potential data collection – including "non-energy benefits" – into discussions with regulators about the RVF. The Northeast is a prime region in which to begin this process, with its highly engaged home performance community and advanced regulatory frameworks (such as New York's REV).
- **Establish a HEMS Alliance to develop interoperability protocols and data security best practices**, in the vein of the OpenADR project. NEEP's HEMS Working Group could facilitate the groundswell of such a group with its long and active list of stakeholders.
- Promote data sharing efforts such as HPXML and evaluate their applicability for HEMS platforms.
- Support the establishment of communication protocols and product testing standards, such as those planned by PNNL and ENERGY STAR.
- **Further articulate the industry's position** that HEMS and smart grid devices could support energy efficiency activities and M&V as part of EPA's Clean Air Act.

These recommendations connect several ongoing efforts throughout the energy efficiency industry to leverage smart home technology for enhanced program delivery and, if stakeholders can work together, may move the dial on some big-picture efforts to claim energy savings as a resource.

5. Potential of HEMS as a Measurement and Verification (M&V) Tool

HEMS have the potential to provide interval data to more accurately project baseline consumption and savings from energy conservation measures; this could be delivered with advanced metering infrastructure (AMI) or through the HEMS directly. This section leverages the May 2015 NEEA white paper Baseline Energy Modeling Approach for Residential M&V Applications[47] to explore how HEMS could enable M&V in energy efficiency programs.

The objective of the NEEA project was to establish a method for developing a robust energy baseline model for homes using hourly interval and weather data, which can be used for M&V. Additionally the NEEA research team set out to review how HEMS may be incorporating automated M&V into their software, if at all. The team surmised that if a methodology for whole-home M&V of energy efficiency projects using interval data could be established, it could:

- Provide home-by-home **savings verification** for behavior (and other measures) savings
- Allow for **interim savings estimates** during program implementation
- Provide **ongoing feedback** for utility customers
- Support an array of **financial transactions** based on measured energy savings

The key metrics used by the NEEA research team included detectable percent savings, which is the minimum reduction of post-implementation energy use that would be needed to achieve statistical significance; and mean bias error (MBE), which is the percentage by which a regression model's predicted energy use differs from the actual consumption. Using these metrics, the team successfully used interval data from 96 homes at the hourly level to model baseline conditions. The paper's key finding indicates that hourly interval models yielded a median value for detectable percent savings of 3.6 percent annually, compared to 4.3 percent for the daily models, at 90 percent confidence levels. Part-year models using nine months of data showed detectable percent savings similar to those of the full-year modeling approaches; the MBE increased moderately using six months of data, and it increased to unacceptable levels using only three months of data, leading the team to conclude that M&V on six months of interval data may be usable in some programs, but that nine months or more is generally preferred.

This section includes discovery and key takeaways in these main sub-topics:

- Using Interval Data: Updates to the NEEA Report and Current Activity
- Regional Differences in M&V Approach
- Summary of IEA-DSM and Behavior-Based Data Collection
- Conclusions and Recommendations Around M&V Potential for HEMS

5.1 Using Interval Data: Updates to the NEEA Report and Current Activity

Since the development of the NEEA white paper "Baseline Energy Modeling Approach for Residential M&V Applications," there have been a few developments to note. Relevant efforts around interval-data based

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[47] http://neea.org/docs/default-source/reports/baseline-energy-modeling-approach-for-residential-m-v-applications.pdf?sfvrsn=4

program M&V have emerged in the past several months that are worth discussing in parallel to the NEEA paper. These efforts, as well as key updates to vendors mentioned in the NEEA paper, are described in this section.

What is OpenEEMeter?

Open Energy Efficiency Meter (OpenEEMeter.org) is a newly developed, open-source platform and source code that aims to help move the energy efficiency industry toward standardization using a portfolio view of savings analysis and near real-time access to metered gross savings. In essence, OpenEEMeter is a standardized approach to billing analysis (using either monthly or AMI data, but ideally AMI) that an investor and/or utility can agree upon. The technical approach is not new, and is similar to the residential baseline energy modeling approach used by CLEAResult (and described in the NEEA paper). This model of the home's metered energy use is compared to the modeled savings (either deemed or using whole-home modeling software) to determine a realization rate. Calculating the realization rate in this manner assumes that measuring savings at the meter is more accurate than modeling the savings, which may not always be true from a home performance perspective since the home may have been used differently over time, but it is measuring the reduction that the utility actually sees. In addition, OpenEEMeter does not promote use of control groups, which are a standard for residential whole home evaluation.

How does OpenEEMeter relate to embedding M&V in HEMS or programs? OpenEEMeter could help advance the acceptance of using interval data for M&V, either within the HEMS themselves, for program analysis, or by evaluators. It is unclear how software providers with their own M&V approaches will participate under the OpenEEMeter platform due to the open-source requirements. It would be beneficial to vet a number of acceptable statistical modeling approaches so that OpenEEMeter can be flexible with all of them.

LBNL Behavior Analytics Group

The Lawrence Berkeley National Laboratory (LBNL) has put together a new research group composed of "leading experts in energy economics, experimental design, analytics, and behavioral theory [that] employ sophisticated statistical techniques and objective, rigorous, and creative research methods."[48] This group is focusing on three areas of study:

- Estimating hourly energy savings: using smart meter data to estimate energy savings
- Identifying specific actions, behaviors, and characteristics that drive energy savings in behavior programs
- Estimating persistence of savings

The group's only posted research report focuses on understanding the impact on peak demand of behavior programs. One key finding from this report is that without the granularity of interval data, it is not possible to determine when savings occur during a day. The researchers examined hourly energy use and savings using a treatment and control group for each hour of the day.

In the future, it would be useful to collaborate with Open EE Meter and LBNL on the energy modeling approach to converge on best practices.

Tendril Update

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[48] http://behavioranalytics.lbl.gov/

Tendril's Energy Services Management (ESM) platform incorporates a proprietary building modeling capability based on the EnergyPlus simulation engine, and was examined as a pertinent tool for conducting program M&V in the NEEA report. The ESM platform has one of the more sophisticated M&V methodologies of HEMS-capable companies reviewed in the course of this research; ESM creates a whole-building simulation according to International Performance Measurement and Verification Protocol (IPMVP) Option D, which is calibrated to actual monthly utility bills, since whole-home interval data has thus far not been available in all program territories. The simulation may be generated with or without a home survey (simulation accuracy is improved with a home survey) and with or without consumption data. Energy conservation measures are applied in the simulation and savings are calculated as the difference between the modeled energy use in the baseline and the retrofit simulation models. Tendril has tested its modeling processes in at least seven million homes in up to five different climate zones (results have not been reported). While savings are reported to the consumer through the dashboard, Tendril is not currently conducting independent M&V for program administrator clients.

EnergySavvy Update

EnergySavvy is a technology firm that has focused efforts in developing tools to complement program M&V. While using monthly billing data and not a HEMS, they continue to evolve and iterate the savings measurement and program optimization module of their Optix platform, entitled Quantify. Another platform that was reviewed for the NEEA paper, Quantify does not equate with a formal evaluation, despite the fact that it conducts billing analysis and produces program performance indicators. Rather, EnergySavvy describes Quantify as a tool to improve and refine program implementation that can be used as a stand-alone or leveraged with other Optix modules. EnergySavvy has continued to expand their footprint with Quantify now analyzing well over 1 million homes of data, and they've added capabilities such as targeted marketing, QA/QC, and contractor feedback to utilize the intelligence provided by usage data modeling. EnergySavvy is also committed to transparency of the modeling approaches used in Quantify and has received positive feedback from customers and other industry stakeholders on their methodology thus far; they plan to share more in the coming months about what they do, and how they do it.

Using Interval vs. Monthly Data

As described in the literature review of the NEEA report, there have been several evaluations published of programs or pilots that explored HEMS devices, including smart thermostats. Of these evaluations, all of them used monthly or daily data in their analysis, even though some had the opportunity to collect hourly interval data. PG&E's Home Area Network (HAN) evaluation[49], one of the most rigorous HAN studies reviewed, utilized hourly consumption data that was then aggregated to establish an average daily value. But the authors noted why they chose to aggregate the data to a longer time period: "...the impacts of the IHDs on customer electricity consumption were estimated by comparing the customers' actual electricity consumption before and after exposure to the IHDs with the energy consumption of a control group identified through propensity score matching. While we recognize the superiority of a randomized controlled trial (RCT) in experiments involving feedback, it was not possible to employ randomization in this case because of the limited time available to

[49] Sullivan, M.J., Churchwell, C.A., Hartmann, C.V., Oh, J. Pacific Gas and Electric Company's Home Area Network (HAN) Pilot - Final Report. November 11, 2013.

recruit customers to the experiment." With a total of 423 installations, this pilot yielded estimated daily energy savings of 5.5 percent at a 95 percent confidence level.

Most pilots do not have the opportunity for this type of rigor, and in fact, only a few pilots have attempted to measure any savings with a HEMS device. The industry standards for M&V rely on using monthly data, but as the PG&E HAN pilot demonstrated, when data is made available at more frequent intervals, smaller amounts of savings may be visible at high levels of confidence. This interval data could, in theory, be more readily available if it came through smart meters at the dwelling, assuming the program administrator allowed access to the data.

Working with Programs without Open AMI Systems

As mentioned in the Introduction, earlier versions of HEMS product development assumed that smart meter deployments would accelerate in programs across the country, and that advanced meter infrastructure (AMI) would open up, such that meter data would be accessible to different technology platforms. With utilities shifting priorities to find new energy resources, accessing smart meters through open AMI is no longer the only focus, and therefore in many instances, if interval data is to be used, it must be gleaned through other "doorways."

Several products exist that allow whole-home energy monitoring and may provide enough data to reach interval levels suitable for program M&V. The key to working with utilities that do not have open AMI systems or utilities that do not have smart meters at all may be using these types of devices in comprehensive HEMS platforms. These devices can be found in Appendix A: Master List of HEMS Products, as well as in the PG&E Report.

5.2 Regional Differences in M&V Approach

EM&V methodologies are based on aggregating energy consumption data for a pool of treatment homes and comparing that data to a control or comparison group of homes, with sample sizes typically in the hundreds or thousands. Data used in these evaluations covers both baseline and treatment periods. The sampling approach is a key consideration, as it is crucial for determining valid reference values from which to measure savings impacts.

The industry-recommended sampling approach for evaluating residential behavior-based energy efficiency (BBEE) programs follows the Randomized Control Trial (RCT) approach. In an RCT, a group of customers is offered enrollment for a program, and then a portion of that group is randomly assigned to receive the program's intervention, while others are informed that they were not chosen to receive program services (this second group becomes the control group). Energy use data for the treatment and control groups is pooled (pre and post), and the two pooled data sets are analyzed and compared in order to discern savings impacts. While RCT with pooled models is a widely recommended approach, the method can be difficult to implement. Some evaluations employ different techniques such as a matched control group or a comparison group from the population at large, due to cost, time factors, or program design limitations. A matched control group design is one in which participants in the program are matched with non-participants judged to be similar based on relevant available data. When a matched control group is employed, data analysis is still based on pooling data for the whole treatment group and the whole control group. The current evaluation community consensus is that RCT is the 'gold standard' for full program-size M&V of BBEE, HEMS, and smart thermostat programs because it corrects for opt-in bias as well as random market effects.

By contrast, residential M&V approaches using interval data are relatively new, and, although literature exists using monthly data as the primary energy data interval, there is a lack of literature on evaluation using interval data at more frequent intervals from smart meters. The NEEP EM&V Forum is working on a "Changing the EM&V Paradigm[50]" report which is meant to address this issue further. Some evaluators are beginning to employ high-frequency metering (1 minute data) on a sample of homes to help identify and disaggregate savings sources at the meter level. But, although utilizing smart meter data for an entire population of homes has remained in the pilot realm to date, this approach should not be discounted. Previous efforts, like those listed below, demonstrate that using interval data is not only possible, but very promising, especially if the data can be channeled more easily through an avenue such as HEMS.

- NEEA Baseline Energy Modeling Approach for Residential M&V Applications, Eliot Crowe, Alex Reed, Hannah Kramer, Joan Effinger, Emily Kemper, and Mary Hinkle. NEEA Research Report #E15-288, May 2015
- Insights from Smart Meters: The Potential for Peak-Hour Savings from Behavior-Based Programs, Todd, Annika, Michael Perry, Brian Smith, Michael Sullivan, Peter Cappers, and Charles A. Goldman, Lawrence Berkeley National Laboratory Report LBNL-6598E, March 2014

5.3 IEA-DSM and Behavior-Based Data Collection

Summary of IEA-DSM and Behavior-Based Data Collection

Internationally, there is ongoing work on an International Energy Agency Project under the DSM Operating Agreement, Task 24 Behavior Change, Subtask 3, Evaluation Tool.[51] The main objective of Task 24 is to create a global network of experts to evaluate and measure the human component of energy use. Subtask 3 is charged with finding ways to monitor and evaluate long-term impacts of behavior change outcomes of DSM programs. Rather than studying whether the HEMS worked, they focus on how, why, and for whom it worked.

This project will result in an agreed-upon data collection toolkit for comparing intervention studies. The project will give a more systematic way of understanding:

- User experience
- Moderation: under what conditions do savings happen
- Mediation: process by which savings happen

The researchers are pre-testing the data collection toolkit with Southern California Edison (SCE) and Pacific Gas and Electric (PG&E), and will be incorporating it into a smart thermostat field test with PG&E (4000 thermostats).

5.4 M&V Conclusions and Recommendations

In the research, the team found little evidence that any HEMS vendor has embedded M&V using smart meter data in their software. EnergySavvy has this capability, but is a program implementation software developer, not

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[50] Report forthcoming in 2015, will be published and available at http://www.neep.org
[51] More information on this effort available at: http://www.ieadsm.org/wp/files/Subtask-3-Deliverable-3-Methodology-Review1.pdf and http://www.iepec.org/wp-content/uploads/2015/papers/077.pdf

a HEMS vendor. To date, leading researchers have focused on whether the HEMS can talk to the meter (the capability of the devices in and of themselves), not how this data might have been used in programs.

Customers currently don't know the actual impact of their energy-saving efforts. This is especially true for behavior programs as well as multi-measure projects that have system interactions, where deemed savings can be most inaccurate. Evaluation teams may perform billing analysis for the overall program, but homeowners never see the results for their home – true energy savings feedback does not exist. Further, it can be difficult to see energy savings at the monthly utility bill level (commonly used by evaluators) due to low levels of savings, weather differences between pre and post project, and the limited amount of data available (one point per month).

So, should M&V be embedded in HEMS? Customers may not care about specific energy savings. Savings and persistence may depend more on the messaging of "you are saving" because each incremental action saves so little on its own and can be viewed negatively if actual cost savings are reported ("I only saved $4?!"). Message testing is an evolving area of research.

While the value proposition to customers may not be clear, the value to programs is strong.

- Currently, program process and impact evaluations are available long after the programs have ended, too late for course corrections to programs. Programs can be blindsided by poor realization rates for energy savings due to factors like underperforming measures and contractor installation problems.
- It can be costly for programs to perform quality assurance for contractor installation of measures, and this is typically done as a spot check to keep costs down. It is difficult to understand which contractors are underperforming (for program intervention), and which contractors are the highest performers (to direct more customers to).
- Utility smart meters are becoming more common; however program administrators have used the smart meter data for little beyond automated meter reading. They have not fully used the capabilities of their investment.
- We typically know little about uptake of programs by market segments (by demographic, zip code, etc.), and which segments are providing the most energy savings.

The savings measurement from HEMS can be used as feedback to customers and program staff on real, measured, ongoing program savings at the home level. This information can help identify contractor problems, underperforming measures, and other difficulties that cause huge issues at evaluation – during the program cycle – while there's still time to fix them, and with specificity into which projects have the problems. Overall, with so many potential benefits to energy programs, there exists a huge opportunity for HEMS vendors and developers to capture interval data and embed M&V analysis capabilities into their products in order to better measure savings while improving programs in a variety of ways.

6. Opportunity Assessment

In order to understand the opportunities HEMS present for efficiency programs, the research team set out to synthesize conclusions on the state of HEMS in energy efficiency programs. This analysis relies on all of the research described in the earlier sections of the report, with the goal to provide opportunities and a path forward in search of program administrator solutions to the following questions and more:

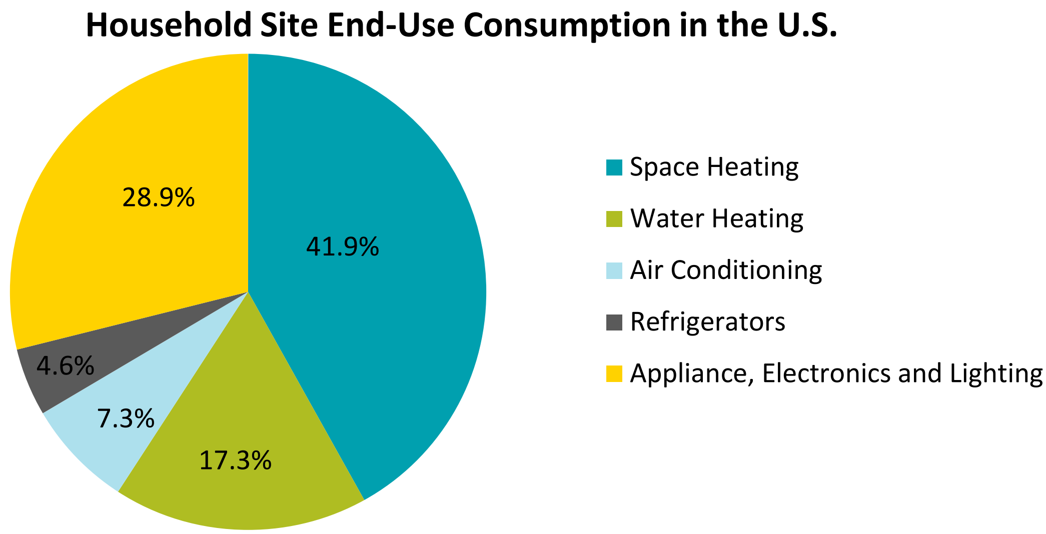
- What program types have been successful in moving HEMS thus far, using which types of products or which type of program approach?
- Which energy end uses are optimal targets for HEMS to enable energy savings?
- What are the key regional considerations for inclusion of HEMS in programs?
- What are the best channels for delivery of HEMS in energy efficiency programs? What consumer education barriers exist to HEMS programs, and what are potential strategies for overcoming them?
- How can administrators leverage behavioral strategies into a consumer engagement plan?
- What role does demand response play in HEMS? Will we rely on smart meters in HEMS programs?
- What opportunities do HEMS offer for enhanced program M&V? How can administrators work with vendors to obtain the data necessary to effectively run a HEMS-enabled program?
- What can we determine for savings assumptions for HEMS and related devices? What inputs are the most reliable for planning purposes?
- And finally, what are the most appropriate mechanisms for launching, running, and scaling programs that use HEMS to save energy?

The research team created sub-sections and “Takeaways” to organize answers to these questions and to explore the range of opportunities for integrating HEMS into efficiency programs.

6.1 Opportunities by End Use

There are a number of end uses in the home that make up the majority of the opportunities for energy savings utilizing HEMS strategies. In Figure 9 below, using data obtained from the Energy Information Agency (EIA), the breakdown of the total home energy consumption are depicted in high level bins. In particular the Appliance, Electronics and Lighting segment at 28.9 percent contains multiple end-uses which are used to determine the potential savings, while the other segments of Space Heating, Water Heating, Air Conditioning and Refrigerators are all comprised of either individual components or are made up of components that work as a unit.

Figure 9: EIA 2009 Consumption by end uses in the home



Between information-based systems and the control-based systems there is a great deal of potential for energy use reduction in each of the end-use categories. Table 5 below looks at the end-use categories and which HEMS devices described in the Technology Assessment section could potentially save energy in each end use. Space heating and cooling, appliances, electronics, and lighting all have several device options for allowing users to save energy, either through control-based devices or by allowing users to view information about how much energy they use, and to take action on that information. Water heating has different opportunities for savings through HEMS devices, such as fault detection, as well as opportunities for demand response and time of use. Refrigerators have perhaps the fewest options for HEMS devices, since they must run constantly.

Table 5: HEMS devices applicable to Energy End-use Categories

Type of HEMS Device Applicable (device descriptions found in the Technology Assessment Section)											
	Information based					Control based					
Energy End-Use Category	Energy Portal	Data Analytics Platform	In-home Display	Load Monitor	Web services Platform	Smart Lighting	Smart Plug	Smart Hub	Smart Thermostats	Smart Home Platform	Smart Switch
Space Heating	X	X	X	X	X			X	X	X	
Air Conditioning	X	X	X	X	X		X	X	X	X	X

Type of HEMS Device Applicable (device descriptions found in the Technology Assessment Section)											
Water Heating	X	X	X	X	X			X		X	X
Refrigerators	X		X	X	X		X	X		X	X
Appliances	X	X	X	X	X	X	X	X		X	X
Electronics	X	X	X	X	X		X	X		X	X
Lighting	X	X	X	X	X	X	X	X		X	X

Following are more detailed descriptions of each energy end-use category, in which overall percentages and potential savings are discussed in context with the proposed enabling devices.

Space Heating and Cooling: The potential energy savings in the overall HVAC category range from roughly 2 percent to 22 percent with information-based HEMS, averaging out to 11.5 percent across all fuel types; while control-based HEMS alone have potential for a range of 2 percent to 16 percent. The range is great due to the massive variations in behavioral- and technology-related actions that can be undertaken by the homeowner/occupant, as well as the overall potential waste on site. This category of energy use and potential savings has the widest variety of technologies available in the HEMS space with Smart Thermostats being the most desired component of any proposed system. When relying solely on information-based systems without a Smart Thermostat, actionable behaviors prompted by the HEMS engaging the homeowner/occupant comprise the bulk if not all of the potential energy savings.

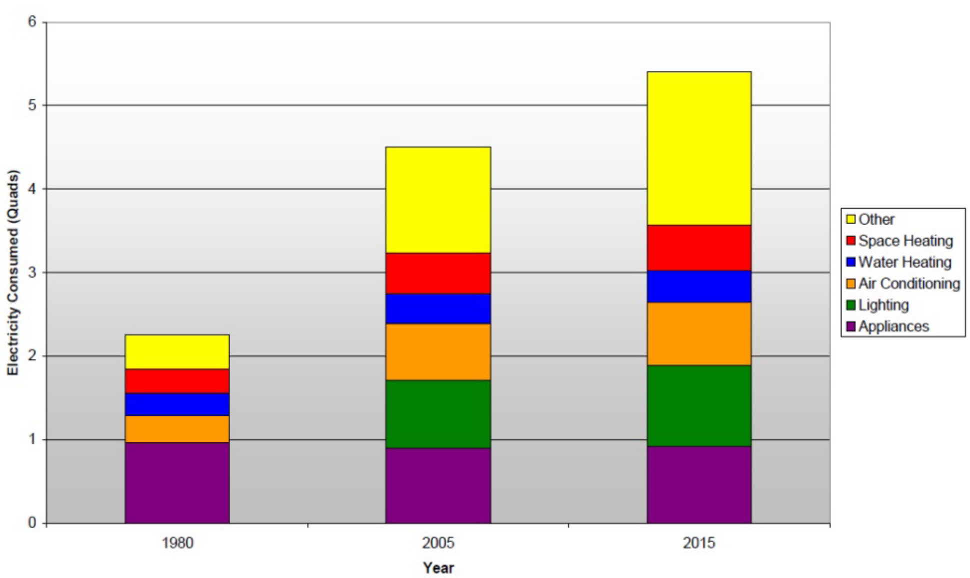
Lighting: Energy savings in the lighting end-use category are seeing a dramatic shift in potential as well as rapid evolution of technologies and applications that have barely begun to have energy savings quantified. The lighting segment of home energy use now relies primarily on LED technology coupled with smart lighting communication capabilities primarily through Wi-Fi, ZigBee and Z-Wave. Smart lamps and additional controls may work independently of any other product, or may be connected to a smart home hub or portal. Considering that much of the potential energy saving benefits from smart lighting are related to the hours of use, the potential savings varies by installation location and how the lamp is used. There are additional applications of smart lighting that have potential energy savings benefits including scene settings that have dimmed light, as well as vacancy and daylighting adjustments. These different controls of the smart lighting provide us with a wide potential range of savings. Smart Lighting is also considered to be the lowest cost gateway into HEMS in the control based category and may be a useful measure to start introducing smart technologies into homes.

Savings attributed to the replacement of incandescent lamps to the changes in hours of use and intensity of output can range from under 1 percent of whole home energy usage to upwards of 10 percent when the replacement of inefficient lamps with a smart lighting product is taken into consideration. However the smart lighting controls on their own have a smaller potential impact with typical home use, but should not be discounted in all regards. The potential non-energy benefits of smart lighting, including improved indoor comfort and safety and improved process control are far greater than the energy benefits alone. These smart lighting lamps and other controls may work independently of any other product or smart home controls associated working together as systems.

Water Heating and Appliances: With the connection to HEMS or smart meters, smart appliances such as water heaters provide opportunities for demand response savings as well as automated efficiency optimization. The ability to shed load during peak times and shift usage of these appliances to off-peak hours allows for demand response capabilities that traditional appliances are not capable of. Some smart appliances including air conditioners, dishwashers, and clothes washers can provide unique opportunities for rate payers to see savings in usage hour shifting and overall performance optimization. Water heating is also the second largest energy end-use - after space heating – with great potential for gas savings. Potential savings has been estimated in a range of less than 1 percent to upward of 5 percent of energy usage in the appliance category.

Electronics / Plug Loads: The current trend in home energy consumption has seen a shift toward plug loads and electronics as a major growth category in electricity usage across the board. According to ENERGY STAR[52], the "miscellaneous" category which includes consumer electronics continues to grow (Figure 10). With this development, plug load management is a real concern that HEMS could potentially address. Either from smart power strips or from individual outlets and switch controls, HEMS provide occupants the opportunity to reduce waste from phantom loads, un-used equipment, and active power down capability to turn off running appliances that are not being used at minimum intervals. An energy savings range between 1 percent and 5 percent appears to be achievable from HEMS-enabled plug load management devices and electronics. More specifically, studies have measured consistent savings of 2.75 percent of the home's electric use. The aforementioned savings are limited to single locations in a home, like a home entertainment center, and therefore the potential for additional locations throughout the home are not recognized in the total savings estimates listed.

Figure 10: Total Residential Electricity Consumption for 1980, 2005, and 2015 (projected)



[52] https://www.energystar.gov/ia/partners/prod_development/downloads/EEDAL-145.pdf?0544-2a1e

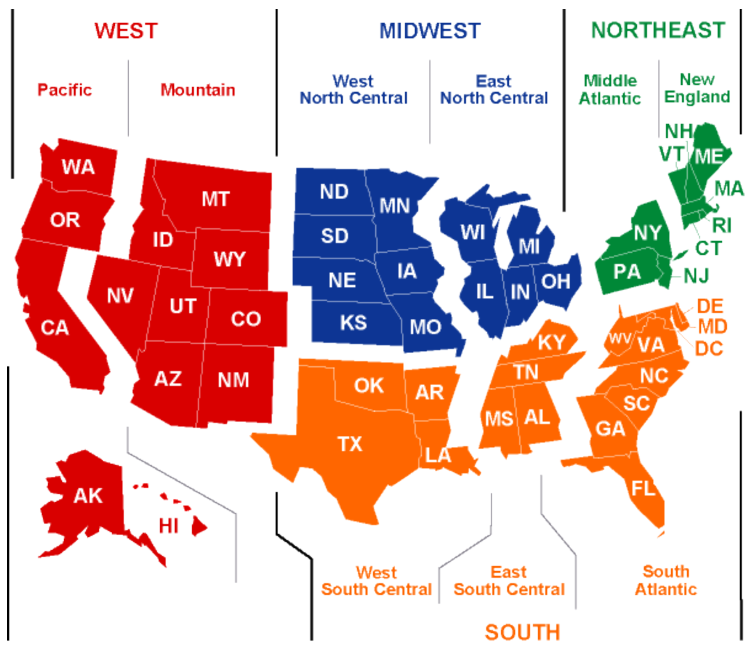
End Use Takeaways

Each energy end-use category could benefit with the addition of HEMS to a home, however, **the space heating and cooling (HVAC) category stands to benefit the most in energy savings** simply because of the large portion of energy that this category uses on average as a baseline. **The next largest area for potential savings is plug loads and electronics**, especially as this category is projected to grow, however the potential for savings here remains small compared to HVAC, and because it applies solely to electricity. Water heating and appliances may provide opportunities for small energy savings as well as demand savings, and smart lighting stands to offer other benefits to end users through enhanced control and security capabilities. As more distributed energy resources come online and the electricity generation mix changes, HEMS will offer additional benefits for managing power demand as well as energy (as discussed in the Opportunities by Resource and Applications of Smart Grid section.

6.2 Regional Considerations

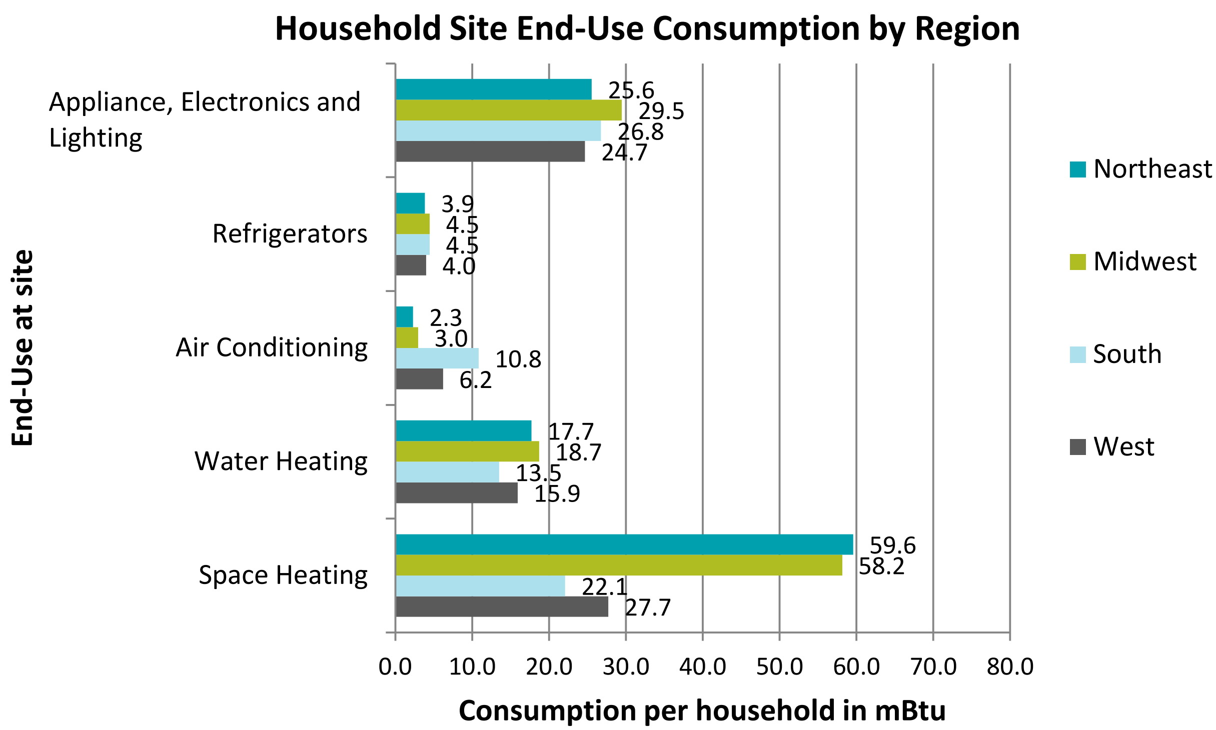
Perhaps as important as a discussion of the applicability of HEMS devices by end-use is the consideration of regional differences with respect to climate, fuel sources and the cost of energy. The EIA uses U.S. Census regions to collect and analyze energy information; in this section, we use the regions assigned by the EIA as shown in Figure 11. In the previous section we looked at global averages for energy end-use categories across the U.S. and described what HEMS devices could be most useful in addressing each end-use. When we look at these same end-uses by U.S. Census region, we observe a much more nuanced picture of how Americans use energy in each region. Using EIA data, Figure 12 shows how homes in the Northeast and Midwest regions use more than twice as much space heating energy as homes in the South and West regions. However, although total energy expenditures for cooling are much less than for space heating, the South and West use at least twice as much energy on air conditioning as the Northeast and Midwest regions. (The EIA's South region encompasses Mid-Atlantic states that are critical to this discussion of HEMS opportunities, and the research team is using some of the metrics for the South region as a proxy for the Mid-Atlantic states.)

Figure 11: U.S. Census regions used in EIA energy data collection.



Another important observation from the data in Figure 12 is the relative amount of total energy consumption in the Appliances, Electronics, and Lighting category. In the Northeast region, this category is the highest energy user after Space Heating; in the South region, this category is actually the largest energy end-use, ahead of space heating (but not as much as space heating and air conditioning combined). This is consistent with the takeaways from the Opportunities by End Use section wherein electronics and plug loads are identified as a growth category and an opportunity for electricity savings.

Figure 12: Regional End-Use consumption data in mBtu



With space heating in the Northeast constituting the largest energy end-use in any category per household in the entire U.S., using HEMS to save space energy in this region is an enormous opportunity. Combined HVAC systems also present a large savings opportunity for the South (Mid-Atlantic) states. HEMS are often thought of in terms of electricity or natural gas monitoring and controls, however, with the emergence of Wi-Fi enabled smart thermostats by many different manufacturers, there exists an opportunity for customers with a variety of HVAC systems to save energy and money. Smart thermostats are nearly always compatible with natural gas and electric HVAC systems, and several projects and pilots have proved savings to that effect (Figure 8 of the Program Activity Assessment); smart thermostats are often compatible with fuel oil and propane systems, however sometimes these heating systems have their own proprietary controls. Where central ACs are used, smart thermostats can also have a big impact, whereas those territories with high window AC adoption may find that the use of smart switches is more impactful (discussed further in the Opportunities by Resource and Applications of Smart Grid).

Table 6 utilizes the general savings estimates discussed in the Opportunities by End Use section to calculate average potential savings in each of the major space heating fuel source categories in the Northeast and the Midwest. The savings in Table 6 are based off of the total consumption of the average home in the region captured in the 2009 Residential Energy Consumption Survey (RECS) data set and only include those heating and cooling energy sources that are most prevalent in the respective areas. The percentages represent the savings from the associated HEMS delivery mechanism with the highest and lowest reported potential removed assuming that they are outliers and not representative of realistic potential.

Table 6: Savings potential in mBtu by major HVAC fuel types in the Northeast and South

HEMS	Northeast Savings Potential (Space Heating ONLY) (mBtu)			South (Mid-Atlantic) Savings Potential (Space Heating AND Air Conditioning) (mBtu)	
	Fuel Oil	Natural Gas	Propane	Natural Gas	Electricity
Information-Based	5.316%	4.554%	53.307%	2.846%	1.337%
Control-Based	6.568%	5.626%	4.086%	3.517%	1.809%

The South region includes states all the way up through the Mid-Atlantic coast to Delaware and Maryland. States in the South region are more likely to have cooling loads than any other states, however, the northern-most states in the South region experience all four seasons and have substantial heating loads during the Winter, as well. Dwellings in the Mid-Atlantic and Midwestern climate zones with large heating and cooling loads must also deal with high levels of humidity in the warmer months. Best practices in building and retrofitting homes in these climate zones means providing systems that work together to maximize interior air quality through ample ventilation and management of excess moisture in the air. In this regard, program administrators could offer HEMS that allow homeowners to monitor and control their HVAC systems while potentially providing the option for moisture management with connected sensors.

Regional Considerations Takeaways

Given the high potential for space heating and cooling savings described in the end use section, and the great potential for this category in the Northeast especially, **smart thermostats and smart controls** are likely the biggest opportunity for HEMS programs in the Northeast, in particular if those smart controls can manage HVAC systems with fuel oil or propane. Another major opportunity for programs that encourage their participants to move away from fuel oil and propane is to **bundle smart thermostats with new efficient natural gas or electric heating systems**. In the Northeast and especially Mid-Atlantic states where summer heat and humidity are a major factor, **a smart-thermostat-based HEMS may have options for humidity management specifically, but should also be demand-response capable**, since cooling systems offer great opportunities for demand savings during peak events (as discussed further in the Opportunities by Resource and Applications of Smart Grid section).

6.3 Opportunities by Channel

"***What are the options to get HEMS in homes through programs****?"* There are several channels frequently utilized in energy efficiency programs to deliver savings opportunities to customers. Direct install is a channel often preferred by program administrators because it offers reliable savings, however it is often the most expensive. **Direct install through service providers** who utilize existing channels for delivery, such as cable or security systems providers, could be considered could potentially provide existing homeowners with the necessary level of installation and set-up to ensure success of the systems; however, most service providers currently do not have a high enough level of customer service to do this successfully. **New construction** is also a big opportunity; getting into new homes early in the process is a cost-effective option and many big name builders are already installing HEMS. In fact, some higher-end builders will include the necessary infrastructure for HEMS and then give prospective owners the option to build a system out to their liking. Another option for programs to distribute HEMS that focus on electricity is through **distributed generation installation providers**, for example solar PV installers; when solar systems are installed, a HEMS can be installed to "communicate" with the onsite source generation, providing easier ways to view feedback and understand how renewable energy is used in the home. This could be an avenue for **electric vehicle** or **energy storage integration**, as well as an eventual enabler for **zero-net energy** electricity-based homes.

"***What consumer education barriers exist and what are the strategies to overcome them****?"* Another frequent topic of program deployment is the option for a customer to self-install, or the "do-it-yourself" (DIY) customers. Several well-known HEMS devices are currently available at retail outlets or online for DIY installation, but challenges with this approach include a lack of understanding of what people want out of their HEMS, or if their HVAC systems are compatible with the HEMS solution they have chosen. Customer education and proper training of potential systems were cited as barriers to adoption in the Technology Assessment section. Several issues with consumer education and awareness, as well as potential solutions, are listed below.

- **General exposure to and awareness of home energy management**: Generally speaking, consumers are growing more aware of specific devices that can contribute to a HEMS but they are not aware of products that may provide whole home energy management, often because these products are lacking in key characteristics or not marketed to a wide enough audience. It is challenging for consumers to find out exactly what products they really need, and therefore selecting the right product and all possible components is difficult. If vendors or technology families and alliances wish to package whole-home HEMS directly to customers, they must work harder to gain market traction and consumer buy-in. Bundled options that are out of the box accessible in a plug and play package are perceived to be the most user friendly option on a level that consumers would be most comfortable with.
- **Installation**: Installation and proper commissioning of the HEMS is often cited as the biggest barrier to selling devices and platforms directly to consumers. Along with schedule setting to make sure that the system is optimized, this important piece of consumer education is often not straightforward and presents additional challenges for vendors and manufacturers, who should *devote ample resources to creating simple, easy-to-understand training materials.*
- **Terminology / Taxonomy**: while the acronym "HEMS" is useful for energy program administration, it is a very technical term and probably not productive to use with customers. *More specific and user-friendly device names* or category types should be established – perhaps with the help of the NEEP HEMS Working Group – and ultimately, a common taxonomy needs to be incorporated into program administrators' communications with customers.
- **Interoperability**: As mentioned in the Technology Assessment, a lack of understanding around what devices can communicate with each other is a barrier to adoption and also a source of great frustration for many customers. *Standardizing systems* or at a minimum, communication protocols, should be a priority for device manufacturers and vendors.
- **User Interface Confusion**: In addition to challenges that consumers may face with a user interface (UI) that is not intuitive or clear, each product or device often comes with its own UI or app that controls each "thing". *Better design of UIs*, with a strategy or product to help *consolidate apps* so that consumers

don’t have to use an infinite number of apps to control their HEMS devices, would help to alleviate this barrier.

One major element of deployment to programs that is not agreed upon universally is incentives. Generally speaking, incentives can and should be offered for HEMS in energy efficiency programs to boost market share and help break down the barriers, but a lack of understanding around energy savings is a prohibitive factor to figuring out how much of an incentive could be offered. Opinions also vary as to where the incentive might show up to the customer, with rebates and bill credits cited as the most likely avenues for customers to realize rebates.

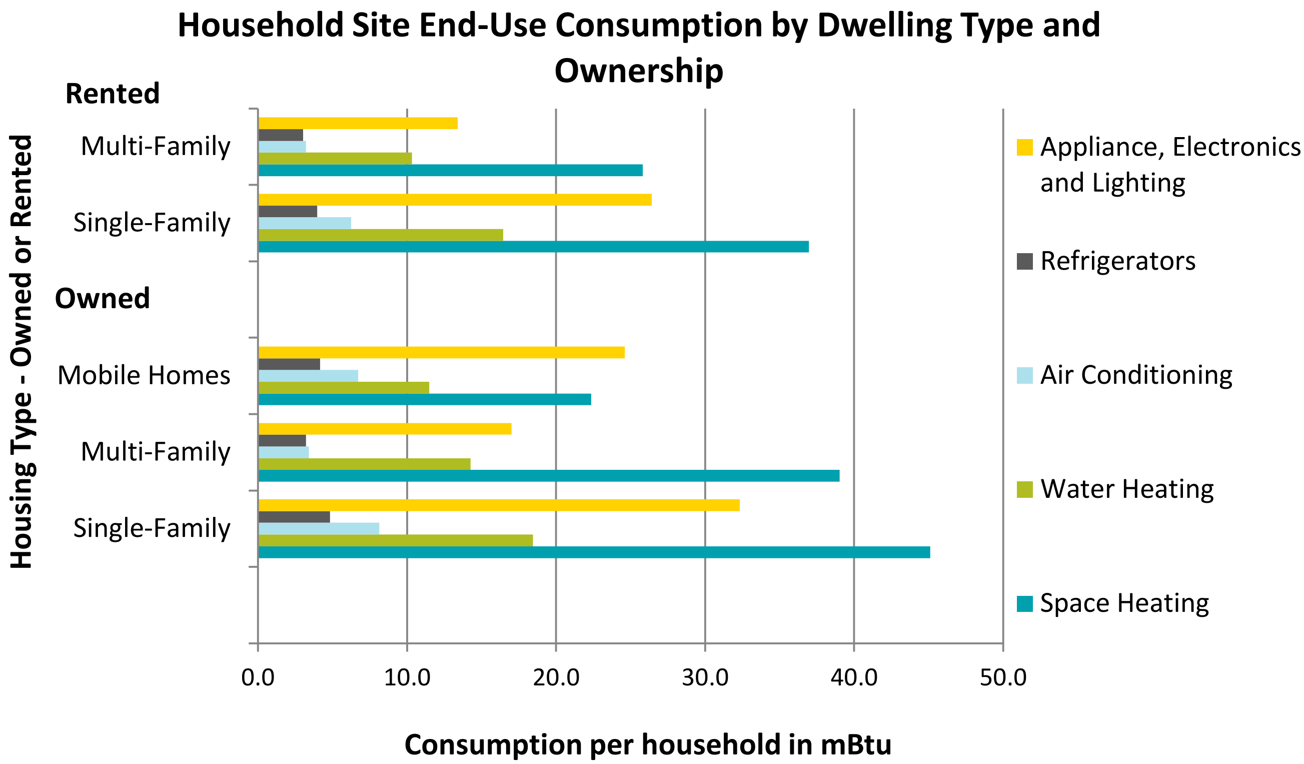
Opportunities by Channel Takeaways

The cost, distribution, and usability barriers identified in the Technology Assessment indicate that customers prefer to “shop” for devices, that they will not use something that they don’t understand, and that ultimately adoption of a new technology such as HEMS requires a “path of least resistance”. In looking at the availability of HEMS products through various channels, the **Qualified Installer and DIY / Self-Install channels seem to hold the most promise for access, distribution, customer education, and ease of installation**. The products that show up through online retailers and big box stores and that have seen the most success in sales are the ones that have simplified user interfaces and step-by-step instructions, often employing online videos for DIY installation, in-app tutorials and well-developed customer service portals and systems. In contrast, customers who work with builders or contractors to build a new house or retrofit an existing one have already placed an enormous amount of trust in that relationship, and that process would be an ideal scenario in which to introduce and install a HEMS along with proper customer education about how to use the device or platform.

6.4 Opportunities by Dwelling Type

Opportunities vary by end-use and structure type. As described already in the Opportunities by End Use section, the amount of energy consumed in each energy end-use category varies greatly and can impact which device or platform should be used. But, as we can see in data from the EIA (Figure 13), the energy used by category differs by dwelling type as well as ownership.

Figure 13: End-Use Consumption by Housing Types[53]



The following points discuss the most applicable devices and opportunities based on dwelling type.

Single Family (SF): As seen by Figure 13, owner-occupied single family homes present the greatest energy consumption per dwelling in all categories compared to the other dwelling types. Space heating and cooling combined provide the largest area of energy consumption with appliance and plug loads close behind. In certain cases, plug load consumption is higher than heating consumption. Smart thermostats, smart plugs, and appliances will provide potentially the greatest savings, though due to the high overall consumption, the majority of HEMS device types will find the most savings potential throughout the single family dwelling type. New homes and existing homes present different delivery opportunities:

- **New Homes**: Installing HEMS devices during new construction provides the advantage of addressing two barriers: *installation first costs* and *technical issues with self-installation*. Installation first costs are greatly reduced as some of the applicable devices do not require much additional labor to install over their standard counterparts; any additional labor can typically be coupled with other work. Smart thermostats and appliances are good examples of this as they typically do not require much extra work to install in place of a standard thermostat or appliance. Installing when a home is under construction also provides a much easier access, and less labor, to install HEMS that require more infrastructure, like lighting controls. Working with a HEMS vendor pre-construction provides builders the opportunity to incorporate and offer industry leading-edge appliances, potentially streamlining bulk purchasing of

[53] EIA RECS CE3.1 End-Use Consumption Totals and Averages

equipment. Installing HEMS devices in new construction also eliminates technical issues that homeowners may encounter with installing these devices themselves. However, by further removing the homeowner from this process, homeowner education is paramount to ensure the new homeowners understand how these devices work are and how to engage them. As mentioned in the Opportunities by Channel section, some builders are already beginning to offer these advanced features, commonly smart thermostats, as a part of their spec.

- **Existing Homes**: This is the most dominant dwelling type and largest channel for HEMS implementation. Existing homes will in many cases present the opportunity for larger savings over new construction given the older and typically less efficient building stock and systems. Self-installation or retail, and direct-install channels will be the most common pathways to implementation with this dwelling type as discussed previously.

Multifamily (MF): The lower energy consumption seen in multifamily dwelling types can be largely attributed to the smaller size of the housing units, as well as thermal insulation by neighboring units that often prevents additional energy loss that is typical of single-family homes. According to early 2015 quarterly data from the National Home Builders Association, the median new single family home size was 2,521 square feet[54], while the a new multifamily residence was nearly half in size at a median of 1,121 square feet[55]. The smaller size, as well as the reduced exposed surface area and stacked layout, lends to less consumption needed for space heating and cooling which is seen in Figure 13. However, there is an even larger reduction in plug load consumption in comparison to detached single family homes that can also be attributed to the smaller space constraints as inhabitants may forgo additional appliances or electrical equipment.

HEMS implementation in the multifamily market is driven by other factors than just energy consumption. Multifamily units are predominantly rentals[56], and the HEMS appeal for this market is two-fold: for renting inhabitants, and the building managers and owners. With varying degrees of ownership and dweller maintenance responsibilities in a multifamily building comes a variety of opportunities for offering incentives and incorporating new technology into dwelling spaces. According to the Freddie Mac 2015 Multifamily Outlook, Millennials have the highest likelihood to rent and will be a driver in the next few years for multifamily demand[57]. Millennials typically constitute the early adopters to new technology and HEMS are being used in multifamily buildings in the hopes of appealing to this market. There are several start-up companies, such as Iotas and Dwelo, which have built out a whole home automation system offerings to cater specifically to multifamily applications; this includes thermostats, lighting controls, appliances, and security controls. Both companies currently have pilots underway.

With these evolving market conditions come strategies specific to multifamily conditions: HEMS are being marketed to building owners as a way to not only differentiate their offerings in the rental market but also as a way to streamline building management. HEMS may also be appealing to condo owners or home owners associations (HOAs) who are looking for enhanced maintenance and control capabilities. For example, fully connected units can help automate maintenance by making it easier to monitor and control lighting, space

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[54] http://eyeonhousing.org/2015/05/new-single-family-home-size-increases-at-the-start-of-2015/
[55] http://eyeonhousing.org/2015/05/increase-for-typical-new-multifamily-residence-size/
[56] http://eyeonhousing.org/2014/11/multifamily-built-for-rent-share-remains-high/
[57] http://www.freddiemac.com/multifamily/pdf/2015_outlook.pdf

conditioning systems and security in vacant units. Direct install has traditionally found great success in this dwelling type, but as described above the market may begin to take this on as service providers/installers begin to pop-up in the HEMS space. Renters, on the other hand, may feel that they have little to no control over their dwelling environments and therefore energy usage, but plug loads and consumer electronics will still be a reachable energy end-use with this demographic; thus, direct install could be another viable avenue for HEMS devices such as smart plugs. And although the savings potential per dwelling is smaller, economies of scale for installation and volume purchases can reduce costs significantly for multifamily projects.

Manufactured Homes (MH): Plug loads are the largest area of energy consumption in manufactured homes, larger than space heating according to Figure 13. The research team conjectures that the higher consumption may actually include plug-in space heaters or room ACs in lieu of the unitary equipment that may have been accounted for in the heating and cooling categories in the EIA study. Nevertheless, smart power strips, switches to help manage plug loads and smart appliances will provide opportunity to manage this high area of consumption. Direct install and self-installation will likely be the most relevant delivery channels for this dwelling type.

Low Income: Low income customers are more likely to live in multifamily buildings and manufactured homes. Although those building types were discussed previously, there are unique opportunities for those customers who are eligible for low-income programs. One important issue is that there is still a considerable discrepancy in internet access when comparing low-income households versus the rest of US households. This gap is largest with low-income renters, which make up a large subset of the rental market. According to a 2013 housing study, almost half, or 46 percent, of renters have incomes below $30,000 with 22 percent of renters below $15,000[58]. For extremely low-income renters, 54 percent do not have internet access at home; for those with internet, cable modem is the most common form of access, with mobile broadband as the second most common form[59]. Many of the HEMS devices require some form of internet connectivity for full functionality and may not be applicable in these households. However some devices, like smart thermostat, can still have full utility in non-connected homes. Alternative channels may also be better for communicating with low income participants, for example, with those customers who pay their own utility bills, a utility program that communicates directly with these customers via their primary bill-paying mechanism is more likely to see uptake. Several utilities, such as Salt River Project, have instituted payment card programs which utilize in-home displays that allow customers to manage their energy use proactively[60]. These types of programs have shown energy savings of up to 12 percent and could be a cost-effective use of HEMS for low-income customers.

Table 7 identifies prominent program types, corresponding channels, applicable dwelling types, and HEMS products that would be available through the respective channels.

[58] http://www.jchs.harvard.edu/sites/jchs.harvard.edu/files/jchs_americas_rental_housing_2013_1_0.pdf
[59] http://www.nhc.org/ConnectivityResearchBrief_FINAL.pdf
[60] http://www.srpnet.com/payment/mpower/default.aspx

Table 7: Available HEMS products by Program Type, Channel, and Dwelling Type.

Program Type	Channel	Dwelling Type	Products Available for Programs
DIY / Customer Self-install	Retail / Big-Box	Existing SF, Existing MH	**Smart Lighting, Plugs, Hubs, Switches, Appliances, Thermostats; Smart Home Platforms; Load Monitors**
	Online e-Commerce Portal	Existing SF, Existing MH	**Smart Lighting, Plugs, Hubs, Switches, Appliances, Thermostats; Smart Home Platforms; Load Monitors; In-home Display**
Licensed Contractor / Qualified Installer	Builder	New SF, New MF	**Smart Lighting, Appliances, Thermostats; Smart Home Platform; Energy Portal; In-home Display**
	Manufacturer	New MH	**Smart Lighting, Appliances, Thermostats; Smart Home Platform; Energy Portal; In-home Display**
	Home Performance Contractor / Trade Ally	Existing SF, Existing MF, Existing MH, Low Income	**Smart Appliances, Thermostats; Smart Home Platform; Energy Portal; In-home Display**
In-Home Service Providers	Cable / Internet Service Providers	New SF, New MF, Existing SF, Existing MF, Existing MH	**Smart Plugs, Hubs, Switches; Smart Home Platform; Load Monitors**
	Security System Providers	New SF, New MF, Existing SF, Existing MF, Existing MH	**Smart Lighting, Plugs, Hubs, Switches; Smart Home Platform; Load Monitors; In-home Display**
Utility Direct to Customer / Mail	On-bill Financing / Payment	Existing SF, Existing MF, Existing MH, Low Income	**Energy Portal; Data Analytics Platform; Web Service Platform**

Opportunities by Dwelling Type Takeaways

The opportunities for HEMS by dwelling type are abundant, but in many cases are as dependent on the channel in which they are available and the occupant as on the dwelling type itself. As outlined above and laid out in Table 7, **single family homes have the most options available** through multiple channels and for HEMS products and devices, with **existing homes presenting a larger savings potential** on balance due to vintage and volume of the market. **Multifamily HEMS also present a volume opportunity** and may see quicker uptake when new multifamily building developers and owners are engaged, and systems can be deployed through the Qualified Installer / Builder channel. **Direct install** program mechanisms that work for **existing multifamily buildings, manufactured homes, and low income customers** can be leveraged for any HEMS program opportunities, especially when the product in question can help to reduce the high energy consumption of plug loads found in these dwelling types.

6.5 The Role of Behavior and Consumer Engagement

While there are a great number of behaviors that have impacts on energy consumption and demand, some behaviors may be considered more impactful or beneficial to target for modification than others, based on ease of adoption and effectiveness in energy use consumption or demand reduction. There are also concerns around the actions that may be suggested, the automation that may be employed, and the implications they may have on the owner's or occupants' lives. Information-based HEMS, in particular, present a great opportunity to reach customers through behavioral strategies and consumer engagement tactics.

"***What types of behaviors should be impacted*?"** There are many different views on what behaviors may be impacted by HEMS and what may not. HEMS users can be categorized by their levels of comfort with engagement and their willingness to modify their behaviors, as well as some categorization of the behaviors themselves. Many of the concerns around behavior with regards to HEMS can be distilled to *Comfort, Cost and Control*. Typical questions that arise for average consumers are, "Will the changes in behavior cause me or my loved ones to be uncomfortable? Will the changes in behavior cost me or my loved ones more money, and if so how much will it cost to make the impacts we want with our energy usage? Will the changes in behavior cause me or my loved ones to no longer have control over our home and our lives?"

Within the behaviors themselves there are those that are free to do or are at no cost and those that may have an associated cost. In the paper "Changing Habits, Lifestyles and Choices: The Behaviors that Drive Feedback-Induced Energy Savings"[61], Karen Ehrhardt-Martinez refers to the behaviors in the categories of "Low Cost/No Cost", "Energy Stocktaking" and "Higher-Cost Investments" and determined that the "Low Cost/No Cost" and "Energy Stocktaking" were the most likely behaviors to have any change. Additional categories of behaviors are related to the end-uses in the home and the savings is thus attributable to the interactions between the inhabitants and the end-uses. Estimates of the potential energy savings from behavior-based energy efficiency strategies range significantly from just around 2 percent to over 10 percent, and are discussed further in the section Savings Estimates for Planning.

There will likely be a number of HEMS users that are fully open to HEMS, others that will be guarded and some that may even be highly guarded. The level of comfort with HEMS may come down to the level of information that is available to a customer's HEMS about day-to-day activities in a dwelling and the lives of its inhabitants. For those that are guarded and highly guarded, there are still outstanding questions around the potential invasiveness of HEMS and the security of the data that is being gathered and utilized by the HEMS, such as when and which behaviors are being tracked. There are also additional groups that are represented as "hands-on" and "hands-off", which describes how they embrace the behavior augmentation. It is important that program administrators conduct proper *customer segmentation* and market research before a program is launched in order to parse out these qualities of their customer base, and ultimately to estimate both projected participation and potential savings in new approaches.

A discussion of how HEMS can utilize behavior modification techniques in programs must include an understanding of the customer engagement/ re-engagement cycle. It is simply not enough to provide energy consumption feedback to the customer; they have to know what to do with it, or else they are likely to do

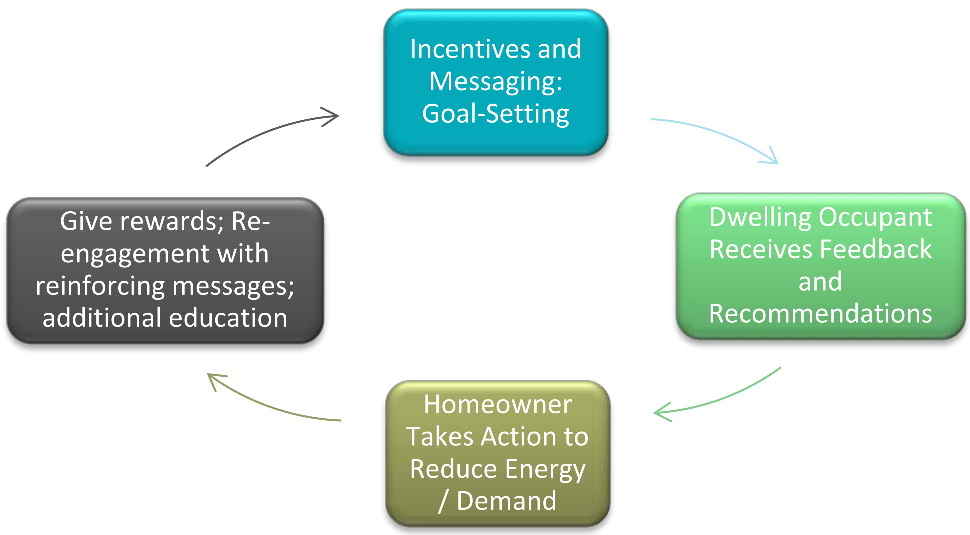
[61] http://web.stanford.edu/group/peec/cgi-bin/docs/behavior/research/Ehrhardt-Martinez%20ECEEE%20Feedback%20Behaviors%208-454%20FINAL%20(2).pdf

nothing. These overarching behavioral strategies are identified in the research as critical elements of behavior-based energy efficiency programs:

1. **Goal setting**. The customer must participate in setting their own goals.
2. **Incentives and Rewards**. Incentives should be offered in order to help the customer achieve their goals. If the customer achieves their goals or reaches intermediate steps, rewards should be given. This could be in the form of a points system or otherwise.
3. **Feedback**. Customers need feedback in order to see how close they are to achieving their goals.
4. **Interaction and/or Social Networking**. The more the customer interacts with the system and others using the system, the more likely they are to continue using it.

Put into practice, these strategies can be applied in the customer engagement / re-engagement cycle shown in Figure 14.

Figure 14: Customer Engagement / Re-engagement Cycle.



Behavior and Consumer Engagement Takeaways

Program administrators can employ **customer segmentation** ahead of full program deployments of **information-based HEMS** to estimate likely participation of their customer base in a behavior-based energy efficiency program. Utilizing the **basic behavior strategies of goal setting, incentives and rewards, feedback, and interaction** gives program administrators the opportunity to develop a program with specific tactics that fit their requirements, customer base, dwelling types, and climate zone. For information-based HEMS to be effective when deployed in a program or otherwise, they should use some elements of these behavior strategies.

6.6 Opportunities by Resource and Applications of Smart Grid

While the thrust of this report is to identify opportunities for HEMS in energy efficiency programs, there can be synergies between energy efficiency and demand response, particularly within electric programs. In the white paper "Making Sense of the Smart Home"[62], the HPC identified potential synergies between home performance programs and automated demand response as a benefit to using smart grid and smart home devices. Residential energy demand makes up 60 percent of peak load in certain parts of the U.S., with states like Texas seeing 75

[62] (Saul-Rinaldi, K. et al)

percent of their peak demand coming from residential and small commercial customers in the summer.[63] The residential sector has the largest seasonal variance in peak usage, with peaks each summer and winter for increased cooling and heating, respectively; according to HPC, customers who participate in energy efficiency measures through home performance programs will have tighter and more insulated homes and "may be more tolerant to the temperature adjustments that are necessary during demand response events, which could lead to higher program retention and enrollment rates."

"***What is the role of demand response in HEMS program implementation***?" Both control-based and information-based HEMS offer new options to program administrators for shaving peak loads in high demand situations, in addition to saving energy. With a control-based HEMS, devices could be installed that can manage loads automatically by turning appliances or systems' motors off, or to a lower power setting, during peak times; this is known as automated, or traditional, demand response (DR), and often referred to as "direct load control" for the actions program administrators take in curtailment.

A well-known example of an automated demand response program that utilized a HEMS device to manage demand is the Consolidated Edison (ConEd) auto demand response program launched in 2012, which used the ThinkEco modlet smart plug to manage 10,000 window and wall air conditioning units throughout New York City[64]. Air conditioners have historically been optimal systems with which to launch DR programs, given that peak load often occurs during the heat of the summer in most North American climate zones, and program administrators estimate an average 1.0 kW of load reduction per connected central air conditioner (AC). The objective of the 2012 ConEd program was to shed 5 megawatts during peak, in addition to the 34 megawatts of DR that the program was already getting from 25,000 central AC customers with Wi-Fi-enabled thermostats. Both the room AC and central AC programs were evaluated and deemed cost-effective, with the room AC program showing average demand reduction of 0.716 kW per customer over two summers, and the central AC program showing average demand reduction of 1.0 kW per customer.[65]

"***What is the role of smart meters, and how little or how much will we rely on them***?" HEMS are able to provide capabilities that are both complimentary to smart meters and potentially redundant. Information-based HEMS enable more two-way energy consumption-level communication by providing a user-friendly interface for the homeowner. These HEMS have potential to "speak" with a smart meter for demand response programs, receiving pricing signals and enabling the homeowner to engage based on their own preset choices. The smart meter itself provides limited value to the homeowner in comparison to HEMS which are able to better engage and empower the homeowner. In fact, by leveraging broadband wifi connections, some HEMS have the capability to entirely bypass the need for the meter for communication[66]. Instead of having to rely on a communication network set up by a smart meter, the internet can provide an alternate pathway with the benefit that this infrastructure is already present in a majority of homes. Smart meters are still important in typical DR programs in order to provide dynamic pricing, but HEMS provide another layer of feature sets to engage the homeowner with. One key feature of smart meters is the ability to provide interval usage data;

[63] Savenije, Davide. 2015. 'Who Cares About Residential Demand Response?'. Utility Dive. http://www.utilitydive.com/news/who-cares-about-residential-demand-response/202868/.
[64] http://www.greentechmedia.com/articles/read/coned-taps-10000-window-ac-units-for-demand-response
[65] http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BB473E520-E7DF-4092-9621-0050873B8018%7D
[66] http://www.energateinc.com/smart-home-energy-management-without-smart-meter/#.VcSslvlViko

certain HEMS are also equipped with this ability – providing individual, whole home, or even disaggregated interval data.

Information-based HEMS present a different opportunity for demand response and energy efficiency programs. With the ability to communicate with consumers about their energy usage, rate and usage information, such as **time of use (TOU)** or **dynamic pricing** changes, could reach consumers much more quickly. Information-based HEMS may also enable program administrators to observe fuel usage other than electricity, and perhaps encourage reduction of energy consumption in natural gas, fuel oil and propane. Many customers perceive DR in isolation to be an "intrusion" by utilities, so more options for communication should be given to consumers. An emerging DR program option for administrators who utilize information-based HEMS devices is behavioral demand response (BDR), in which a message about a curtailment event is delivered to a participant in a BDR program, and then the person choses whether or not to participate in that event. Customers who participate will reap the rewards of the program while those who do not will likely experience higher TOU pricing.

Not all HEMS are capable of demand response, but with the advent of electric vehicles and the enormous pressure they will likely be placing on electric utilities' infrastructure in the not-too-distant future, HEMS may be the key to load shifting, managing energy storage, and ultimately energy balancing. For instance, program administrators looking for solutions to increased strain on the electric grid due to a sharp uptake in electric vehicles, particularly those that charge during peak daytime hours, may discover that a HEMS can both automatically manage electric vehicle chargers while encouraging owners to charge during off-peak times. In a similar vein, HEMS also provide an interface with which to manage the usage of energy storage, potentially shifting electricity from solar PV arrays to storage batteries when the solar array is in full production and then allowing stored energy to flow back into the dwelling once the sun has gone down or to the grid during peak events. Dwellings without storage banks could use HEMS to inform them of energy production from distributed generation, and to help balance the flow and draw of electricity to and from the grid. These are capabilities that many HEMS do not currently offer, but vendors and manufacturers that produce hardware and dashboards to monitor energy consumption and respond to demand events are the most likely candidates for product evolution.

Water efficiency and carbon emissions reductions are also critical issues for many jurisdictions, which are looking for new mechanisms, both through the market and regulation, to help deal with water shortages and ways to curb air pollution and greenhouse gas emissions. HEMS monitoring and control capabilities may extend to home energy metrics and labeling, which could give customers an idea of how much they are contributing to carbon emissions; as well as water consumption and conservation, through Wi-Fi enabled sensors and advanced control systems.

Table 8 describes opportunities for HEMS as they pertain to resources, with distinctions noted between information-based and control-based systems.

Table 8: Opportunities for HEMS Devices by Resource

Resource	Information-based	Control-based
Energy Efficiency	Providing feedback about energy use to customers Providing info on rewards, incentives, additional actions, and other EE program measures	Providing options for controlling energy-using products or systems by customers
Auto Demand Response	Informing customers of an impending DR event	Provides direct load control of energy-using products or systems by program administrators
Behavioral Demand Response (BDR)	Informing customers of a change in energy rate (time of use pricing - TOU) Asking customers to reduce use; making suggestions about how to reduce use Asking customers to opt-in to next DR event	
Load Shifting / Energy Balancing (from Distributed Generation)	Pertains to Electric programs Inform customers of renewable energy production	Pertains to Electric programs Automatically shift home energy consumption from grid draw to solar PV draw when the sun is shining and PV array is in full production
Greenhouse Gas Emissions / Labeling	Informing customers of key metrics about home's energy consumption Informing customers of how much GHGs they are emitting Automatically giving home an energy label Metrics to facilitate home sales	
Energy Storage	Informing customers of how much electricity they have "stored" in batteries	Shifting to stored energy in case of power outage/emergency (grid resilience) Allowing grid to draw on energy stored in batteries or thermally
Water	Informing customers of their water usage/costs Informing customers in case of leaks	Automatically shut off water in irrigation systems when overused Manage community water usage (at scale)

Resource and Applications of Smart Grid Takeaways

HEMS present a major opportunity for program administrators who wish to achieve demand savings in their energy programs. Both information-based and control-based systems offer capabilities that could enable a program to **deliver energy savings as well as demand response cost-effectively**. More than just savings, however, HEMS may be critical to managing energy at a local level that could **facilitate electric grid resiliency**. And, beyond energy, HEMS may also provide **auxiliary resource conservation benefits** to customers, such as water usage control capabilities and information about greenhouse gas emissions, which could scale and ultimately provide benefits to a broader community.

6.7 Potential for Program M&V

M&V of HEMS programs will seek to measure three main categories of energy savings: behavioral/operational savings stemming solely from the occupants' interaction with information-based HEMS; savings that stems from automation algorithms built into control-based HEMS; and savings from any additional retrofits motivated by the feedback provided by the HEMS to the occupants. Behavioral and operational savings are very difficult to measure using engineering calculations, and best practice is still randomized control trials (RCT); however, this practice has its limitations and so ranges based on all available research are proposed in the following section. The difficulty stems from the wide range of changes offered by HEMS and the problem of collecting reliable data on which changes occurred and at what times. Savings from retrofits motivated by the HEMS-provided information could be substantial, but presents risks of double-counting with other programs as well as opt-in bias. Savings from control-based devices has proven to be more straight-forward to quantify; several programs identified in the Program Activity Assessment have reported results showing savings using control-based devices, which have been vetted in multiple evaluation circles.

In the short term, International Performance Measurement and Verification Protocol (IVMVP) Option C – whole-home M&V – seems to be the most applicable solution to helping solve the challenges posed by information-based systems. This option could take multiple forms. Billing analysis of hundreds or thousands of homes together, particularly if performed in a "gold-standard" control vs. intervention study, would certainly pass muster with regulatory bodies. Alternatively, promising work has been performed on automated individual-home analysis[67]. Compared to traditional billing analysis, this newer approach could provide more actionable greater program insights – for example, which types of homes, households, or devices save more than others - and potentially provide value through trusted savings estimates to the customer as well.

"***What data points do we need to make HEMS programs successful***?" While energy savings is key, additional efficiency metrics should include time of use, the number of "widgets" impacted or used, as well as the type of communication used in the program. Communication could differ from an automated interaction with the widget, or user prompted, with varying messaging, timing, platform and response that should be tracked. One added benefit of a HEMS system is the ability to capture a snapshot of the baseline energy consumption of a dwelling, and then monitor for any potential rebound or "takeback" effects after program mechanisms or upgrades are applied.

Ultimately, some programs will likely seek to use deemed savings estimates for proven HEMS approaches. However, reliable deemed savings estimates will likely not appear for years, and will be less stable than for other technologies, due to the rapid product evolution inherent in HEMS hardware and software. Furthermore, systems that use the same strategy (information or control) can use different algorithms and approaches, adding to the difficulty of generating reliable deemed savings estimates. However, national standards and protocols, such as ENERGY STAR setting expectations for qualifications of smart home products, could hasten the effort to provide deemed savings within limited product categories.

[67] NEEA Baseline Energy Modeling Approach for Residential M&V Applications, Eliot Crowe, Alex Reed, Hannah Kramer, Joan Effinger, Emily Kemper, and Mary Hinkle. NEEA Research Report #E15-288, May 2015

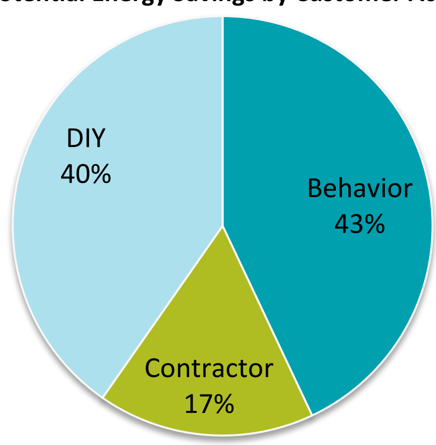
Potential for Program M&V Takeaways

Given HEMS' evaluation challenges, successful programs **should design for evaluation and include ease of EM&V in program priorities**. Especially if an RCT or control vs. intervention study is not planned, data collection to support a logical link from program participation to observed energy savings is of high importance. A careful balance between program flexibility in allowing different technology sets and M&V feasibility is needed. If program participants mix and match a wide variety of products for their individual home systems, determining which products resulted in energy savings in M&V is likely to be impossible through traditional billing analysis and difficult through individual-home analysis. It may be possible in such situations to quantify overall program savings, but not to provide guidance on program approaches and product inclusion. This is where the greatest potential for HEMS to measure savings may show up; if manufacturers and developers can incorporate dynamic data collection protocols that **capture individual home energy usage at interval-data frequency into HEMS platforms, M&V algorithms could measure savings in near-real-time** and provide immediate value to programs.

6.8 Savings Estimates for Planning

"***How are HEMS saving energy? What inputs should be used for savings estimation? What methodology would establish confidence in savings estimates for planning purposes***?" Analyses of HEMS programs have calculated widely varying savings estimates for different programs. As noted in the PG&E Report, savings estimates vary from 2 percent to 22 percent; their meta-analysis indicates that future programs should expect savings more in the range of 4 percent to 7 percent. Utilities and administrators planning programs will need to compare their proposed program design to past implementations in order to choose an estimated savings percentage within an acceptable observed range for their territories usage patterns and climate zone. The primary savings estimates listed above are not indicative of the demand response load shedding potential of HEMS integration and there are studies (not reviewed in this report) looking into that combined savings potential.

Figure 15: Potential Energy Savings by Customer Action Category



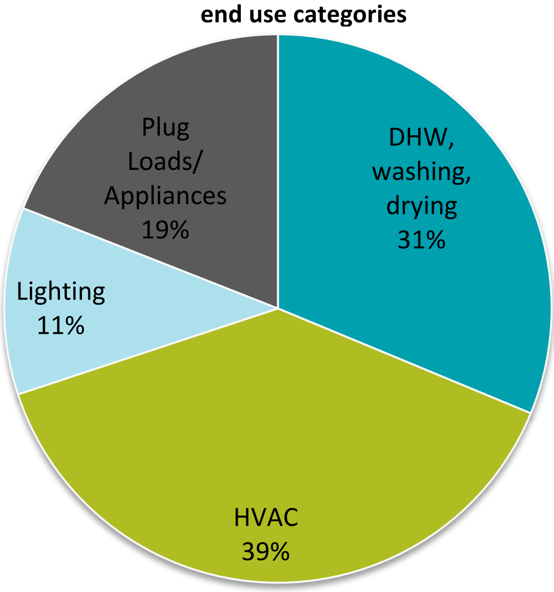
The research team has estimated potential savings for a wide range of potential customer behavioral tactics by end-use category; these estimates are based on the findings from the complete list found in Appendix F: Behavioral Savings Research. With this analysis, the team acknowledges that many of the tactics acted upon by consumers in energy efficiency programs result in retrofit activities, and will be categorized as "DIY" (self-install) or "Contractor" (qualified installer). As seen in Figure 15, behavior-only actions comprise about 43 percent of potential savings, the remaining savings being 40 percent DIY actions and 17 percent actions that would typically include hiring a contractor. Combining the potential savings from the actions recommended in an information-based HEMS, such as behavior savings plus a DIY action taken, could give rough guidance for the end-use savings estimation of a particular program. Potential behavior-based annual energy savings for the Plug Loads and Appliances category is shown in a range of kWh in Table 9 below; the example measures are categorized by "Behavior" or "DIY", and give a more detailed view of the ranges developed in the behavior savings estimation exercise.

Table 9: Potential Behavior Savings for Actions Taken with Plug Loads and Appliances compiled from resources in Appendix F: Behavioral Savings Research

Plug Loads / Appliances – Behavioral Tactics		Annual Energy Savings Range (in kWh)	
Behavior or DIY	Action	MINIMUM	MAXIMUM
B	unplug when not in use	50	200
B	unplug consumer electronics	50	500
B	Don't have orphaned power cords	20	25
B	Switch computer to standby (if leave on currently)	250	300
B	Switch computer off (don't just leave on standby)	20	25
B	unplug routers, modems	300	325
B	hair dryers, electric shaver, toothbrush	30	40
B	adjust your coffee maker settings	250	275
D	Recycle old refrigerator	111	450
D	Use an advanced or smart power strip	20	450
D	buy a E* appliance (including TV, etc)	40	100
D	switch from PC to laptop	150	200

Breaking out the behavioral actions for a HEMS program gives us insight into the type of customer engagement necessary to achieve a given level of savings. The estimated potential savings that is achievable with HEMS for all combined end-uses is shown by percentage in Figure 16.

Figure 16: Estimated HEMS Savings Potential by major end use categories



The growth of Internet of Things (IoT) and HEMS over the last few years has yielded a rapidly expanding list of potential components of HEMS, which has influenced the relative costs in the marketplace for products that are commercially available through retail channels. Other products that are not available through traditional retail channels such as web service platforms, data analytics platforms, and some energy portals come with recurring fees, install costs, and other potential costs that can add up to large first costs; or, when contracts are required, for instance with software-as-a-service (SaaS), the costs are deferred over time. Because of costs associated with monitored platforms, specific market segments may find this to be more beneficial or appealing.

Multifamily buildings and neighborhoods that can negotiate pricing and discounts may see the greatest uptake independently of utility based programs. HOAs and other neighborhood associations have shown interest in web service platforms, load monitoring, data analytics and benchmarking to deliver energy savings messages and have “friendly competition” amongst their communities.

The information-based systems that are low cost or no cost to homeowners and occupants may serve as a gateway to purchasing control-based HEMS devices. Currently there are many control-based devices on the market ranging from around the $11.00 mark (smart plug) to smart refrigerators and other appliances that are pushing costs upwards of $4,000. While amenity and convenience factors of many of the control-based HEMS may be the reason for customer purchase, there is a great deal of potential in the energy savings and demand savings that can be delivered back to that customer’s utility. In Table 10, examples of potential costs of the HEMS categories are exhibited based upon the data compiled for the technology assessment. Building up larger systems of HEMS around those low-cost “gateway” products can be fairly easy, but comes with slightly higher costs. Combining smart lighting, smart plugs and smart switches with a smart hub can be done in a bundled package and purchased together with the smart hub manufacturers such as Wink, SmartThings, Iris, Amazon Echo and others. These bundles or starter kits can be purchased for around $150.00 to start and can quickly add up to over $300.00 for more home automation or security solutions. The average cost of $214.55 for Smart Hubs shown in Table 10 does not include any other pieces of equipment; however the average there is misleading due to the high cost of the Control4 HC-800 Controller. That product costs $1300.00 and allows users to access far more than most other smart hubs including home computers and audio equipment. When the Control4 product is removed the average cost for a smart hub is under $90.00 and is far more accessible.

Within the control-based HEMS category, the smart thermostat currently provides the greatest potential energy savings and demand opportunity, and entry level costs are as low as $75.00. When used with a service provider like Alarm.com, the thermostat may require monthly service fees. Some of the thermostats in the Technology Assessment rely on their connectivity to services to enable the smart functionality or smart algorithms while others use geo-fencing, motion sensors or combinations with algorithms to provide the energy savings.

Table 10: Minimum, Average, and Maximum Costs of HEMS Products by Category

Category	Information (I) or Control (C)	Min Costs	Average Costs	Max Costs
Smart Lighting	C	$15.00	$46.89	$150.00
Smart Plug	C	$11.00	$64.90	$250.00
Smart Hub	C	$50.00	$214.55	$1,300.00
Smart Switch	C	$60.00	$74.50	$129.00
Smart Appliance	C	$54.00	$1,503.50	$4,000.00
Smart Thermostat	C	$46.00	$247.13	$615.00
Smart Home Platform	C	$46.00	$612.54	$4,000.00
Energy Portal	I	$20.00	$240.14	$900.00
Data Analytics Platform	I	$0.00	$0.00	$0.00
In-Home Display	I	$18.00	$186.96	$1,500.00

Category	Information (I) or Control (C)	Min Costs	Average Costs	Max Costs
Load Monitor	I	$10.00	$47.58	$200.00
Web Service Platform	I	$230.00	$230.00	$230.00

With low-cost smart lighting starting under $15.00 and other control-based HEMS devices like smart plugs available at retail, these products are easy to purchase, relatively inexpensive, and provide an introduction to the possibilities of the smart or connected home. With load monitors, energy portals and in-home displays available at costs under $20.00, interested homeowners or occupants can find out how much electricity their electronics, appliances, and other devices around the home are using. Some libraries and municipalities provide loaner load monitors at no cost, while in-home displays may be going away for app based data and information delivery, the stand alone devices are still available as low cost solutions.

One of the challenges in looking at the savings of HEMS through the different functionality lenses of information-based and control-based are the cumulative savings of the combination of the two, and the overlap of several technologies that provide both control and information functions. The synergy that is created from using both functionalities, while complicated to observe in savings, is also beneficial to the end-user and should enable higher performance systems. Building up larger systems of HEMS around those low-cost "gateway" products can be fairly easy, but comes with slightly higher costs. Combining smart hardware with a smart hub, as described in the Technology Alliances and Trends section, can be done via the bundling of devices from smart hub manufacturers such as Wink, SmartThings, and Iris. However, despite the platforms envisioned in Table 3, totally comprehensive systems that offer the control functionality of smart hubs with the information functionalities of in-home displays and energy dashboards remain elusive, and savings even harder to quantify. As such, savings associated with control-based HEMS and information-based HEMS vary widely by the end-use or uses being targeted.

Whole home savings for information-based HEMS fall in a range of around 1 percent up to 15 percent realistically achievable. Many of the information-based HEMS savings from behaviors are difficult to quantify individually, but when done in conjunction with one another can become apparent in one's energy bill or monitoring system, and the ability to see monetary savings becomes very real. While much of attributable savings from information-based systems that have been studied stems from behaviors, control-based systems can provide savings for the occupant with virtually no interaction with the systems and can provide anywhere from 1 percent to 17 percent energy savings independently of the information-based systems. The primary end-uses that exhibited the greatest savings potential for both information-based systems and control-based systems are in Space Conditioning and Water Heating, which is directly proportionate to the overall home end-use profiles shown in Figure 16: Estimated HEMS Savings Potential by major end use categories. The trend of utilities and program administrators to investigate HEMS in the form of smart thermostats comes for the observation of space heating and cooling potential.

It is important to mention that savings potential is also flexible, depending upon what the established baseline is for the HEMS measure or the HEMS type. One example of savings that is highly dependent upon established baseline is smart lighting. If a smart lighting LED lamp is replacing a standard incandescent lamp, the savings from the basic change in wattage is a part of the savings; however, if only the smart aspect of the lamp is considered when calculating savings, then the baseline is an equivalent wattage LED lamp without the connected smart capabilities. When smart LEDs are replacing existing LEDs, the Wi-Fi connected functionality of the LED has a constant watt draw, and the savings that can be attributed to automation and programming can be diminished. With an average Wi-Fi module requiring 0.58 kWh[68] annually for standby power, the total reductions due to standby losses from connectivity are low. This type of scenario is true for a number of HEMS control-based components including smart switches, appliances, plugs, hubs, and thermostats. Currently, assumptions can be made by programs at to what the baseline should be in a retail channel for HEMS delivery; or, alternatively with a direct install, contractor, or in-home service provider, the baseline technology could be more easily established and the savings scenario may be clearer from the outset. Additionally, with products such as load monitors, energy portals, and other information-based HEMS, a control-based HEMS device could set baseline energy usage (as discussed in the Potential of HEMS as a Measurement and Verification (M&V) Tool section), and could then measure the savings. While some of the individual savings from control devices like smart switches, smart hubs, smart plugs, and other small savings generators may appear as noise in some data sets on their own, done in conjunction with other plug load management mechanisms, the additive impact is far more visible.

The estimates provided in this document reflect the studies that have been reviewed and referenced throughout this report, as well as analysis conducted using established practices for calculating energy savings. The savings estimates provided in Table 11 and Table 12 depict the wide variation alluded to previously. More detailed savings estimates can be found in Appendix F: Behavioral Savings Research. Due to the wide variation in savings reported within individual end-uses and delivery methods, and regional differences in HEMS and energy use, continued investigation through pilots and programs, such as those described in the Recommendations section, will help inform more detailed allocation of savings potential across all of HEMS.

Table 11: Whole Home Savings Estimates for Control-Based HEMS

Control-Based HEMS Savings Estimates by End-Use							
Products	**End-Use**	**Savings Range (whole home energy usage as baseline)**			**Cost Range**		
Smart Hardware / Smart Home Platforms		Low	Avg.	High	Low	Avg.	High
	Space Heating	1%	7%	13%	$46.00	$247.13	$615.00
	Space Cooling	1%	9%	17%	$46.00	$247.13	$615.00
	Water Heating	1%	8%	15%	$799.99	$1350.00	$1,900.00
	Appliances	<1%	3%	6%	$54.00	$1,503.50	$4,000.00
	Plug Loads	<1%	3%	5%	$11.00	$208.41	$1,300.00
	Lighting	1%	2%	3%	$15.00	$46.89	$150.00

The savings in both Table 11 and Table 12 refer to whole home energy savings potential by end-uses. The cost ranges for the information-based HEMS in Table 12 are across all different delivery mechanisms and end-uses

[68] http://www.neep.org/sites/default/files/resources/HEMSCommonUnderstandingFinal7-29.pdf

due to the ability to message across all categories. The average costs shown in Table 12 are the averages of all delivery mechanisms.

Table 12: Whole Home Savings Estimates for Information-Based HEMS

Information-Based HEMS Savings Estimates by End-Use							
Products	**End-Use**	**Savings Range (whole home energy usage as baseline)**			**Cost Range**		
		Low	Avg.	High	Low	Avg.	High
Customer-Facing Energy Portal / In-home Display / Load Monitor	Space Heating	1%	8%	15%	$20.00	$197.00	$4000.00
	Space Cooling	1%	5%	9%			
	Water Heating	1%	8%	15%			
	Appliances	<1%	1%	1%			
	Plug Loads	<1%	2%	3%			
	Lighting	<1%	2%	3%			

Estimating Total HEMS Savings: As discussed above, the process for estimating total savings from a HEMS, especially one that includes both information and control functionalities, remains complex; this report does not suggest values for total savings, as there are nearly infinite possibilities presented by the various characteristics of the devices in all discovered HEMS categories, as well as the desired savings by end use and other program parameters. The important thing for program administrators to remember is that, within a dwelling, savings will not likely be simply additive. Using the average values provided in Table 11 and Table 12, this means that a program could employ a smart thermostat with an in-home display and expect to see around 7 percent whole-home energy savings gleaned through space heating, but they are not likely to see an additional 5-9 percent whole-home savings achieved through space cooling. Total whole-home savings reached with the HVAC systems would depend on a number of variables, including the home's energy consumption baseline, algorithms of the smart thermostat, as well as savings goals set by the occupants and occupant behavior towards those goals. This unpredictability of total HEMS savings estimation is yet another reason to develop an M&V plan for the particular program desired, so that savings can be measured rigorously.

Non-Energy Benefits: With many of the HEMS products available, there are benefits that fall outside of energy related savings. These non-energy benefits are becoming more and more important and have sparked discussions on their integration into cost-effectiveness testing on a national level, as discussed in the Policy Opportunities and Recommendations section. Although there are costs and savings associated with these benefits, quantifying the non-energy impacts of HEMS remains one of the greatest hurdles in program and pilot adoption of HEMS. The traditional non-energy benefits such as improved indoor air quality; comfort, health, and safety; water savings and waste reduction; reduced labor; and convenience are all non-energy benefits that can be claimed by many HEMS components, as detailed in Table 13. Still, there are additional non-energy benefits that are attributable to the various HEMS products, some of which are more definitive and concrete than others. A dwelling may prove more resilient to acts of nature through the installation of HEMS, which may qualify homeowners for reduced insurance rates or additional monetary savings, as well as critical systems alerts, backup power systems, and ultimately peace of mind. Other non-energy benefits, like maintenance notifications from a smart appliance or system fault detection from your HEMS, can provide the owner the opportunity to have repairs done before conditions worsen, and can save a great deal of time and money.

While the aforementioned non-energy benefits have additional monetary value, enhanced pride of a home does not, and is difficult to quantify its worth as a benefit. Another issue is a matter of scale: plug-load and smart lighting-related HEMS can yield small amounts of energy savings across many circuits, but quantifying savings on an individual dwelling basis would not provide a representative picture of the potential benefits to the homeowner or occupants. Once non-energy benefits are included, the wider frame of reference reveals a much more accurate representation.

Table 13: Non-Energy Benefits of HEMS Devices

	Improved indoor environment, comfort, health, and safety	Labor and time savings	Improved process control	Increased amenity or convenience	Water savings and waste minimization	Improved communication about habits and behaviors	Transmission or distribution savings	Peak Load Reduction	Improved Resilience of the Home
Smart Lighting	X	X	X						
Smart Plug	X	X	X	X					X
Smart Hub	X	X	X						
Smart Hub and Smart Switch	X	X	X	X					X
Smart Switch	X	X	X						X
Smart Appliance	X	X	X	X		X	X	X	X
Smart Thermostat	X	X	X			X	X	X	
Energy Portal	X	X	X		X				
Data Analytics Platform	X	X	X		X				
In-Home Display	X	X	X	X	X				
Load Monitor	X	X	X	X					
Load Monitor + Smart Plug	X	X	X	X					X
Smart Home Platform	X	X	X	X	X				X
Web Service Platform	X	X	X		X				

Savings Estimates for Planning Takeaways

From the potential 12 percent whole home savings described in the 2010 ACEEE report, to the 4-7 percent revised savings estimate provided in the 2015 PG&E report, HEMS are an answer to a question that energy program administrators and evaluators don't know how to ask. HEMS devices, platforms, and products have attributes and capabilities never before leveraged into energy efficiency programs, primarily because the technology has not previously existed. However, with the analysis conducted in this report as well as previous and ongoing research in several different areas throughout the country, **program administrators should have confidence that HEMS can deliver energy and other resource savings**, as well as enhanced customer satisfaction, as long as the appropriate program design considerations are taken. With the assumptions from the NEEP HEMS Research Project in hand, **programs in the Northeast, Mid-Atlantic, and beyond, could achieve space heating and cooling savings of up to 17 percent from a whole-home baseline, or smaller increments of savings across a wide variety of end uses (**Table 11**)**, by pulling the appropriate program levers. The opportunity also exists for programs and regulators to reconsider the way that programs are evaluated at a portfolio level in order to **encourage adoption of HEMS products that can conserve resources while providing non-energy benefits** to users such as enhanced safety, health, and security.

6.9 Opportunities at Scale

With the opportunities presented in this report, there are a wide variety of avenues for programs to take if they wish to bridge the gap from small HEMS projects to full program deployments. Indeed, most of the program activity observed to date suggests that program administrators in the Northeast, Mid-Atlantic, and beyond are interested in HEMS, but unsure how to proceed beyond limited pilots or test deployments. This may be due to what program administrators perceive HEMS to *be*, compared to traditional program mechanisms. HEMS do not fit nicely into a "measure category" that can be incented to customers; one can not necessarily walk into a store, buy a HEMS, and then receive an instant rebate for it, as many programs are currently structured. This does not mean that incentives should not be offered, but that program administrators must be more thoughtful about how HEMS are delivered to program participants. Some of the most critical questions to ask when considering a scaled HEMS opportunity include:

- **Is this a one-time incentive opportunity, or will customers be able to add to their systems later on?** Answers to this question will have implications for the customer engagement plan as well as current and future incentive budgets.
- Are the systems portable? If / when a customer leaves their dwelling, will the HEMS move with them, or will it stay with the dwelling? This will also impact cost, and any participants who stop using HEMS will impact participation rates, which should be considered in M&V planning.
- **Can HEMS more accurately measure persistence**? If greater amounts of data from a home are possible over longer periods of time, program administrators should consider measuring persistence of savings from the HEMS, as well as any other potential energy efficiency upgrades that can be tracked.

Despite the complexity that these systems may bring to full-scale deployments of program design, HEMS also offers the potential to address multiple challenges and program drivers within a connected, harmonious system. This gives the industry an unprecedented opportunity for energy programs to dig deeper, and for the entire community of administrators, consultants, building scientists, and homeowners to reach for new levels of performance in dwellings. The millions of houses built in the 19th and 20th centuries in North America are a testament to the evolution of the population and building practices during that time; now, with technology in hand, the houses built and retrofitted in the 21st century can include HEMS as a reflection of the advances that have been made towards better, safer, and more energy efficient living.

7. Recommendations

After exploring the opportunities presented by HEMS technology, there is new clarity around the potential savings and benefits provided by HEMS in energy programs. Assessment of the technology and the device categories has helped qualify barriers and potential benefits, while giving more details about the variety and capabilities of products than ever before, and continued tracking of the market will pave the way for collaboration between NEEP and its stakeholders. Scanning the efficiency program landscape yielded great insight into the work being undertaken by program administrators in the Northeast and Mid-Atlantic regions and beyond to incorporate HEMS and connected devices into energy efficiency programs. There are increasing opportunities for advancing HEMS and smart home technology through policy and regulatory channels; and, with utility evolution on data transfer protocols and savings measurement, HEMS could prove to be a useful tool in the acceleration of near-real-time M&V.

The Opportunity Assessment section synthesized previous and new research to provide insight into opportunities for HEMS to save energy through multiple lenses. The next step is to use the opportunities identified to establish pathways for program designs that utilize HEMS.

7.1 HEMS Program Design Framework

For a program administrator who wishes to consider including HEMS in a program to save energy, there are several questions worth asking in order to determine if the desired program type is viable, beyond the common program concerns of cost-effectiveness. As discussed in the takeaways of the Opportunity Assessment, HEMS and connected devices can be used on multiple energy end-uses, in all regions, with multiple fuel types, and in various dwelling types. The questions that program administrators should ask themselves when considering a HEMS-enabled program include:

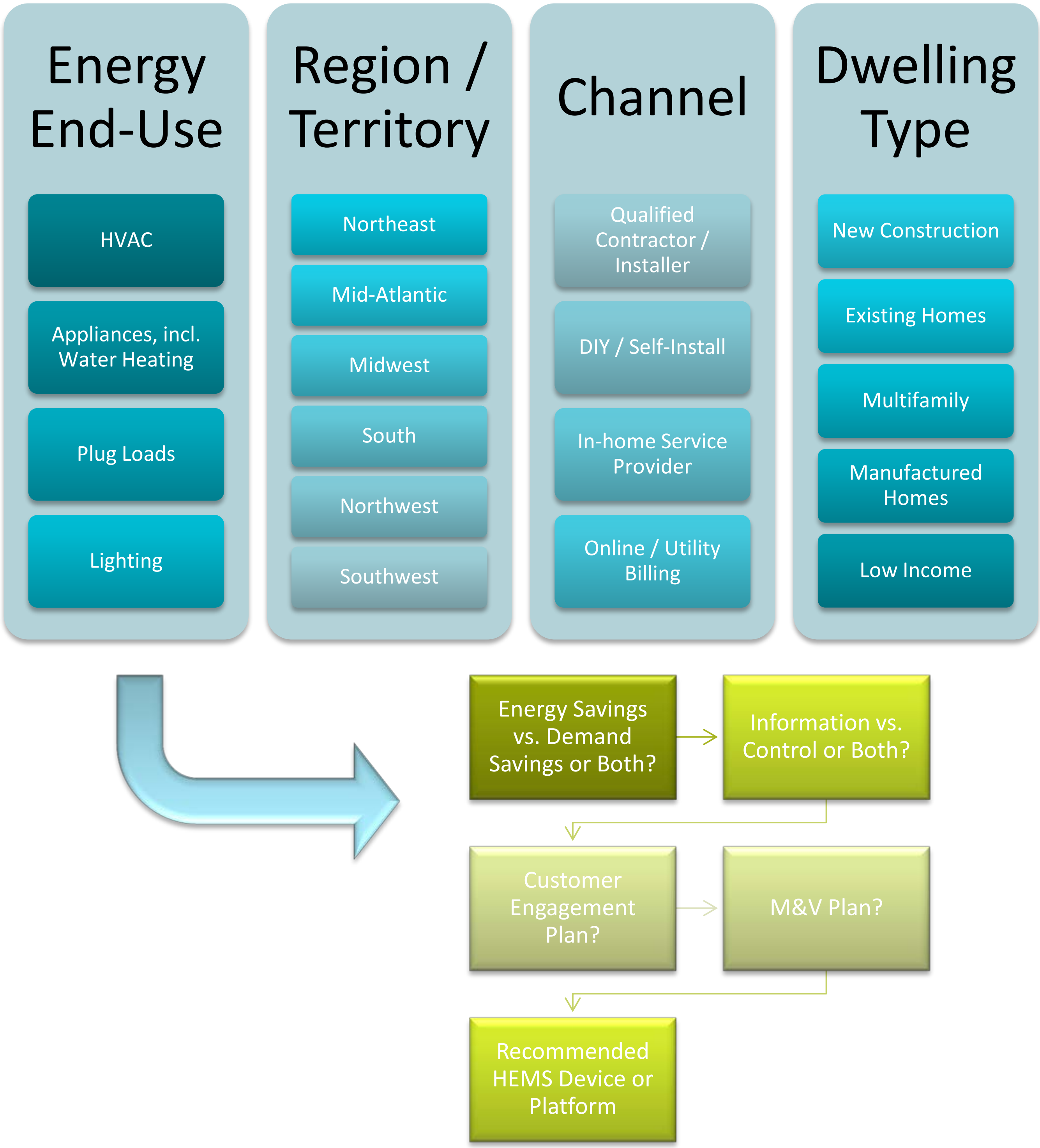
1. Which energy end-uses will be affected?
2. In what region or territory will this program be deployed?
3. Within which channels can the program be implemented?
4. What dwelling type will be affected?

The above questions should form the basis of program planning; once these are answered, subsequent details about specifics to implement a HEMS-based approach can be discovered:

5. Will the program deliver energy savings, demand savings, or both?
6. What functionality (information vs. control) is most necessary for the program?
7. What is the customer engagement plan?
8. How will the program savings be measured?
9. Can HEMS support streamlining or improving the EM&V process?
10. Which device category or platform should be used?

Figure 17 is a graphic depiction of this process and the options described in the Opportunity Assessment. Many of these questions are a normal part of program design, however, the types of HEMS devices and platforms available to a program are heavily dependent on answers to the questions upfront, in order to determine feasibility and create estimates for cost-effectiveness.

Figure 17: Planning process for a program design including HEMS



Although every program is different and the answers discovered as a part of this process may vary widely, the Opportunity Assessment provided strong guidance as to the direction that programs can take; following are summaries of the recommendations that have emerged from this extensive analysis.

- **Energy End-Use**: Focus on space heating and cooling end-uses for the most savings potential, especially when non-electric fuels are a priority. Continue to monitor the growth of plug loads and consumer electronics, and plan for HEMS-based strategies that can facilitate electricity savings in this end-use category.
- **Region / Territory**: Within the Northeast region, smart thermostats and associated smart climate controls hold the most immediate promise for HEMS-enabled programs, especially when bundled with existing retrofit measures for efficient equipment upgrades. In some Northeast and Mid-Atlantic program territories, smart climate controls should offer energy and demand savings capabilities in order to take advantage of future HEMS product advancements.
- **Channel**: The DIY / self-install channel, and to a lesser degree, the qualified installer channel, are currently the paths of least resistance through which most vendors and manufacturers are moving their products. Programs should leverage these channels for cost-effective delivery while exploring other potential avenues for encouraging HEMS and connected device uptake.
- **Dwelling Type**: HEMS hold promise for nearly every dwelling type, but the nature of the systems available and desires vary widely by vintage, building type, and occupant income level. Existing homes are the biggest opportunity by sheer volume, but the multifamily market is growing quickly in many metropolitan areas throughout the country and should be examined for new program opportunities. Additionally, using the direct install channel strategically in low income properties, manufactured homes, and in existing multifamily structures is highly recommended for any programs looking to bring HEMS into those building types.
- **Energy, Demand, and other Resources**: The capabilities of HEMS are such that program administrators who wish deliver energy savings now and other, additional resource savings at a later time should be able to do so through product updates and add-ons. Demand response capabilities of HEMS should be available for any program that is forecasting peak load issues, whether in summer or in winter. Energy and thermal storage as well as energy balancing abilities inherent in HEMS will be critical aspects of grid resilience planning; and, to the extent possible, energy programs should begin exploring opportunities to claim savings for water and greenhouse gas emissions where these benefits can be accounted for.
- **Customer Engagement Planning**: Conduct proactive customer segmentation and employ the basic behavioral strategies when designing a program that utilizes information-based HEMS.
- **Designing Programs with M&V**: Strive for using interval data in HEMS program M&V, for both rigor and timeliness; and settle on data collection protocols that allow for this capability before programs are launched.

Given these considerations and the opportunities laid out in this report, several hypothetical “strawman” proposals are provided below to illustrate this process. The hypothetical scenarios outlined here, although not currently (known to be) real, are possible with the HEMS technology that exists in the market as of the writing of this report. Program designers may also find the NEEP HEMS common criteria document[69] helpful in establishing parameters for data collection in HEMS-enabled energy efficiency programs.

[69] http://www.neep.org/sites/default/files/resources/HEMSCommonUnderstandingFinal7-29.pdf

Hypothetical #1: Northeast Energy Savings Program Strawman

A Northeastern program administrator is seeking energy savings in a territory dominated by natural gas and fuel oil heating systems. The administrator has determined that there is equal opportunity through both the Qualified Installer channel, by leveraging an existing Home Performance with ENERGY STAR Trade Ally network; and through the DIY / Self-Install channel, by leveraging existing relationships with big box retailers. Given that space heating is a major energy savings opportunity in the Northeast, and that several pilots have demonstrated energy savings for gas with control-based smart thermostats, the program administrator designs an evaluation-ready program with smart thermostats available to consumers through retail outlets and trade allies. Using a savings range of 8-12 percent of total space heating energy, incentives are offered on qualified smart thermostats at a higher level to customers through the Qualified Installer channel when they choose to upgrade their heating system. Smaller but significant incentives for qualified smart thermostats are offered to customers at point of purchase through the DIY / Self-install (retail) channel. An M&V plan is designed to allow sharing of pre- and post-installation energy consumption data from a sub-set of customers through both channels, with control groups drawn from a comparative pool of non-participants.

Hypothetical #2: Mid-Atlantic Demand Savings Program Strawman

A utility in the southern Mid-Atlantic region is seeing an increase in peak demand during the summer season. The utility asks a program administrator for help in finding electric demand savings. The program administrator determines that an above average portion of customers in the utility's territory live in multifamily buildings, many of which have window AC units or packaged terminal air conditioners (PTACs). The utility has an existing multifamily HVAC efficiency program with an established list of participating building owners who, when surveyed, are generally in favor of participating in the program; they are additionally motivated when they discover how peak rates will change with the utility's new dynamic pricing plans. The program administrator recommends smart switches for those units with window AC units, and direct-installed occupancy and direct load controls for those units with PTACs. With the projected enrollment of many multifamily buildings, both devices offer the utility the ability to control large amounts of potential demand during peak events, with the added functionality of enhanced data about customer usage which enables more accurate forecasting as well as near-real-time M&V capability.

> *"HEMS [are a] resource for fostering new technology – Green Tech startups, entrepreneurial & small business products [that can] validate potential savings… [HEMS] promote the idea for utilities to 'innovate local' along [the] lines of the 'shop local' movement"*
>
> *- Frank Nitti, MassSave*

Hypothetical #3: Multi-regional Feedback Energy Savings Program Strawman

Several utilities and program administrators in different regions, states, and climate zones are interested in seeing deeper energy savings in new homes in their jurisdictions. With multiple building codes in the mix, as well as one state with aggressive goals for zero net energy (ZNE) new homes, there is no way to use a single baseline to estimate energy savings; however, the programs are able to leverage strong existing relationships with multiple large home builders to offer incentives on a whole-home information-based HEMS to be installed as the home is being built. This HEMS has several characteristics that make it desirable for this program, including the ability to create an initial "ballpark" baseline using building characteristics, building physics, and consumer data;

the ability to give the customer feedback about their energy usage as compared to neighbors; the ability to allow the homeowner to set energy savings goals; an open framework for additional functionality including eventual renewable energy management; and most importantly, a smart phone app that allows the new homeowners to do all of this easily through Wi-Fi. Builders are given incentives not only to install the systems, but also to train new homeowners on set-up and usage of the systems. In the state with ZNE goals, builders are given additional incentives for building the home to "solar ready" specifications and connecting the HEMS to PV circuitry. The HEMS selected for the program uses a "family" of devices and systems in the home that allows the homeowner control over some, although not all, energy using products; and, the system provides a specific "utility portal" in which program administrators can observe trends in energy usage, communicate with customers, and measure savings after a minimum required period of occupancy for the homes.

7.2 Recommendations for Further Research

The following recommendations are put forward as research projects that the research team determined would be the most impactful to the industry. The projects work to leverage existing information, test theories, and to help take the next steps forward in the HEMS program space in order to support the transformation of the HEMS market. The research team recommends that these are considered as further funding opportunities, and NEEP will consider these research projects with the project advisory committee as part of the Regional EM&V Forum's work in 2016.

Analyze pre- and post-implementation interval data for a set of existing electric-only homes with control-based HEMS installed. Due to desired confidence levels, no less than 100 existing single family homes are recommended for this research which would include smart thermostats, smart lighting controls, plug load controls and sub-meters for pulling energy end-use data at interval levels. Based on conclusions from the NEEA paper, the study duration is at least 9 months of pre- and 9 months of post-installation data. This project would be hardware intensive and labor intensive at the beginning; however, due to the richness of the interval data that would be provided, it has the most potential to demonstrate savings in whole-home HEMS.

Work with a vendor to deploy a unified monitoring system that yields interval data for both electricity and natural gas at an individual dwelling level. Ad-hoc monitoring systems, such as the many monitoring devices used in NEEA testbed homes, can yield interval level data for electricity and natural gas, but not in a single system that gives the homeowner actionable information. This research would prove fruitful for those who wish to procure interval data for natural gas programs, as well as those to want to test the functionality of monitoring devices for natural gas systems and appliances.

Deploy a smart thermostat in partnership with a home energy dashboard, and conduct M&V to determine energy saved. A compelling argument for combining two products is that savings have been observed from smart thermostats in several pilot projects to date, and the dashboard would be a natural extension of the homeowner's smart thermostat usage. Adding an information-based dashboard to a control-based smart thermostat would give researchers the chance to experiment with layering behavioral tactics onto a device with proven control-based savings, and examining any interactivity between the two functionalities. Combining two products (as opposed to more than two) may also be easier given the manufacturer landscape, and customers have already shown a willingness to purchase smart thermostats, especially with incentives. The recommendation for this type of research is at least 200 homes in the treatment group, with 200 or more homes in the control group; if possible, a randomized control trial (RCT) is desired for this approach.

Test one or more connected home devices as enabling tools for behavioral demand response (BDR), and test behavioral modification approaches. The research team has identified at least one vendor on the market who is device agnostic (AutoGrid) and could provide a platform with which to test behavioral tactics that would drive BDR. This could advance program designs in this emerging space as well as test for behavior modification effectiveness and other information-based techniques.

7.3 Recommendations for New Program Strategies

While there is still new research to be done to test out HEMS approaches, there are some available HEMS technologies that could couple with existing program strategies that have not been attempted to date. These are strategies that the research team thinks would be especially worthwhile for program administrators to strive towards and collaboration is encouraged amongst programs that may pilot these approaches.

Employ HEMS in a New Homes program deployment. This strategy could test ideas about HEMS supporting a pathway to Zero Net Energy for new homeowners, especially those who may be interested in getting solar PV at some point. It would also be a good way to test the concept of HEMS with more progressive builders, and to test consumer education and engagement strategies. Additionally, a HEMS that could deliver a home energy label or universal metrics to the homeowner would be an excellent trial for behavior-based energy efficiency programs. An added benefit of this program type is a low cost to entry, wherein the majority of the costs would be for incentives to the builders for training and hardware.

Offer HEMS packages as part of a comprehensive home performance program. An idea championed in the HPC's Smart Grid paper, they recommend developing strategies for using HEMS to promote implementation of whole-house upgrades. This approach is appealing because it leverages existing home performance program infrastructure and trade allies to deploy a new technology that could be used to re-engage existing program participants to continue making energy efficiency purchases. While potentially very rewarding, this approach could also face some challenges because the environment for proving cost-effectiveness in home performance programs is currently very dynamic.

> *"[Ideally] your intelligent building and all end uses exchange relevant information with each other to seamlessly operate your home in the most comfortable, convenient and grid friendly manner with very little user input required."*
>
> *- Lieko Earle, National Renewable Energy Lab*

Leverage a DR program or Time-of-Use Pricing structure to introduce HEMS. Within an established DR program where customers are already used to seeing direct load control events or messaging from the utility, the addition of a device into a customer's home may not be such a hurdle, and programs could use the new functionality to seek energy savings on top of peak load reduction.

There are likely additional recommendations for HEMS in programs that readers of this research paper will imagine, given the possibilities described. Indeed, it is the hope of NEEP and the research team that this report can serve as a blueprint to program administrators in the Northeast, Mid-Atlantic, and throughout the United States. HEMS have the ability to work in nearly every type of dwelling, in every region in the country, to address nearly every household system, and can manage energy loads as well as peak demand, renewable generation, and energy storage. With their current and as-yet unrealized capabilities, HEMS can be the bridge that administrators are seeking to advanced cost-effectiveness calculations, more accurate and timely savings measurement, and ultimately, a more evolved approach to residential energy efficiency programs. For homeowners, HEMS could be the key to transitioning the analog homes of the present to the responsive, comfortable, and net-zero energy homes of the future.

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Appendix A: Master List of HEMS Products

The Technology Assessment prepared for this report is now publically available at http://www.neep.org/initiatives/high-efficiency-products/home-energy-management-systems. NEEP will be working to keep the list up to date, in conjunction with the HEMS Working Group, CLEAResult, and the PG&E research team.

The assessment is downloadable and sortable and includes the following fields for 244 products (at time report was published):

- Company
- Product
- Description
- Product category
- Cost information (sortable by Cost Low, Cost High, Monthly Average, and a Cost Description)
- Updates
- Notes

Appendix B: Findings from 2014 CLEAResult Home Automation Market Survey

CLEAResult Home Automation Market Survey, 2014

As part of CLEAResult's ongoing primary research into new technologies and program development, the research team conducted an online survey of 500 Oregon residents about their interest in home automation and related devices in late Q4 2014. Using a margin of error of 5 percent, the results from the survey gave us some very pointed insights into the market for Internet of Things (IoT) devices and where they are headed in the next several years, namely:

- 52 percent of men, versus 36 percent of women, are "Absolutely" or "Probably" investigating purchasing a HEMS device in the next 2 years
- Men also more interested in comfort and smartphone or appliance apps
- Respondents making over $75,000 are more interested in security than cost
- The higher wage bracket respondents are much more likely to buy in the next 2 years
- These respondents are interested in using smartphones and wall displays

Additional results can be seen in the graphics below. The first results table shows that cost, security, and system issues are the top three customer concerns (Figure 18).

Figure 18: Most common customer concerns around Home Automation products

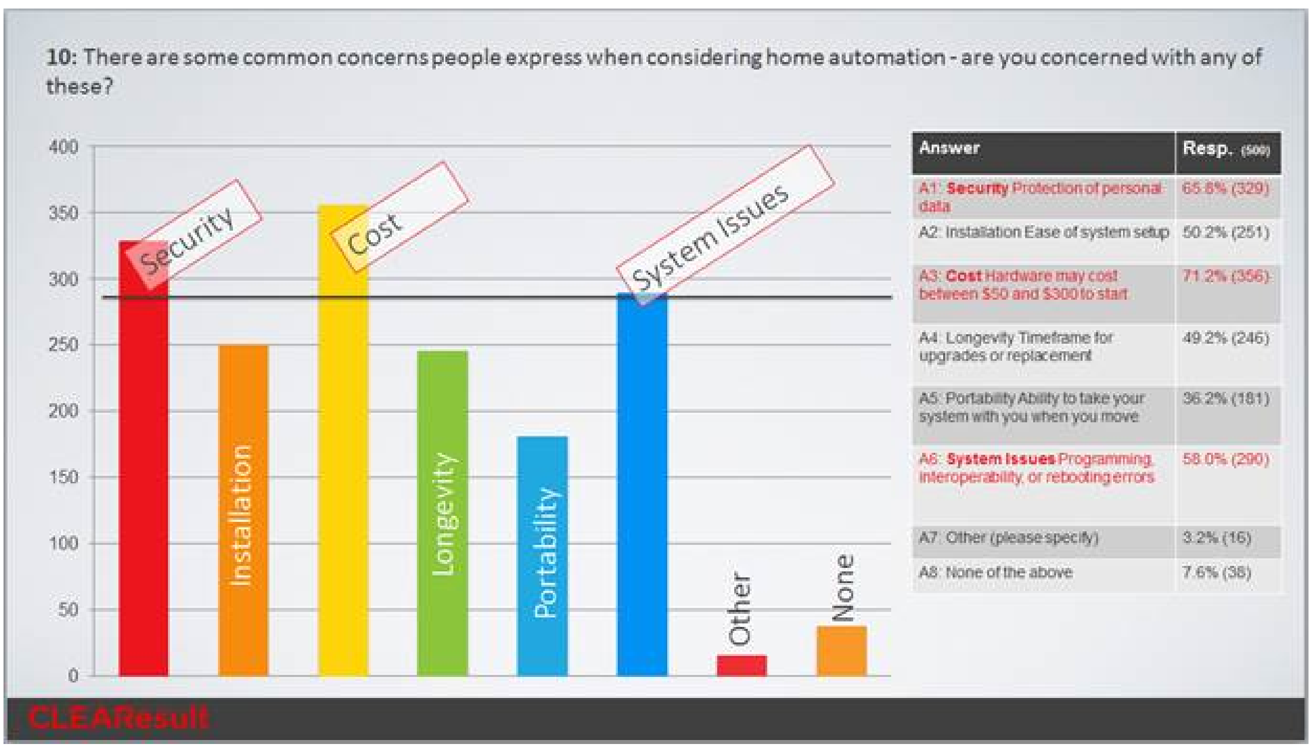


Figure 19 demonstrates that customers remain interested in program administrator-funded incentives for major appliances, LED lighting, and HVAC products.

Figure 19: Consumer interest in program administrator-funded incentives

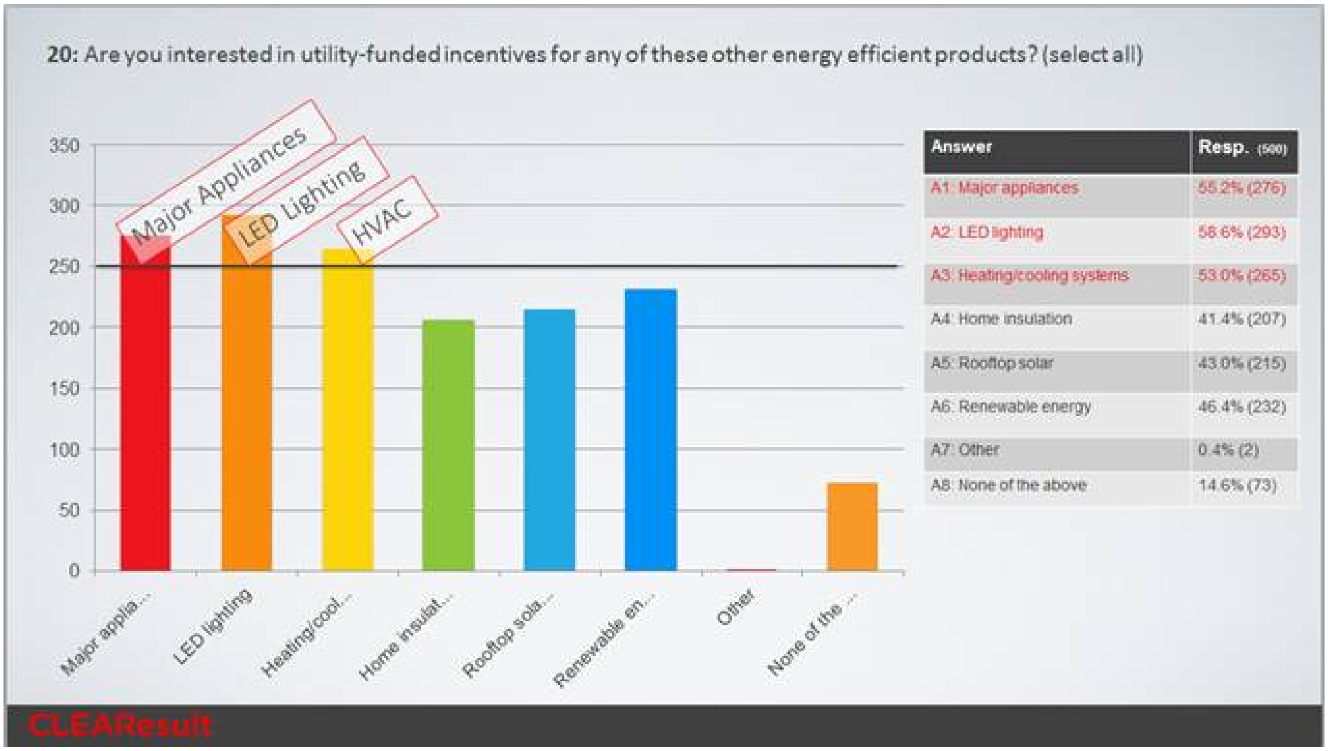
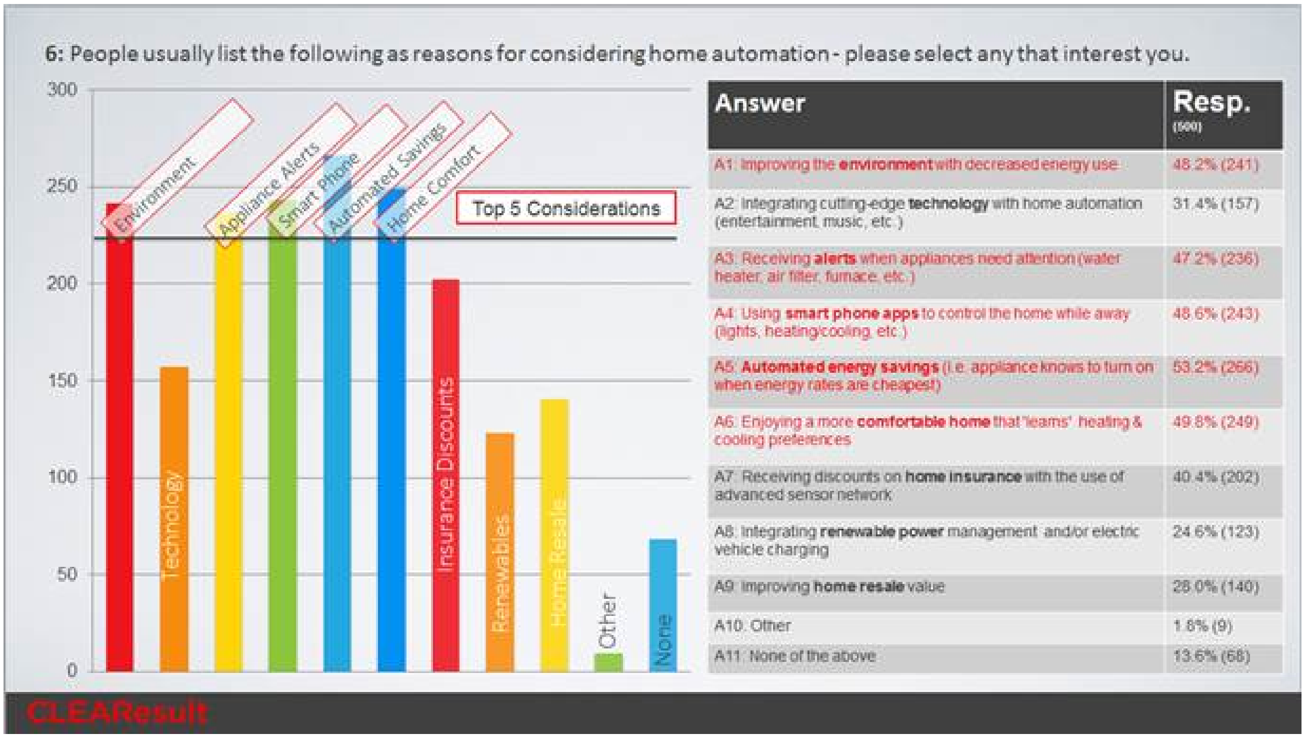


Figure 20 tells us the top five reasons that consumers are considering home automation products, and automated energy savings is at the top of that list.

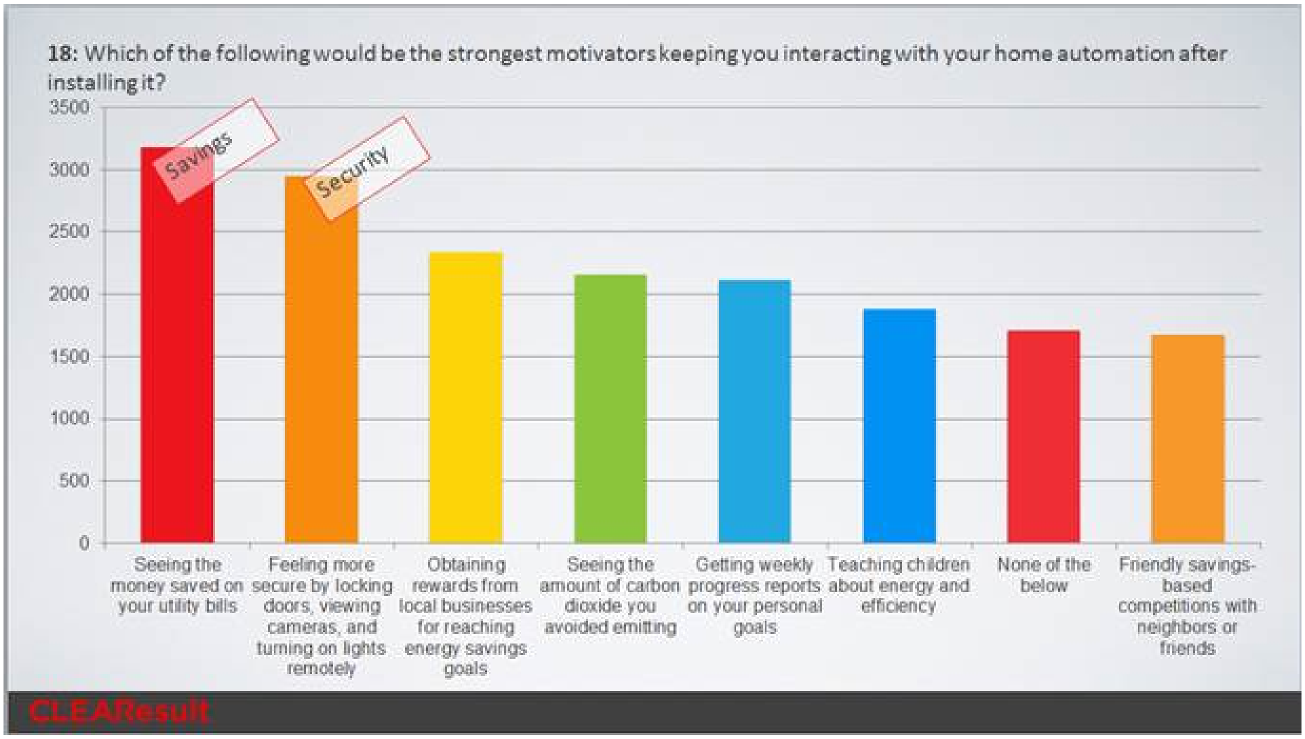
1. Automated savings
2. Home comfort
3. Smartphone apps
4. The environment
5. Appliance alerts

Figure 20: Consumer reasons for considering home automation products



Finally, in Figure 21, CLEAResult's market survey indicates that the strongest motivators for consumers to stay engaged with their home automation devices would be to see the money that they've saved on program administrator bills, as well as security functionality.

Figure 21: Primary motivators for consumers to stay engaged with home automation devices



Appendix C: List of Studies, Pilots, Projects and Programs found in Program Activity Assessment

Advanced Power Strips Programs

- National Grid Advanced Power Strips: $15: http://programs.dsireusa.org/system/program/detail/3025
- PSEG $10 Smart Power strip incentive: https://www.psegliny.com/page.cfm/Efficiency/Appliances/PowerStrips
- Efficiency Vermont Advanced power strips: sold through retailers at discounted price:: https://www.efficiencyvermont.com/For-My-Home/ways-to-save-and-rebates/Home-Electronics/Advanced-Power-Strips/Rebates
- National Grid Advanced Power Strip incentive: $15 off: http://www.energyfederation.org/100216/default.php/cPath/5794
- Consumers Power Inc (CPI) FREE smart power strips: http://www.cpi.coop/rebate/smart-power-strips/
- Lansing BWL: $10 discount on smart power strips: http://www.lbwl.com/Articles/Rebates-on-Smart-Strips/
- Entergy Smart power Strip Rebate: $10 rebate: http://www.energysmartnola.info/for-your-home/aps.php
- Black Hills Power $10 rebate for smart power strips: https://www.blackhillspower.com/save-money-energy/rebate-information/residential/advanced-power-strips
- KCP&L Smart Power Strip $10 Rebate (May be Expired): http://www.kcpl.com/~/media/Files/Save%20Energy%20and%20Money/HomeApplianceRebateCoupon.pdf
- Lodi Electric Smart Power Strip $10 Rebate: http://www.lodielectric.com/eurebates.html?page=a
- Alger Delta Electric, Cloverland Electric Cooperative, City of Escanaba, Great Lakes Energy, Homeworks Tri-County Electric, Marquette Board of Light & Power, Midwest Energy, Newberry Water & Light Board, Presque Isle Electric & Gas, City of Stephenson, Thumb Electric: $10 off smart power strips: https://www.energyfederation.org/cal/default.php

Home Energy Monitoring Equipment / Home Automation Systems Incentives or Programs

- Maryland Home Energy Loan Program: Energy monitoring Equipment is eligible: http://www.mcecloans.com/eligible-projects/
- Federal PowerSaver Loans: Home Automation Systems are eligible: http://energy.gov/eere/buildings/powersaver-loans
- Duke Energy My-Home Energy Interactive: In-depth web portal for real time energy use updates, goal setting, etc.: http://www.duke-energy.com/ohio/savings/home-energy-interactive.asp
- NV Energy mPOWERED: https://www.nvenergy.com/home/saveenergy/rebates/mpowered/
- Duke Energy HoM program. Web Portal and Smart Thermostat Program. Requirements are single family residence with AC. https://www.homenergymgr.com/overview requirements: https://www.homenergymgr.com/customer_agreement
- Reliant Energy has multiple programs. Web Portals, in Home displays, smart t-stats, DR, etc.

Smart Thermostat Programs

- National Grid Wi-Fi Thermostat Incentive: $50, does not specify what models qualify, must just be Wi-Fi enabled: https://www1.nationalgridus.com/WiFiThermostatRI-RI-RES
- Nest, Free or more incentives: https://nest.com/incentives/
- Austin Energy "Power Partner Thermostat" program (more than just NEST): http://powersaver.austinenergy.com/
- Smart Thermostat Programs overview Article 2014/12/19 Tweed, Katherine: http://www.greentechmedia.com/articles/read/Smart-Thermostat-Programs-Roll-on
- Full List of NEST Energy Partners: https://nest.com/support/article/About-the-Nest-energy-partners

General HEMS Pilots

- Centerpoint Energy 500-participant smart meter In-Home Display pilot program, 2011. Based on surveys, 71 percent of customers reported that they have changed their electricity consumption behavior as a result of the energy use data they accessed on their in-home displays. Results Here: http://investors.centerpointenergy.com/releasedetail.cfm?ReleaseID=594825
- Kansas City Power and Light home energy report pilot: http://kcpl.com/save-energy-and-money/for-home/home-energy-report-pilot/mo
- SMUD Demand Response Pilot: Smart Grid Sacramento Residential Response to Real-Time Data and Dynamic Pricing
- Empowering Consumers through Smart Technology: Experimental Evidence on the Consequences of Time-of-Use Electricity Pricing, February 14, 2015: https://editorialexpress.com/cgi-bin/conference/download.cgi?db_name=ESWC2015&paper_id=1452
- Public Service of New Hampshire "Customer Engagement Pilot program". , Opower system used with web portal for behavioral based modification of energy usage. 25,000 participants. 2012-2013: http://www.puc.nh.gov/Regulatory/CASEFILE/2010/10-188/LETTERS,%20MEMOS/10-188%202012-03-28%20PSNH%20LTR%20DESCRIPTION%20OF%20CEP%20PROGRAM.PDF
- Knowledge is (Less) Power: Experimental Evidence from Residential Energy Use†, By Katrina Jessoe and David Rapson: http://kysq.org/docs/energy%20prices.pdf
- Several pilots described in this source: DTE Energy - Portal Pilot; Baltimore Gas and Electric- The BGE Smart Energy RewardsSM program; First Energy Energate Trial; Idaho Power Energy Portal; "SmartHours" Oklahoma Gas and Electric Energy Portal 2012 Trial; ConEdison and ThinkEco modlet AC Pilot 2012: http://www.edisonfoundation.net/iei/Documents/InnovationsAcrosstheGrid_LoRes_InstElcInnv.pdf
- eGauge Pilot by Efficiency Vermont, 2014: SiteSage Pilot.
- Duke Energy, Home Energy Solution Pilot 2014.
- Duke Energy Home Time-Of-Use Pilot: http://www.duke-energy.com/tou-nc-residential/default.asp
- Energate: Energate says they have done more than 25 pilots across US and Canada for their smart grid solutions and in home demand response systems.

http://www.businesswire.com/news/home/20110628005667/en/Energate-Issues-Precedent-Setting-Results-Pilot-Projects-Oklahoma#.VWX-tflViko

- Queen Park's smart home pilot, 2015: http://www.energateinc.com/queens-park-kicks-in-cash-for-power-pilot-project/#.VWX_gvlViko.
- Alameda County Residential Behavior Pilot, 2014. Results showed 7.4 percent (38kWh/mo) KWH savings and 13 percent (5 therms/mo) Therms savings: http://beccconference.org/wp-content/uploads/2014/12/presentation_Brown.pdf
- Bidgely White paper discusses 2 pilots in California that did usage disaggregation from 2012. Claims with 95 percent confidence the energy reduction is between 4.67 percent and 7.43 percent. https://www.bidgely.com/resource-files/White_Paper_Savings_&_Engagement_v2_Case_Study.pdf
- Omaha Pilot that compared three real-time in-home displays. IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 59, NO. 4, APRIL 2012: http://projects.absolutepowerandcontrol.com/Why%20Monitor%20Study.pdf

Smart Thermostat Pilots

- Massachusetts Ecobee (http://ma-eeac.org/wordpress/wp-content/uploads/Wi-Fi-Programmable-Controllable-Thermostat-Pilot-Program-Evaluation_Part-of-the-Massachusetts-2011-Residential-Retrofit-Low-Income-Program-Area-Study.pdf)
- New Hampshire Venstar Colortouch T5800: http://www.puc.nh.gov/Regulatory/Docketbk/2012/12-262/LETTERS-MEMOS-TARIFFS/12-262%202013-08-22%20ENGI%20DBA%20LIBERTY%20FILING%20ITS%20PROGRAM%20EVALUATION%20STUDY.PDF
- Puget Sound – Honeywell VisionPro thermostats w/ apps (see https://vimeo.com/95201029)
- Xcel Energy: http://www.xcelenergy.com/staticfiles/xe/Marketing/Files/CO-Smart-Thermo-Pilot-2014.pdf
- Randolph Electric Membership Corporation – Ecobee 3: http://randolphemc.com/content/ecobee3-smart-thermostat-pilot-project
- South River EMC – Ecobee 3: http://sremc.com/content/smart-thermostat-pilot
- Salt River Project – EnergyHub: http://www.srpnet.com/newsroom/releases/121814.aspx
- Hydro One – bring your own thermostat pilot (Toronto) - http://hydroonebyot.com/
- Austin Energy did a demand-response pilot with Ecobee in 2012/2013: https://www.ecobee.com/2012/12/ecobee-partners-with-austin-energy-to-launch-pilot-program/
- PG&E Behavioral Messaging thermostat trial results presentation, 2014. No Significant Energy Savings identified. http://beccconference.org/wp-content/uploads/2014/12/presentation_Churchwell.pdf
- Weatherbug Pilot 2014: http://www.reuters.com/article/2014/01/29/md-earth-networks-idUSnBw295356a+100+BSW20140129
- Weatherbug Home e5 Pilot 2 Texas DR pilots utilizing WeatherBug home: 2012 pilot with 1100 participants. Results show 13.8 percent savings during cooling season. According to report: "It was found that optimized houses saved 5.24 percent of whole house electricity per ft^2 over the Control Group. Of this, 3.85 percent was directly attributable to the WeatherBug Home Optimization." https://www.puc.texas.gov/industry/projects/rules/38578/EEIP_112712/8_Earth_Networks_e5_EEIP_Presentation-November_2012_v1_2.pdf

- Honeywell Total Comfort Connect T-Stat research study conducted by Honeywell. Review by the Cadmus Group. Study done using 1,769 TCC stats in 2012. 6.6 percent total combined savings. The Pacific NW shows an increase in energy use while all other climate zones showed savings. (The approach for getting at their savings estimates may be questionable.) http://beccconference.org/wp-content/uploads/2014/12/presentation_Stewart.pdf
- Franklin Energy Nest Pilot. http://www.efficiencyexchangenw.com/session/youre-getting-warmer-smart-thermostat-pilot-update-2014/
- Energy Trust of Oregon Nest Heat Pump Pilot: http://energytrust.org/library/reports/Nest_Pilot_Study_Evaluation_wSR.pdf

Relevant Studies, Notable Articles, and sources from the PG&E Report

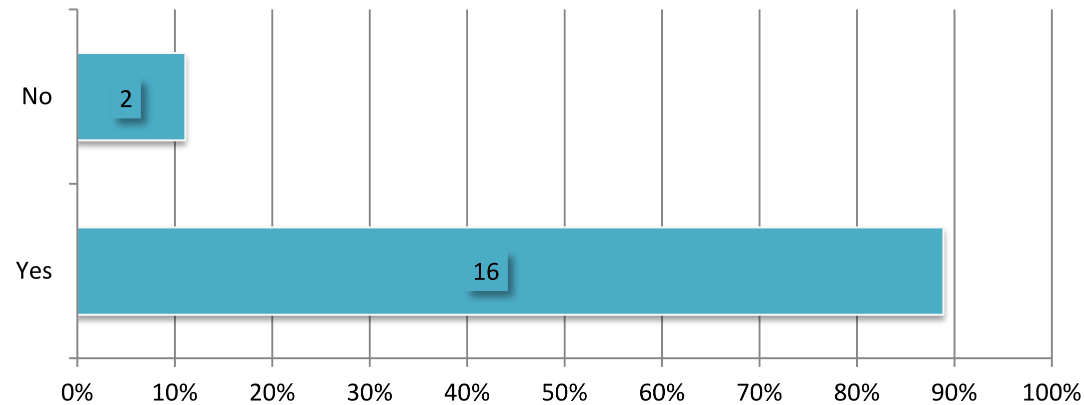
- Bozorgi presentation compares the cost effectiveness of enhanced billing reports vs. in home energy displays: http://beccconference.org/wp-content/uploads/2014/12/presentation_Bozorgi.pdf
- Navigant Research Group. (2012). In-home displays, networked HEM systems, standalone HEM systems, web portals, and paper bill hem reports: Global market analysis and forecasts. Retrieved from http://www.navigantresearch.com/research/home-energy-management (Need to purchase to view whole report)
- "The Connected Home reaching critical mass for the grid?" by Jeff St. John, 5/21/15. Informative article about the most current state of market saturation for the connected home. http://www.greentechmedia.com/articles/read/the-connected-home-reaching-critical-mass-for-the-grid
- Aricent Group. (2013). Home energy management: Beyond the numbers. Retrieved from http://www.aricent.com/pdf/Aricent_Group_HEMS.pdf
- Hargreaves, T., Nye, M., & Burgess, J. (2010). Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors. Energy Policy, 38(10), 6111-6119. https://blog.itu.dk/hest/files/2012/10/hargreaves_energy-impacts-of-the-smart-home-e28093-conflicting-visions.pdf
- PG&E Report: Peterson, P. (2011). Smart Home Opportunity Research. (Report Number: ET11PGE1108). Retrieved from Emerging Technologies Coordinating Council: http://www.etcc-ca.com/reports/smarthome-opportunity-research/
- University of Oxford Environmental Change Institute Direct Feedback Literature Study, 2006. http://www.eci.ox.ac.uk/research/energy/downloads/smart-metering-report.pdf

Appendix D: Survey Responses to NEEP Program Activity Assessment Survey

Question 1: **Yes or No Response**

Have you worked on or led, or are you currently working on, a program, pilot, or project that uses a whole-home energy monitoring or management system? Or, have you worked on/are you working on a residential program, pilot, or project that uses connected devices of some variety, such as smart thermostats?

Figure 22: NEEP Program Activity Survey Responses to Question 1



Question 2: **Open-Ended Response**

If you answered "Yes" to Question 1, what is the name of the project?

(If you have MULTIPLE PROJECTS to describe, please complete this survey for each project.)

Table 14: NEEP Program Activity Survey Responses to Question 2

1	Mass Save Home Energy Services Program
2	Home Energy Management and Automatic Temperature Control Evaluation
3	PG&E Smart thermostat Pilot
4	Consumer Engagement in the Integrated Homes (informal title)
5	(No answer)
6	The IHD Study
7	Efficiency Vermont 2015 R&D Project: Smart Lighting & HEMS Hubs
8	C.A.P.E. Presence Pro Energy
9	Energize CT Smart Thermostat "Pilot" Program
10	AEP Texas SMART View In-Home Device R&D Project
11	(No answer)
12	Nest Thermostat Study - Vermont
13	MA Home Energy Services (SF Retrofit)
14	Thermwise Builder and Thermwise Appliance
15	CPS Energy Nest Pilot
16	Evaluation of the 2013-2014 Programmable and Smart Thermostat Program (for Vectren)

17	Evaluation of the 2013-2014 Programmable and Smart Thermostat Program (for NIPSCO)
18	Wi-Fi Programmable Thermostat Pilot Evaluation (for Liberty Utilities)

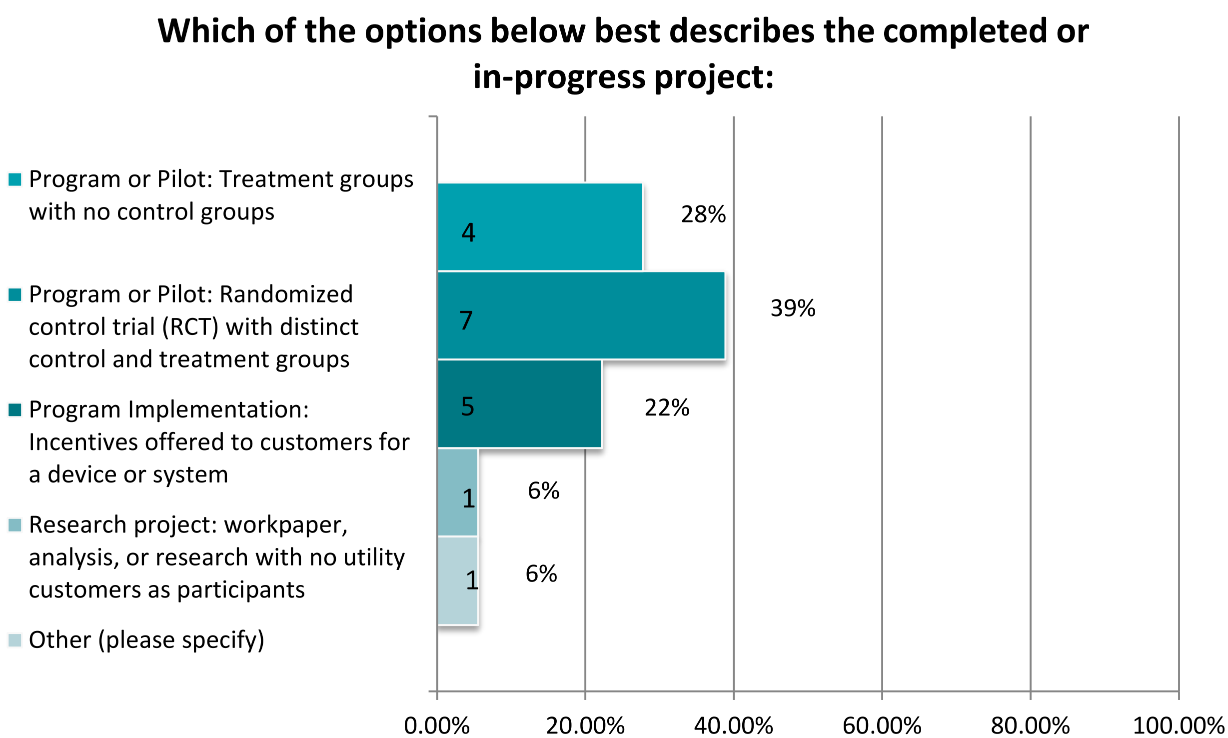
Question 3: **Four Pre-Defined Responses to choose from, or other to be specified**

The following questions pertain to the project mentioned in Question 2.

Which of the options below best describes the completed or in-progress project?

A. Program Implementation: Incentives offered to customers for a device or system
B. Program or Pilot: Randomized control trial (RCT) with distinct control and treatment groups
C. Program or Pilot: Treatment groups with no control groups
D. Research Project: Workpaper, analysis, or research with no utility customers as participants
E. Other (please specify)

Figure 23: NEEP Program Activity Survey Responses to Question 3



Question 4: **Open-Ended Response**

If completed, are the outcomes or results publicly available? If not, can the results be shared privately amongst NEEP members? Please elaborate and provide links to results, if available.

Table 15: NEEP Program Activity Survey Responses to Question

1	Not sure. Contact me about this.
2	results cannot be shared at this time
3	Not started yet
4	Not completed!
5	(no answer)
6	The project is under review for the Journal Energy. The results will be publicly available at that time.
7	No, project is currently underway. Expected completion date 12/31/15.
8	n/a
9	This pilot is not complete at this time. The pilot is not accepting new customers and is now under review for future changes.
10	We would have to ask AEP for permission to share the results, but I would expect them to be cooperative.
11	(no answer)
12	Not yet complete
13	All program information available through Mass Save Data.
14	(no answer)
15	NEXANT Evaluated
16	http://www.cadmusgroup.com/papers-reports/evaluation-2013-2014-programmable-smart-thermostat-program/
17	https://myweb.in.gov/IURC/eds/Modules/Ecms/Cases/Docketed_Cases/ViewDocument.aspx?DocID=0900b631801c5039
18	http://www.puc.nh.gov/Regulatory/Docketbk/2012/12-262/LETTERS-MEMOS-TARIFFS/12-262%202013-08-22%20ENGI%20DBA%20LIBERTY%20FILING%20ITS%20PROGRAM%20EVALUATION%20STUDY.PDF

Question 5: **Key Metrics (Utility, State and Sample Sizes)**

In what utility and state was/is the project located? And, how many participants did/does the project involve? (If none, please enter "0")

A. Utility
B. State or States
C. Treatment Group
D. Control Group
E. Total Number of Participants

Table 16: NEEP Program Activity Survey Responses to Question 5

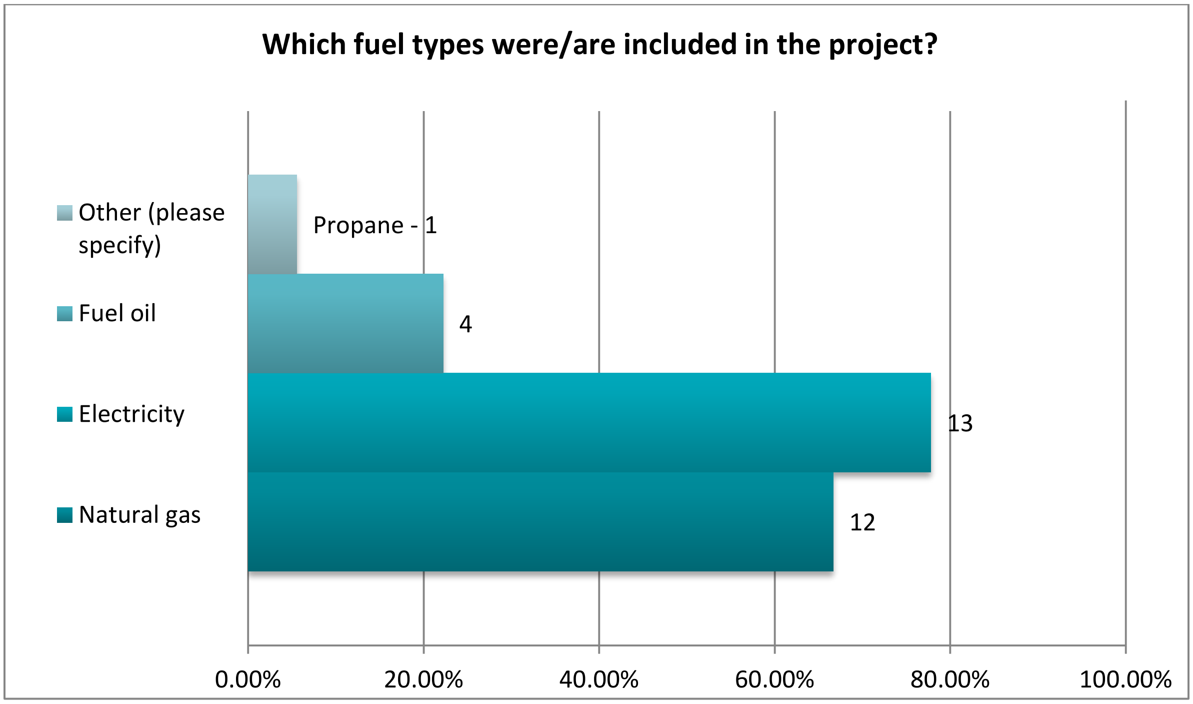
	Utility:	State:	Treatment Group:	Control Group:	Total participants:
1	National Grid	MA	ongoing	0	~150 for full program so far.
2	National Grid	MA, RI	Home Energy Management Group, Automative Temperature Control Group	0	103
3	PG&E	CA	3000	0	3000
4	0	MA	0	0	0
5	0	0	0	0	0
6	SDG&E	CA	309	122	431
7	Efficiency Vermont	VT	15	0 (see "other" comment in question #3)	15
8	Cape Light Compact (CLC is not a utility)	MA	0	0	600
9	United Illuminating and Southern CT Gas	CT	0	0	50
10	AEP Texas	TX	414	419	833
11	0	0	0	0	0
12	Efficiency Vermont	VT	~1000	~1000	~2000
13	Fitchburg Gas and Electric	MA	0	0	~600-700 in 2014 (rough estimate)
1	Questar	UT	0	0	0
15	CPS Energy	TX	325/320	325/320	625
16	Vectran	IN	300	2611	2911
17	NIPSCO	IN	400	522	922
18	Liberty Utilities	NH	29	n/a	29

<u>Question 6:</u> **Selecting Any Fuel**

Which fuel types were/are included in the project?

A. Natural Gas
B. Electricity
C. Fuel Oil
D. Other (to be specified)

Figure 24: NEEP Program Activity Survey Responses to Question 6

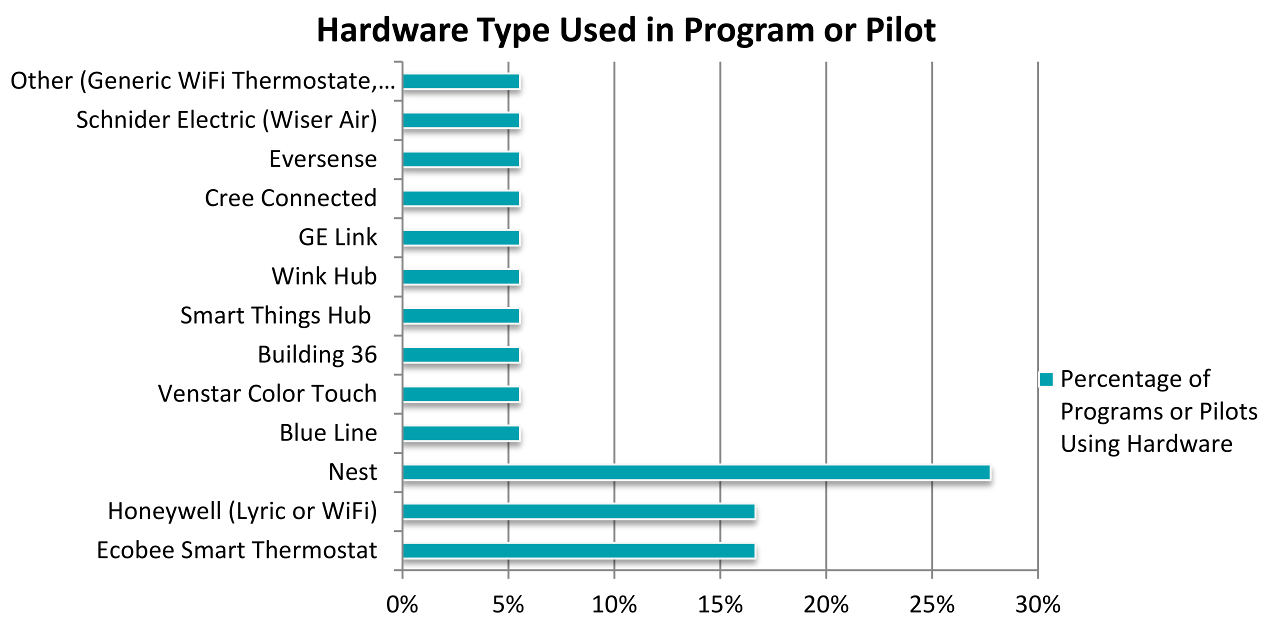


Question 7: **Three Choices**

What product, platform, or system was/is used in the project? Please fill in the blanks below or write "n/a" if not applicable.

A. Hardware (if applicable)
B. Software (if applicable)
C. Were/are in-home displays, online dashboards, or mobile apps used? Please list.

Figure 25: NEEP Program Activity Survey Responses to Question 7



<u>Question 8:</u> **Open-Ended Response**

What were/are the goals of the project?

Table 17: NEEP Program Activity Survey Responses to Question 8

1	Increased energy savings
2	Assess value of smart thermostat features Assess value of home energy monitoring system Evaluate energy impacts of Automatic Temperature Controls Evaluate demand impacts of demand response events
3	To estimate savings opportunities
4	Understand the full landscape of program opportunities associated with communicating devices and consumer engagement
5	(No answer)
6	To test which was more effective, feedback, cost, or normative frames on and IHD.
7	Primary goal Begin to map, define, and measure the interactions of Home Energy Management System (HEMS) hubs and their connected devices. - Map the baseline energy usage of smart lighting controlled by HEMS hubs - Catalogue consumer usage of smart plugs Secondary goal Understand the consumer experience with set-up, engagement, and use of HEMS devices.
8	To encourage customers to make changes in the way the use electricity.
9	Energy Saving thru optimization of customers HVAC systems plus behavioral message savings
10	measure energy savings attributable to presence of in-home display in the home
11	(No answer)
12	Find out thermal savings for Vermont customers

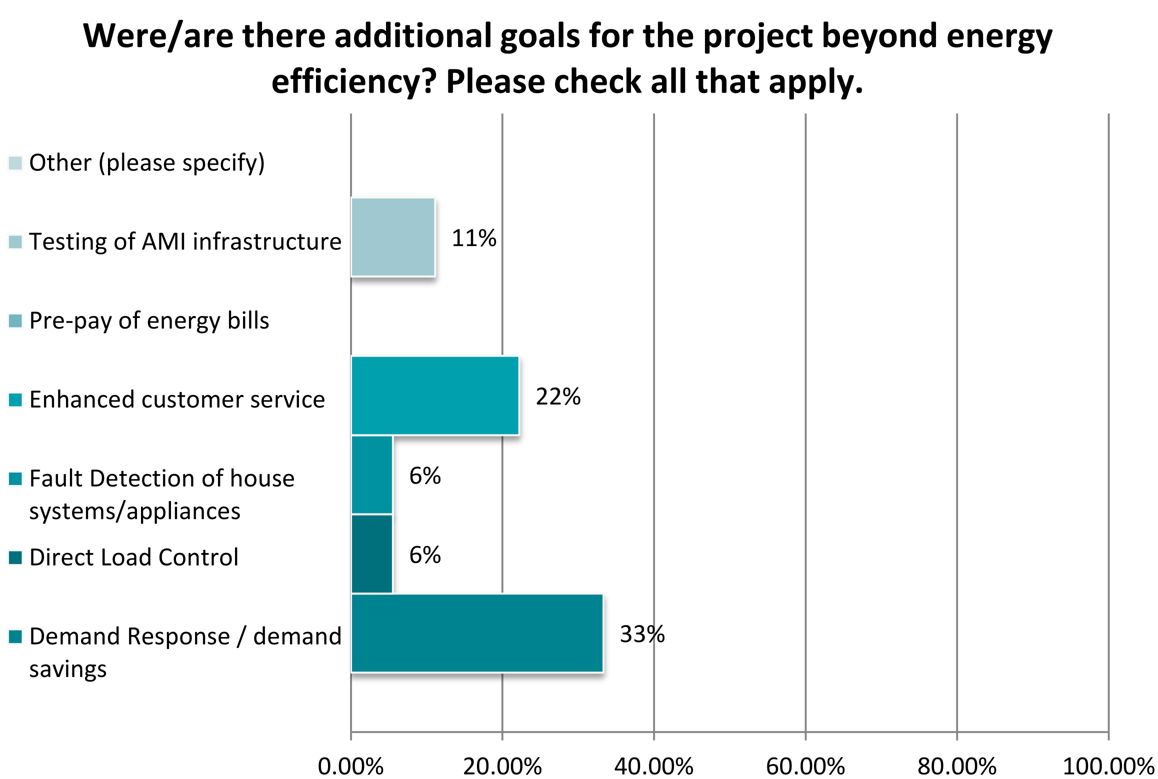
13	Reduce energy consumption while maintaining/improving comfort in home.
14	2800 units
15	measure the cooling demand impact from adjusting the temperature on the NEST thermostat
16	Evaluate gas saving in heating season Evaluate electricity savings in cooling season
17	Evaluate gas saving in heating season Evaluate electricity savings in cooling season
18	Evaluate gas saving in heating season

<u>Question 9</u>: **Multiple Choice**

Were/are there additional goals for the project beyond energy efficiency? Please check all that apply.

A. Demand Response / demand savings
B. Direct Load Control
C. Fault Detection of house systems/appliances
D. Enhanced customer service

Figure 26: NEEP Program Activity Survey Responses to Question 9.



Appendix E: Additional Charts, Graphs, and Tables from EIA used in Opportunities Assessment

Figure 27: Household Site End-Use Consumption by Vintage

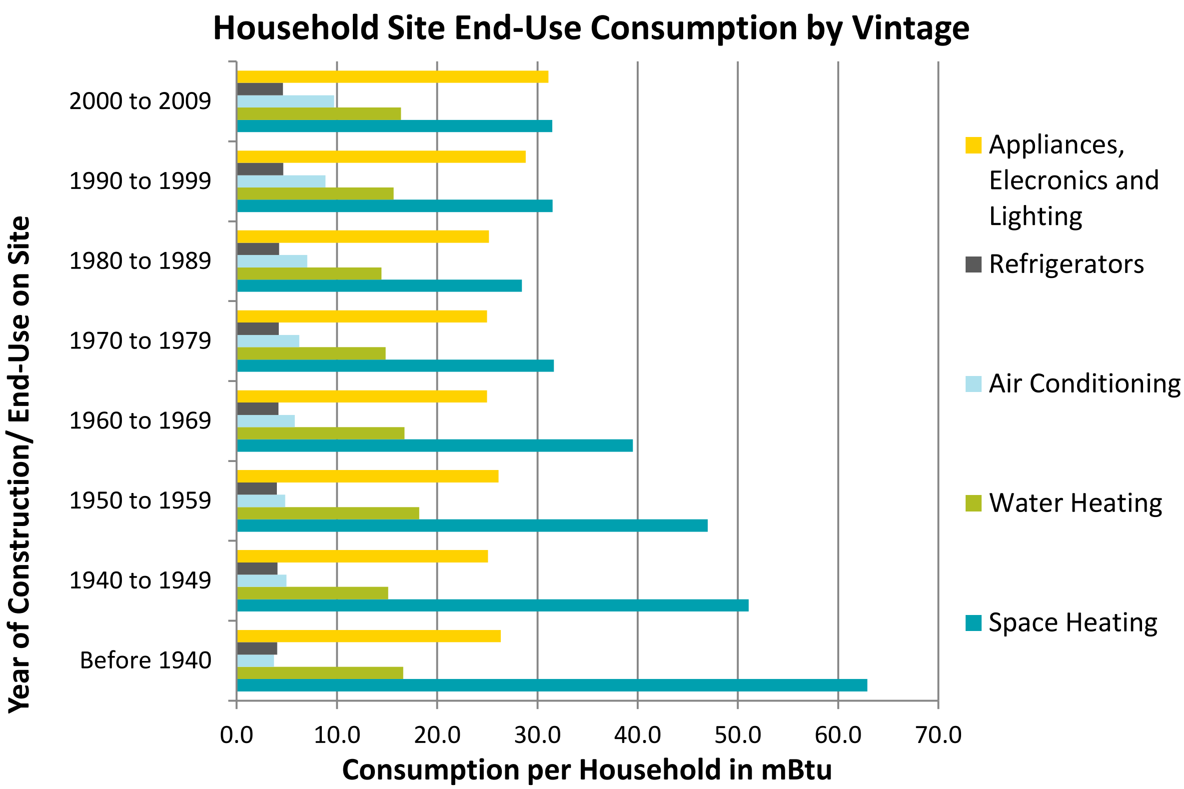


Figure 28: Household Site End-use Consumption - by Fuel Type, by Region

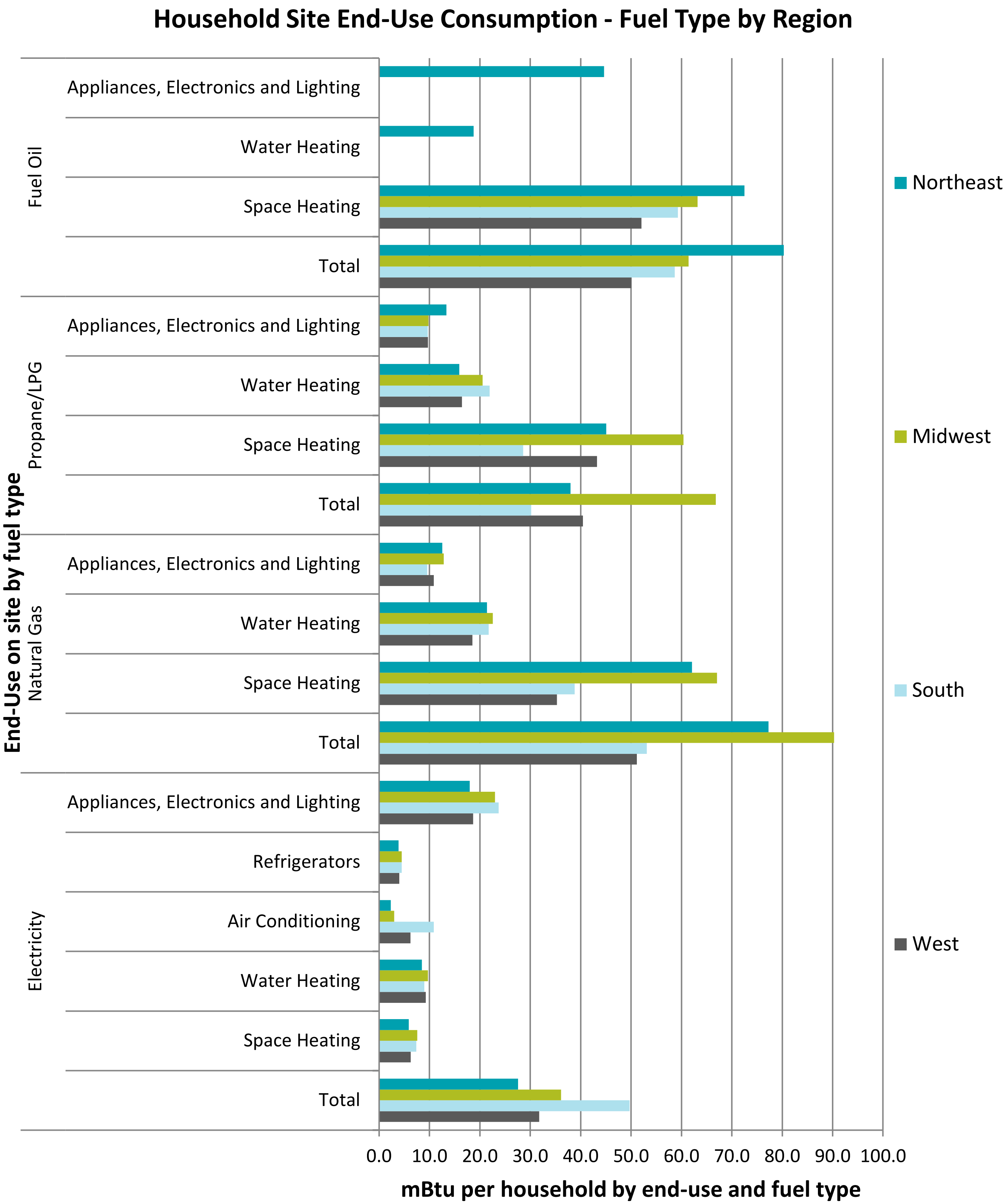
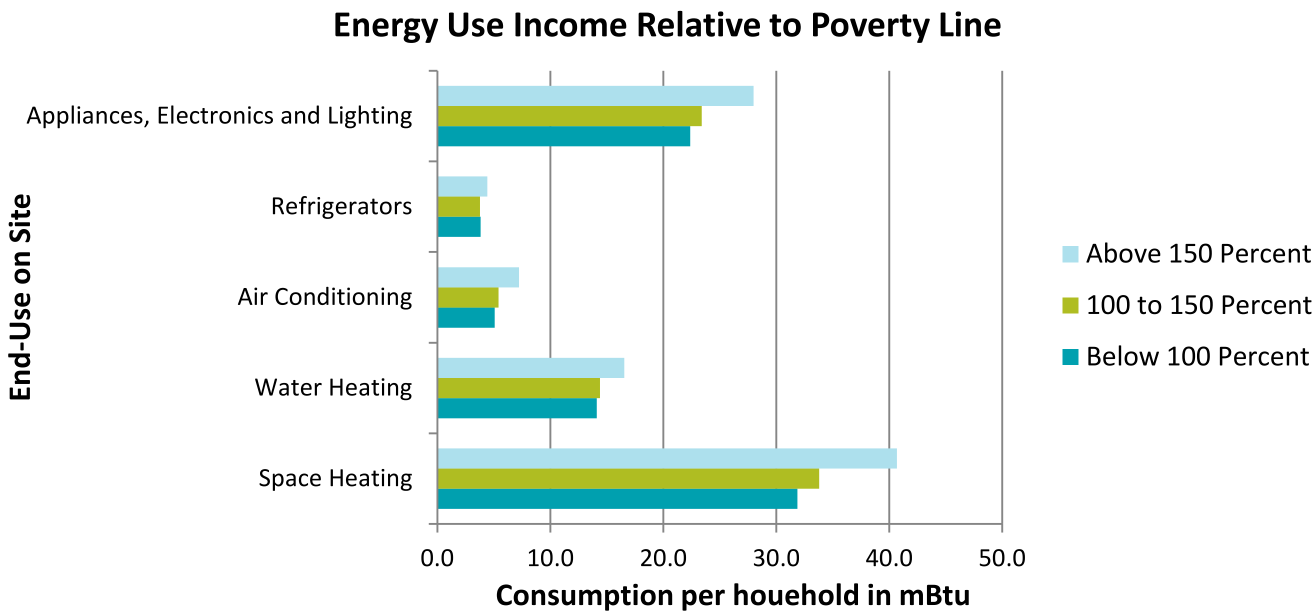


Figure 29: Energy Use Income Relative to Poverty Line



Appendix F: Behavioral Savings Research

Category	Behavior, Contractor, or DIY	What are we asking them to do?	Details	Energy Savings Range (kWh) MINIMUM	AVERAGE	MAXIMUM	Total % of Household savings of average home Low	High
HVAC	B	Raise AC thermostat temp (summer)/ lower temp (winter)	raise in summer from 72 to 76 lower in winter from 72 to 68	500	550	600	4.58%	5.50%
	B	close curtains in day time when windows are in direct sunlight	Use blinds during summer days	15	27.5	40	0.14%	0.37%
	B	use fans instead of AC	use freestanding or ceiling fans to cool the home	400	625	850	3.67%	7.79%
	B	keep doors/windows closed while AC or heating is running					0.00%	0.00%
	C	**install efficient ac (central)**		100	225	350	0.92%	3.21%
	C	**install swamp cooler**		100	800	1500	0.92%	13.75 %
	D	**purchase efficient ac (window)**	SEER 10 --> SEER 15	40	70	100	0.37%	0.92%
	D	buy a programmable thermostat	Program for occupied/unoccupied/sleep hours, and setback when on vacation	350	500	650	3.21%	5.96%
	D	Program your Thermostat	The $180 savings assumes a typical, single-family home with a 10 hour daytime setback of 8° F in winter and setup of 7° F in summer, and an 8 hour nighttime setback of 8° F	800	1200	1600	7.33%	14.67 %

			in winter and a setup of 4° F in summer.					
	D	Change your AC/Heating filter		100	112.5	125	0.92%	1.15%
	D	repair window/door seals					0.00%	0.00%
	B	Reduce the number of hours that heating is on					0.00%	0.00%
	B	reduce the number of hours that cooling is on					0.00%	0.00%
	B	isolate rooms that are heated or cooled					0.00%	0.00%
Lighting	B	turn off lights when not in use	reducing the use of 5, 60 watt bulbs by 2 hours per day	50	137.5	225	0.46%	2.06%
	B	use appropriate level of lighting	using task or replacing bubls for lower wattagelighting instead of overhead	20	260	500	0.18%	4.58%
	B	right wattage for task	using task or replacing bulbs for lower wattage lighting instead of overhead	20	260	500	0.18%	4.58%
	B	dim EE smart light to 25% output		4.663 08	6.538 08	8.413 08	0.04%	0.08%
	B	dim EE light to 33% output		5.023 08	6.178 08	7.333 08	0.05%	0.07%
	B	dim EE lights to 50% output		3.663 08	4.538 08	5.413 08	0.03%	0.05%
	B	dim EE lights to 66% output		2.218 08	2.795 58	3.373 08	0.02%	0.03%
	B	dim EE lights to 75% output		1.538 08	1.975 58	2.413 08	0.01%	0.02%
	B	use 1 EE light 2 hours less a day from 5 hrs						
	D	**install EE light bulbs**	Replace 10 incandescents with CFLs	100	225	350	0.92%	3.21%
	D	install dimmers	Typical Residential Savings	10	12.5	15	0.09%	0.14%
		install and use smart	assumes the use of 7 w	9.543	21.81	34.08	0.09%	0.31%

		switch	led low and 25 w cfl	719808	42167	47136		
	D	outside lights on motion detectors	Replace 500W flood light	250	262.5	275	2.29%	2.52%
	D	outside lights on photosensors	Changing from 24hrs to 8 hrs	99	137.5	176	0.91%	1.61%
	D	replace two lamps with ones that are 25% more efficient	See Assumptions Tab	9	23.5	38	0.08%	0.35%
	D	replace 85% of all installed light bulbs with a mix of CFL and LED	See Assumptions Tab	615.364869	867.6682435	1120	5.64%	10.27%
	D	replace 100% of all installed light bulbs with a mix of CFL and LED	See Assumptions Tab	723.9252787	1020.962639	1318	6.64%	12.08%
	B	discontinue using 1 light that is on all night	See Assumptions Tab	36	62	88	0.33%	0.81%
	D	LED christmas lights (& timer)	Replace conventional lights w LED	5	27.5	50	0.05%	0.46%
	B	Use task lighting	may require the purchase of a new portable luminaire				0.00%	0.00%
DHW, washing, drying	B	wash clothes in cold water	Changing from hot to cold	650	675	700	5.96%	6.42%
	B	line dry clothes	Use a drying rack 2 loads per week	400	420	440	3.67%	4.03%
	B	clothes washer/dryer - full loads (but not overloaded)	reduce 2 loads per month	150	162.5	175	1.38%	1.60%
	B	avoid peak times	Varies by utility and program				0.00%	0.00%
	B	clean lint trap/ vents regularly	each load/ 4x a year	75	87.5	100	0.69%	0.92%
	B	use auto setting on dryer	Dryer turns off when the clothes are dry, not based on a timer	50	100	150	0.46%	1.38%
	B	use appropriate wash cycle (not too long)					0.00%	0.00%

	B	Take a short shower	change from 15 minutes to 7				0.00%	0.00%
	B	Reduce the number of showers taken					0.00%	0.00%
	C	switch from electric to gas dryer	assuming 4 loads/wk	700	750	800	6.42%	7.33%
	D	**buy E* washer**	assuming 4 loads/wk	50	225	400	0.46%	3.67%
	D	Reduce Water Heater Temperature	Reduce from 130 to 115 degrees. Turn down further when on vacation	200	900	1600	1.83%	14.67 %
	D	use timer with water heater tank to avoid peak time use						
	B	turn off when going on vacation or use vacation mode if available						
	D	Insulate Hot Water pipes and first 2 feet of cold connected to water heater						
Plug Loads/ Appliances	**B**	switch off at night	Varies by appliance				0.00%	0.00%
	B	switch off when not at home	Varies by appliance				0.00%	0.00%
	B	switch off when not in use	Varies by appliance				0.00%	0.00%
	B	unplug at night	Varies by appliance				0.00%	0.00%
	B	unplug when not at home	Varies by appliance				0.00%	0.00%
	B	unplug when not in use	Kitchen Appliances: coffee maker, microwave, toaster	50	50	50	0.46%	0.46%
	B	unplug consumer electronics	Audio/ Visual Equipment: TV, DVD, Game Console, & Cable Box	50	275	500	0.46%	4.58%
	B	Don't have orphaned power cords	Computer Equipment (Normally on standby for 16 hrs/day)	20	22.5	25	0.18%	0.23%
	B	Switch computer to standby (if leave on currently)		250	275	300	2.29%	2.75%

	B	Switch computer off (don't just leave on standby)	Computer that would be on standby for 16 hrs/day	20	22.5	25	0.18%	0.23%
	B	Use power saver settings on laptops, monitors, phone					0.00%	0.00%
	B	unplug rechargeable drills, tools, shop equipment					0.00%	0.00%
	B	unplug printers, scanner					0.00%	0.00%
	B	unplug routers, modems	Unplug Cable box w/ DVR (20 hours unplugged/day)	300	312.5	325	2.75%	2.98%
	B	hair dryers, electric shaver, toothbrush	Cut hair dryer usage in half	30	35	40	0.28%	0.37%
	B	throw away, recycle (or at least unplug) unused electronics					0.00%	0.00%
	B	adjust your coffee maker settings	switch off when done drinking	250	262.5	275	2.29%	2.52%
	B	Dishwasher: full loads, economy cycle (no-heat dry)		5	7.5	10	0.05%	0.09%
	B	Using the smallest pan or pot for the job					0.00%	0.00%
	B	using the right burner for the size pan or pot fit					0.00%	0.00%
	B	using the right amount of water when boiling					0.00%	0.00%
	B	reducing heat when food or water boils					0.00%	0.00%
	B	using a lid while cooking or boiling water					0.00%	0.00%
	B	turn off heat 3-4 minutes before cooking time is complete					0.00%	0.00%
	B	use convection fan when baking and oven used					0.00%	0.00%
	B	do not boil water in kettle when not needed					0.00%	0.00%

	B	turn up refrigerator and or freezer thermostat temperature setting					0.00%	0.00%
	B	Reduced microwave oven use					0.00%	0.00%
	B	Reduce Oven Usage					0.00%	0.00%
	B	Reduced Cooking Range Usage	assumes 2 hours less cooking time per month	30	43.5	57	0.28%	0.52%
	B	Open refrigerator door less often or close more rapidly	depends on the size and age of unit	6.87	10.04 5028 57	13.22	0.06%	0.12%
	B	Turn Refrigerator temperature up to 38F from 33F	depends on the size and age of unit	24.8	37.2	49.6	0.23%	0.45%
	B	Turn Freezer temperature up from -5F to 5F or 0F	depends on the size and age of unit	24.8	37.2	49.6	0.23%	0.45%
	D	**Recycle old refrigerator**		111	280.5	450	1.02%	4.13%
	D	Use a manual power strip and switch off					0.00%	0.00%
	D	Use an advanced or smart power strip	on a timer?	20	235	450	0.18%	4.13%
	D	buy a E* appliance (including TV, etc)	E* TV replacement (35 in comparable models). See table below	40	70	100	0.37%	0.92%
	D	switch from PC to laptop	computer used 5 hours a day	150	175	200	1.38%	1.83%