Characterization and Potential of Home Energy Management (HEM) Technology

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Table of Contents

Executive Summary

The Home Energy Management (HEM) market is rapidly expanding alongside substantial investments to improve energy efficiency and upgrade electricity infrastructure to a smart grid. These changes enable consumers to take greater control of their energy use, which can be enabled through the use of Home Energy Management Systems (HEMS).

Defining HEMS

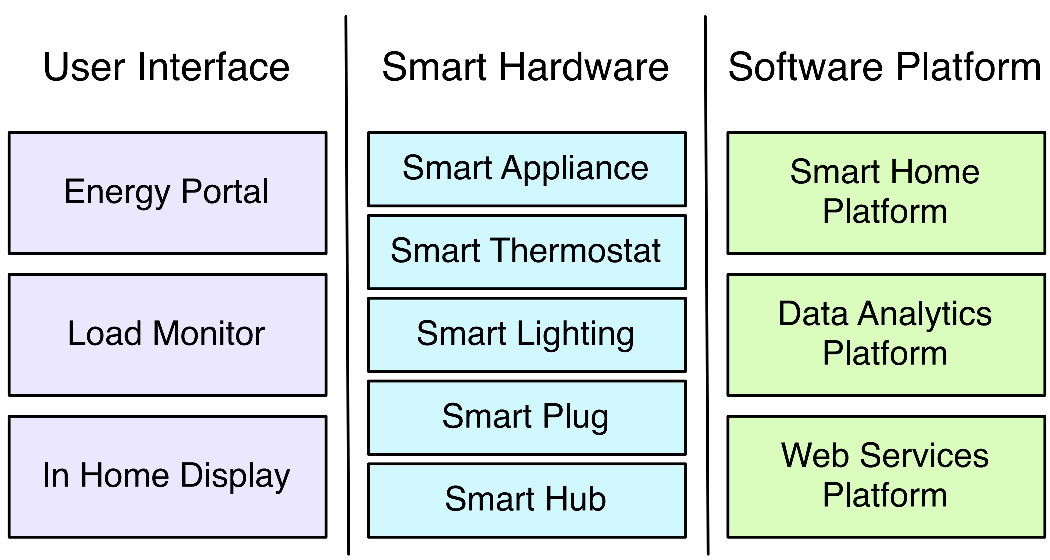
HEMS can be broadly defined as those systems (including both hardware and software linked together via a network) that enable households to manage their energy consumption. This can be done in one (or both) of two ways:

1. HEMS can provide energy consumers with **information** about how they use energy in the home and/or prompts to modify consumption
2. HEMS can provide the household (or third parties) the ability to **control** energy-consuming processes in the home, either remotely via a smart phone or web service or based on a set of rules, which can be scheduled or optimized based on user behavior.

As such, HEMS enable the delivery of a wide range of both household and utility objectives around energy management, financial benefits, comfort and convenience, greenhouse gas emissions reductions, as well as to ensure access to a reliable energy supply.

HEMS Technology

The HEMS sector is growing rapidly, and at the time of writing this report, 12 distinct product types or categories that make up a home energy management system were identified. These fall into three groups: (1) user interfaces, (2) smart hardware, and (3) software platforms.



User interfaces include: energy portals, in-home displays, and load monitors, whose primary function is to incorporate the user into the home energy management process by providing them with information to help make more informed energy use decisions and/or enabling them to implement remote or rule-based control.

Smart hardware, including appliances, thermostats, lighting, plugs, and hubs, describes those products that physically enable household energy demand to be controlled such that the energy demand patterns of particular appliances are modified to meet particular objectives.

Software platforms facilitate the communication of information between users, utilities, and hardware in the home. They include: (1) smart home platforms, which deliver a managed environment and provide core services to enable a standardized way for devices and appliances to interact; (2) data analytics platforms, which are typically hosted on the cloud and analyze large volumes of data to provide additional insights about energy use patterns; and (3) web services platforms, which provide end-users additional functionality for managing connected devices.

The rapid expansion of the HEM market and the desire for increasing levels of interoperability between products and platforms has led to the emergence of new types of communication protocols and alliances based on these. Over the coming years, this may open up the opportunity for further engagement between manufacturer and a variety of developers to create fully integrated home management solutions that better meet the needs of customers.

HEMS Savings Potential

Past research on information-only HEMS discusses average savings that range from 2% to 20%, while a meta-analysis of 42 such studies indicates that the true savings (correcting for statistical bias) are more likely to be in the range of 4% to 7% (Karlin, Ford, & Zinger, in preparation). Moderator analysis revealed that goal comparisons, combinations with other interventions, and computerized displays all increased the effectiveness of energy feedback information.

Research on information-only HEMS long pre-dates research on control-based HEMS since technologies enabling the latter are relatively new in comparison. This means that the replicable, empirical field studies investigating control-based HEMS are sparse and strong conclusions cannot be made at this stage regarding potential savings.

In order to better estimate savings of HEM technologies, further research is suggested, with an emphasis on studies that:

1. Integrate of **theory** into hypothesis generation and design to better interpret results;
2. Test of multiple variables via **factorial designs** to identify and isolate variation;
3. Pay greater attention to the **physical design** of HEMS to reflect user needs;
4. **Improve reporting** of methods and results to enable replication and interpretation; and
5. Collect **additional data** to allow testing of how and for whom HEMS are effective.

HEMS Adoption Potential

While the savings potential of HEMS is likely to depend on the type of system implemented and the functionality offered, the big picture impact of HEMS also depends upon the extent of HEMS adoption. The adoption process proceeds in five phases, as consumers move from a state of (1) knowing about the technology to (2) forming a positive attitude toward the technology to (3) making a decision to adopt the technology to (4) using the technology to (5) seeking to reinforce their decision to adopt. Both individual characteristics and communication channels influence this process at each stage.

Preliminary studies suggest that a large number of Americans are still largely unfamiliar with HEMS technology but seem to have positive attitudes towards HEM functionality with asked about it. While much research has investigated and shed light on one aspect of HEMS adoption, such as the individual characteristics that distinguish early adopters of smart home technologies from non-adopters, few studies have systematically evaluated naturalistic adopters. To more broadly advance our understanding of how HEMS might be adopted in the wider marketplace, it is necessary to ensure that further research is both grounded in theory and attempts to systematically identify multiple aspects influencing the adoption process.

The Role of Utilities

Energy utilities have an opportunity to take a central role to better take advantage of the full energy savings, demand response, and customer convenience benefits of HEMS by supporting research and testing, providing a gateway for connections and data transfer across devices, serving as a trusted energy advisor, building supportive energy efficiency and demand response programs, and developing customer data security processes.

Conclusion

It is clear that HEMS is an ever-changing market and every prediction is a moving target. The creation of a supportive environment that promotes energy efficiency and demand response initiatives can help facilitate the further development and evolution of a strengthening HEMS market. Additionally, further research to help better understand consumer uptake, behavior, and interaction with HEMS will assist in piecing together a more accurate market forecast. It seems that many market predictions to-date have overshot the market potential, which may mean that the products are not as attractive to consumers as preliminary researchers and product developers think and further research focused on the user experience could be fruitful. However, if they are able to attract consumers, it seems that Home Energy Management Systems have a great deal of potential for energy efficiency and demand side management within the residential sector.

1. Introduction

Billions of dollars are being spent each year upgrading energy systems to maximize demand side management (DSM) potential. Reports estimate up to $70-100 billion are spent each year to upgrade the larger energy efficiency of the U.S. economy (Laitner, 2013), and by 2015 as much as $200 billion may be spent on smart grid investments (Fox, Gohn, & Wheelock, 2009).

One major benefit of the Smart Grid is that it can enable consumers to take an active role in managing energy consumption by providing information in the form of energy use feedback. Traditionally, energy customers receive 12 data points per year about their energy consumption, corresponding to one per month based on the meter reading taken by the electric utility. A utility collecting smart meter data in hourly increments can produce thousands of data points per year, significantly increasing the amount and type of information available. Sampling within the home can enable even greater granularity of information to be collected, processed, and provided back to consumers (Figure 1). This allows for statistical analysis to distinguish energy use by time, and possibly by end-use, and information can be provided to consumers without having to process the information via the utility provider. “Adding sensors to the feedback equation helps solve problems of friction and scale. They automate the capture of behavioral data, digitizing it so it can be readily crunched and transformed as necessary. And they allow passive measurement, eliminating the need for tedious active monitoring” (Goetz, 2011).

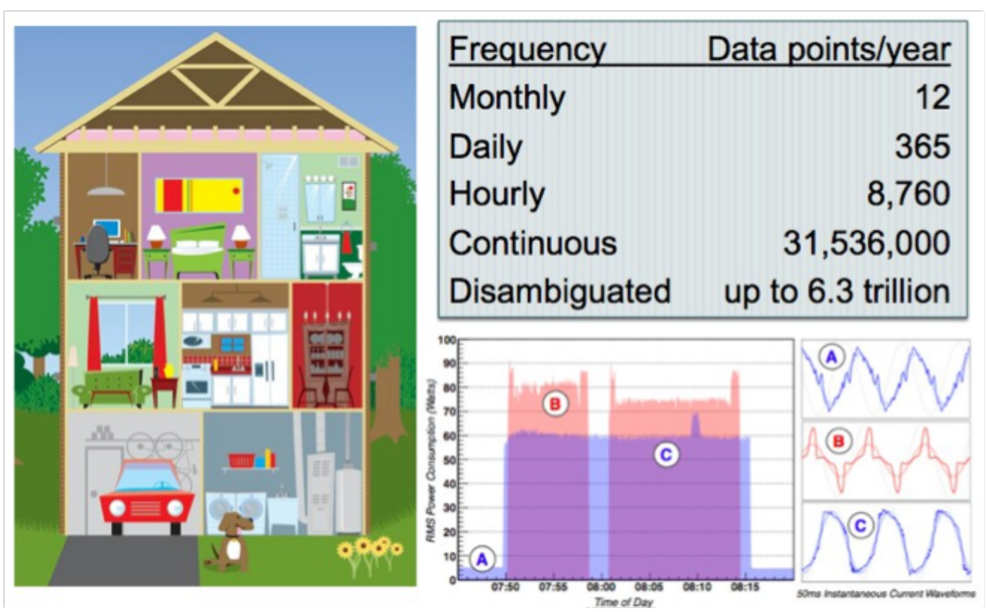


Figure 1. Data Granularity for various sampling frequencies of energy information

Alongside the developments enabling more frequent and more granular feedback to be provided to users are improvements in information and communication technologies that integrate into the user's home (e.g. through the smart meter or Internet router) and in data analytics related to energy use (e.g. the analysis of smart meter data by companies such as Bidgely). This has resulted in the ability to provide prompts to consumers intended to trigger behavior-based demand management. These prompts may come from the utility in the form of an economic incentive designed to encourage a shift in consumption away from peak-demand (Ford et al., 2014). The prompts may also come in the form of information about actions that the household can take to modify their consumption more generally. On top of the information (i.e. feedback and prompts discussed above) that is becoming increasingly available due to the addition of sensors, processors, software, and connectivity in household devices, more and more products are able to communicate and be controlled remotely and/or automated via rules that the user or utility can set (Heppelmann & Porter, 2014).

These capabilities are often referred to as Home Energy Management and the systems that enable them Home Energy Management Systems (HEMS). Both the public and private sectors have recognized these changes and are creating and supporting new technologies to provide improved information and control to consumers. For instance, the U.S. White House Green Button Initiative is encouraging utilities to provide consumers with real-time access to their energy information and promoting private sector development to create devices that integrate with this system (Chopra, 2011). In addition, advances ranging from improved energy reporting by companies to machine learning algorithms in products like smart thermostats are beginning to deliver on the promise of a "smart" home in which consumers have both better information about and control over their home's energy use. In recent years, a growing number of HEMS products have emerged in the global marketplace (Karlin et al., 2014; LaMarche et al., 2012), ranging from simple energy feedback displays to fully integrated whole-building energy management systems.

Despite this diverse and constantly evolving marketplace, and the wide variety in how home energy management is enabled, much of the discussion has treated HEMS as a unified construct. This is reflected in the research, which has devoted little attention to understanding how or for whom HEMS work. Products differ in several ways, including display medium (e.g., website, in-home display), energy message (e.g., cost, social comparison), and data collection (e.g., internal sensor, smart meter). All of these variables have been hypothesized to impact consumer response; savings in pilot studies vary from 2-3% for Opower feedback to 20+% for advanced systems, yet little research comparing products has been conducted and the public lacks information about which HEMS are available or how they vary in terms of these key characteristics. There is also little understanding of the market or near-term technology potential for the more "advanced" options, and even less linking the two to make informed predictions about user adoption and savings scenarios. An improved understanding of the functions, products, and savings potential of HEMS would be of great benefit at both a theoretical and practical level.

Report Roadmap

This report reviews the range of Home Energy Management (HEMS) products that are currently on the market, assesses current knowledge on savings and adoption potential, and suggests key considerations for future research and practice. It was produced for Pacific Gas and Electric in order to help inform the development of current and future programs for the utility. The report specifically aims to address the following four questions:

1. What are the key **functionalities** and **characteristics** of Home Energy Management?
2. What are the key HEM **products** in the market, and how do you differentiate them?
3. What is current knowledge on energy **savings and adoption potential** for HEMS?
4. What are some key **considerations** for the future of HEMS, and what is the utility's role?

In Chapter 2 the methods used to answer these research questions are discussed. In Chapter 3 the functionalities and characteristics of HEM technologies are discussed, and Chapter 4 outlines actual HEM products on the market and describes them in terms of 11 primary product categories. Chapter 5 presents secondary analysis of the savings potential of HEM technologies, and Chapter 6 addresses what is known and not known regarding near-term adoption potential of HEMS. Chapter 7 provides conclusions and recommendations regarding the uptake and impact of HEMS in California.

As HEM technologies become increasingly ubiquitous, with a growing capacity to leverage personalized energy information, there is an urgency to ensure that they are utilized to their full potential. As a whole, this report aims to extend what is known about HEMS and to make suggestions for future research.

2. Methods

To address the research questions outlined above, our research procedure consisted of the following four work streams.

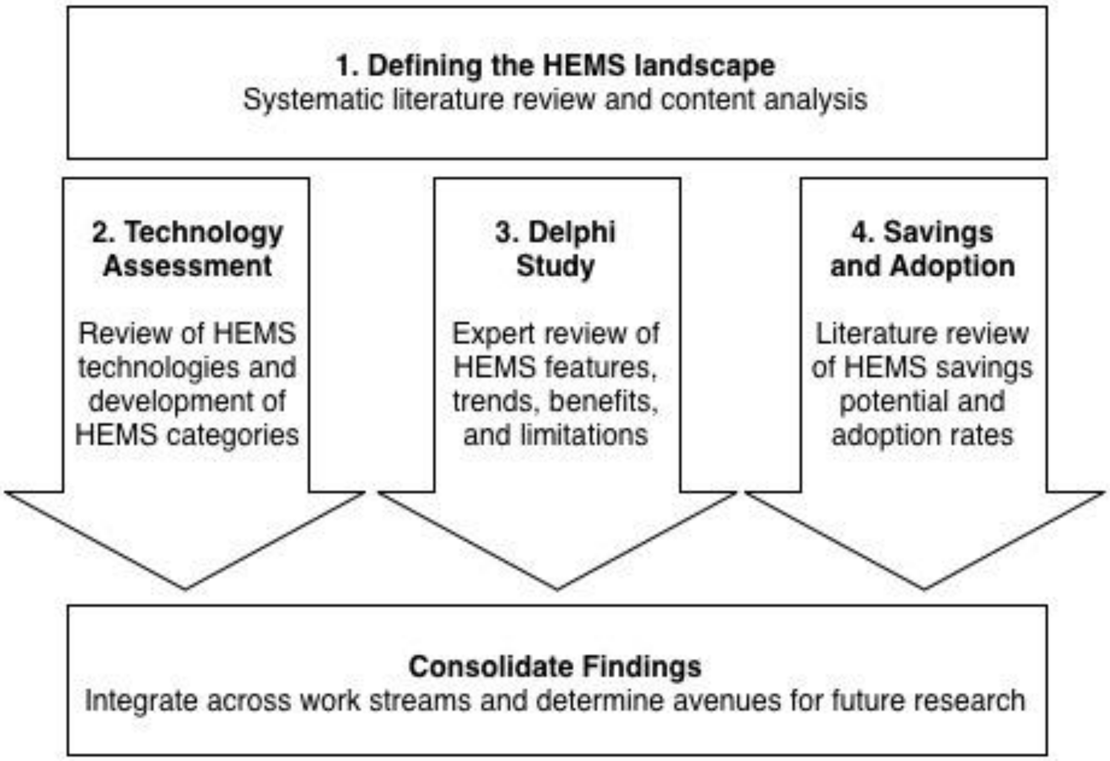


Figure 2. Methods

2.1. Defining the Landscape

First, previous literature on Home Energy Management was systematically reviewed using content analysis, which is a method of inferring patterns from text by creating categories and coding the text into those categories based on specified criteria (Krippendorff, 1980; Stemler, 2001). We conducted a systematic literature review and content analysis to determine what is or should be included in the category of Home Energy Management. Relevant articles were identified via (a) keyword search in PsycINFO, JSTOR, Web of Science, and Google Scholar, (b) backward and forward search of highly relevant articles, and (c) recommendations from personal contacts. After all articles were compiled, definitions for key terms (e.g., HEMS, HAN, smart, feedback, control) were extracted and common definitions were analyzed using emergent coding (Haney, Russell, Gulek, & Fierros, 1998). The identified literature was reviewed to determine key themes used to discuss HEM objectives, definitions, and functionalities.

Following this initially literature review, the key themes were used to guide Steps 2, 3 and 4 corresponding to the technology assessment, Delphi study, and an evaluation of the savings and adoption potential of HEMS.

2.2 Technology Assessment

The technology assessment extends and updates previous work conducted by the study authors (Karlin et al., 2014, Ford et al., 2014) to analyze and classify HEM technologies. As such, information on over a hundred specific products and platforms were identified and collected from August-November 2014 and coded for information related to product category, capabilities, and company information. Data were identified using the following four methods:

1. **Report authors' past reports**. The product lists from Karlin et al., 2014 (208 products) and Ford et al., 2014 (82 products) were reviewed; 68 unique products were identified.
2. **Internet keyword search.** Keyword searches were conducted using the terms home energy management, home automation, and smart appliance, lighting, thermostat, & plug.
3. **Media sources.** Relevant media and news channels were also searched for products. Key sources included GreenTechMedia, Mashable, Techcrunch, Gigaom, and CABA.
4. **Personal contacts.** Additional HEMS were identified via communication with an identified set of experts in our Delphi Study (see below).

The total number of HEMS technologies compiled and reviewed using all four of the above search strategies was 168. As the HEM technologies were identified they were added to a coding sheet where their main functionalities were detailed. This was used alongside the HEM literature review to develop categories of HEM technologies and characterize each product identified.

2.3 Delphi Study

The Delphi method is a structured communication method for systematic forecasting using a panel of experts who answer questions in a series of successive rounds that are summarized and provided back to the experts (with the reasons they provided for their judgments) by a trained facilitator (Hsu & Sandford, 2007). Thus, experts engage in a structured, interactive dialogue, revising answers in light of others' replies, ideally leading toward a convergence of opinion(s), which reflect the collective wisdom of the group. Delphi is generally conducted in writing over a series of weeks or months, but can also be used in face-to-face meetings or online. We conducted a modified Delphi study combining traditional elements with the newer real-time Delphi method (Gordon, 2009) using an idea management platform called GroupMap.

Our study consisted of two online "rounds," each of which was open for one week and designed to take 10 minutes to complete. Each round consisted of five open-ended questions or prompts; questions in Round 2 were designed to clarify and expand on the responses provided in Round 1. For each question, participants were shown the question along with responses of all participants to-date. They could add one or more responses if their viewpoint was not already captured in the existing list and then were prompted to provide feedback by both commenting and voting on others' ideas. After providing feedback, participants navigated to a results page where results to-date were summarized. They were allowed to return to a question to review/revise their answers for as long as each round was open. All ideas and responses were anonymous to other participants. The following questions were asked in each round:

Table 1. Delphi Round 1 and Round 2 questions

	Round 1	Round 2
Products, Players, Platforms	Who and what are the key products, players, and protocols?	N/A
Features of HEMS	What do you think are some of the important features of Home Energy Management products and systems?	We've listed the top 10 HEMS "features" that you identified in Round 1. Please arrange them below based on their potential (cost) and benefits (savings).
Benefits of HEMS	What do you think are some the main benefits that HEMS can deliver?	N/A
Trends and Innovations	What do you think are some of the most influential trends and innovations leading to changes and/or growth in Home Energy Management (HEM)?	Looking into the future, what do you think HEMS will, should, or could look like in the near-term (3-5 years) and the long term (10-15 years)?
Barriers	What are the some of the key barriers to growth in this market? These may or may not be directly related to HEM, and could include social, economic, political or environmental factors.	We've listed the top three barriers to HEMS market growth that you identified in Round 1. Please share any ideas that you may have as to how to overcome these barriers?
Role of Utilities	N/A	What do you think should be the role of utilities in home energy management? What utilities should do MORE of? LESS of? What utilities should KEEP doing?
Defining HEMS	N/A	Based on your responses from round 1 as well as a review of related literature, we have drafted a definition of HEMS. Please comment whether you agree with this and/or have any suggested edits/additions

Forty-four HEMS experts participated in the Delphi Study, with an average of 12.5 and as many as 31 years' experience with the majority of participants coming from research/academia or tech/industry (Figure 3).

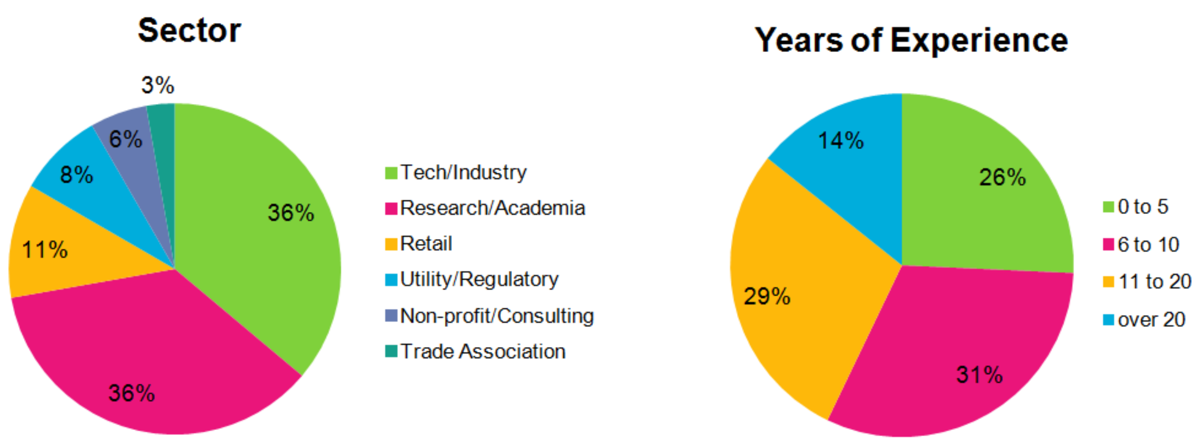


Figure 3. Breakdown of Delphi participants by sector and years of experience

2.4 Savings and Adoption Assessment

The savings and adoption literature review utilized some of the same literature as the initial HEMS systematic literature review as well as literature specific to energy savings potential and consumer adoption or awareness of HEM technologies. Specific searches were conducted for the specific subtopics in each section.

In the final phase of our work, the data from the 4 work streams described above was consolidated and thematically analyzed to identify key characteristics impacting the future directions of HEMS.

3. The Home Energy Management Landscape

While widely discussed, there is not yet a specific operational definition of Home Energy Management (HEM) or an agreed-upon description of Home Energy Management Systems (HEMS) or the functionalities and categories of products included within them. This chapter will serve as a systematic introduction to HEM and HEMS. We review past literature and synthesize viewpoints to present the holistic ecosystem of HEMS, which will guide the discussion in the rest of this report. We will discuss HEM in terms of its objectives and benefits, provide an operational definition of HEMS, consider their key functionalities, and highlight the main characteristics that define and describe such technologies.

3.1 HEM Objectives and Benefits

As their name implies, Home Energy Management technologies serve the primary purpose of enabling residential users to manage home energy use by reducing consumption (Han et al., 2011, Khan et al., 2013; Rossell & Soler, 2011; Van Dam, Bakker, & Van Hal, 2009) or shifting/trimming peak demand (Chaudhari et al., 2014; Ford et al., 2014). This enables households to "select and implement a strategy for their use of energy" (Delphi participant) and delivers benefits such as a better understanding of their energy use, better information about energy use in the home, and insight into problems with equipment (i.e. fault detection).

The benefits of HEMS to the user go can go beyond the modification of energy consumption patterns (Wilson, Hargreaves, & Hauxwell-Baldwin, 2014). Benefits of HEMS from the consumer perspective include "to save money, live more comfortably, and save time" and "comfort, convenience, and control" (Delphi participants). The importance of these non-energy benefits is starting to be reflected in products emerging on the market; as the makers of Nest say, *"It's about making your house a more thoughtful and conscious home.™"* (Tanous, 2014)

Alongside the benefits to households, HEMS may enable utilities to meet energy objectives. Delphi participants identified the main benefits of HEMS to the *utility* as the ability to enable demand response and time-of-use pricing, increase customer engagement and improve customer relationships, and provide a low-cost way to balance supply and demand and evaluate programs. Of these benefits, enabling demand response was the most popularly discussed.

HEMS have the opportunity to play an important role in bringing together the objectives of households and utilities around energy management, meeting policy objectives around greenhouse gas emissions reductions, and securing a reliable energy supply; in fact, HEMS technologies are an important technological solution to enable the delivery of a wide range of objectives (Wilson et al., 2014). Thus, it is important to review the functionality of such energy management technologies for delivering the desired benefits to a wide range of stakeholders.

3.2 HEMS Operational Definition

Without a clear operational definition, it is difficult to determine what distinguishes HEMS from related products. Several current definitions are consistent with the objectives above, including the ability of HEMS to provide "monitoring and control of selected devices for residential buildings" (Hertzog, 2011), and consequently providing "the platform for increased interaction between consumers and the energy grid" (Mirzatuny, 2013).

Whilst Aricent Group (2013) characterizes HEMS as just the specific elements of smart homes that provide feedback *and* enable homeowner and utility control, Roth and Sache (2013) define HEMS more broadly as "any device or system in the home used to: (1) control an energy consuming device, (2) identify or diagnose energy savings opportunities, or (3) provide information to occupants to influence how they consume energy"; this definition was also used by Ford et al. (2014) and Rosenberg and Liecau (2014).

Others link HEMS to smart homes, such that smart homes are enabled by HEMS, consisting of "information and communication technologies (ICTs) distributed throughout rooms, devices and systems (lighting, heating, ventilation) relaying information to users and feeding back user or automated commands to manage the domestic environment" (Wilson et al., 2014).

HEMS are most often characterized by their ability to provide the user with (1) feedback about energy use in the home, (2) information to help users manage their energy consumption, and (3) control of household appliances and devices. Many descriptions highlight their ability to provide not the user, but a third party (e.g., energy utility), with greater control of household appliances and devices for the purposes of shifting peak demand. This ability is depicted in Figure 4.

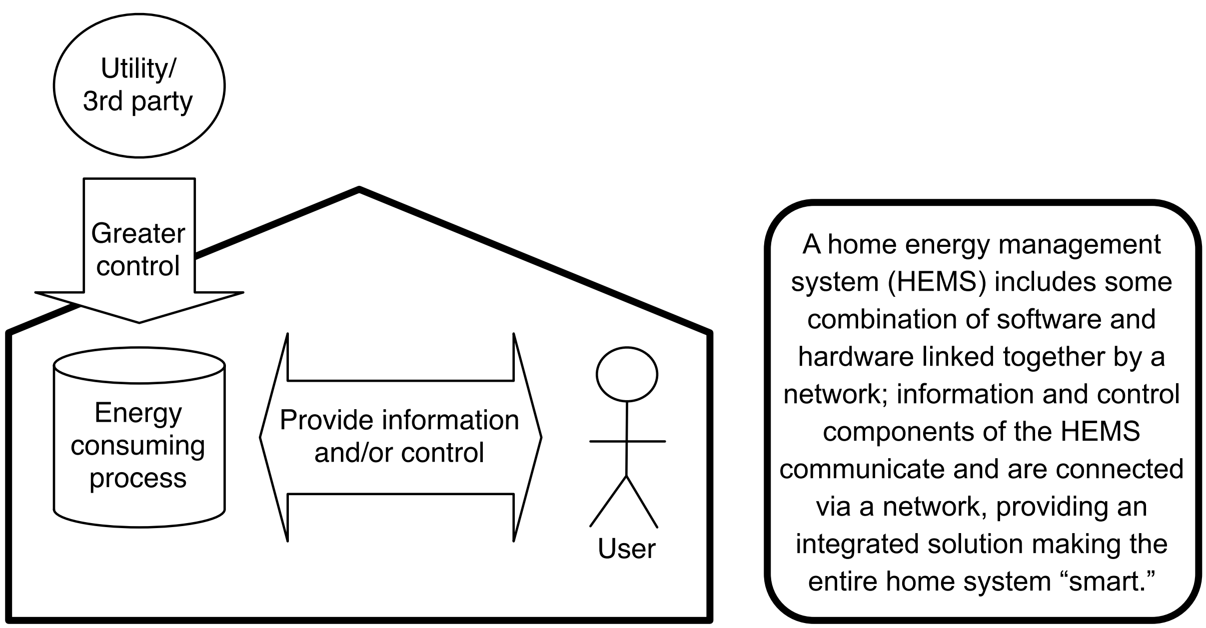


Figure 4: Defining HEMS

Based on these characterizations, we provide an operational definition of home energy management technologies as those that enable households to more actively manage their energy consumption by providing **information** about how they use energy in the home or to prompt them to modify their consumption, and/or providing the household (or third parties) the ability to **control** energy-consuming processes in the home. These functionalities are discussed in more detail in the next section.

3.3 HEM Functionalities

To enable HEMS technologies, as defined above, to meet their objectives, HEMS technologies must offer a set of information and/or control based functionalities to users (see Figure 5). Our Delphi participants highlighted the need to consider both energy monitoring and management, with one respondent suggesting that "a distinction be made between managing and monitoring" when defining HEMS. These elements may include "residential utility demand response programs, home automation services, personal energy management, data analysis and visualization, auditing, and related security services" (Bojanczyk, 2013). We have grouped them into the two primary categories of information and control and describe them in the current section.

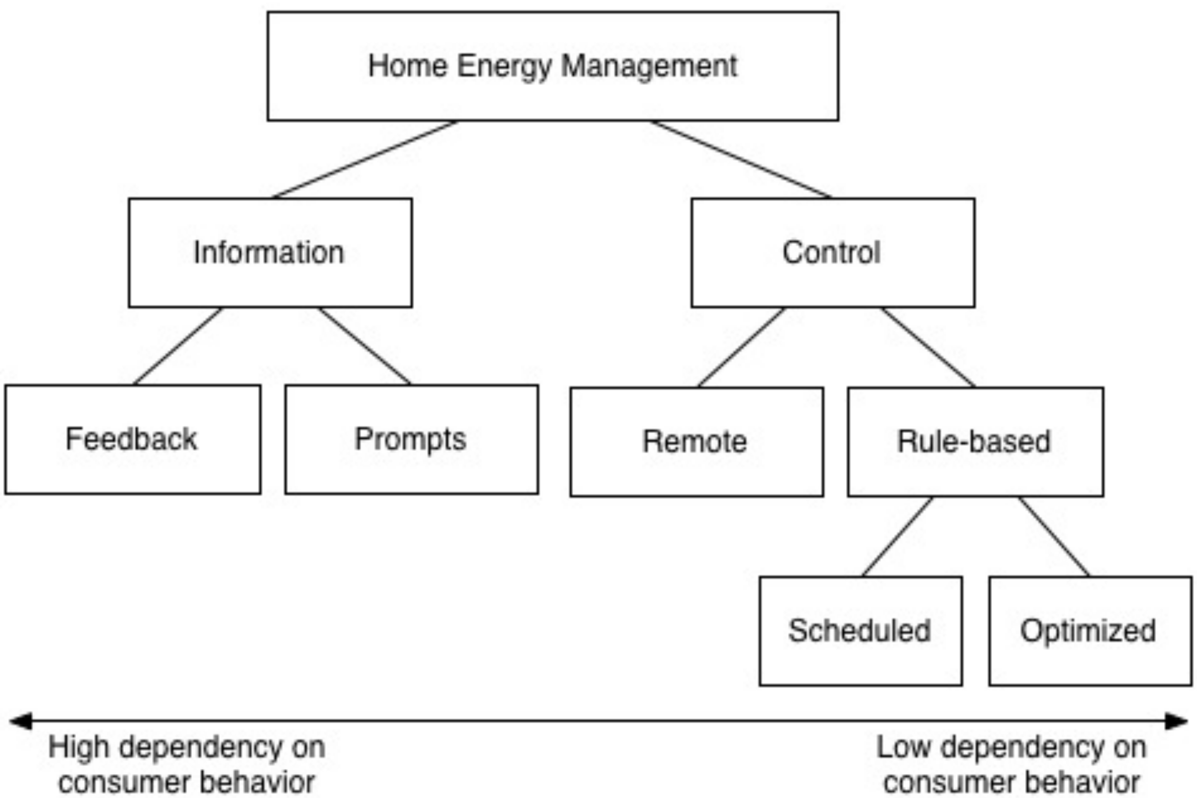


Figure 5. Home Energy Manage Functionalities

Information

The information function of HEMS refers to the ability of systems or products to provide information on energy usage (specific or general) back to the energy user. We break this functionality down the two primary components of feedback and prompts.

Feedback refers to the process of giving people information about their behavior that can be used to reinforce behavior and/or suggest behavior change (Karlin et al., 2014). In the context of home energy management, feedback specifically refers to information about household energy use and is often referred to as energy feedback or eco-feedback (Froehlich et al., 2010). Karlin et al. (2014) define energy feedback "as information about actual energy use that is collected in some way and provided back to the energy consumer" (p. 381). The use of feedback for home energy management has been discussed in the academic literature going back to 1976 with the earliest studies conducted using very rudimentary cards taped to residents' windows with information about the householders' energy use (e.g., Becker, 1978; Hayes & Cone, 1981). Since then there has been substantial growth in the energy feedback marketplace; over 200 feedback products have been identified by the study authors (Ford et al., 2014; Karlin et al., 2014), and as a consequence much feedback is now implemented using technological home energy management solutions.

The provision of energy feedback (i.e., information) has been identified as a key defining functionality of HEMS; Van Dam et al. (2009) define HEMS as "intermediary products that can visualize, manage, and/or monitor the gas, water, or electricity use of other appliances or of a household as a whole." This perspective was also reflected in our Delphi study, with participants emphasizing the importance of feedback stating that "not all HEMS (actively) help manage consumption, but rather only visualize it," and that HEMS refers to "a system that provides households with feedback on their energy consumption and possibly the option to automate or otherwise control energy demand from appliances."

Prompts are another form of information that HEM can provide; they do not provide information on energy usage, but rather send targeted or timed suggestions to the energy user that enable them to more actively manage demand. Often in the form of time of use pricing tariffs, economic incentives, and actionable advice, prompts can help users to shift the time of use of an appliance, increase the efficiency with which actions are performed, or swap one activity for another less energy-consuming one that provides the same service (Ehrhardt-Martinez et al., 2010; Ford et al., 2014; Navigant Research Group, 2013; Wacks, 1991). Prompts provide consumers information and incentives to trigger them to shift their power demand patterns (Ford et al.,2014). As a Delphi respondent suggested, prompts can "provide information on pricing, bills, even payment options, not just consumption detail." The characteristics of the information functionality of HEMS are presented in

Table 2.

Table 2. Information Characteristics

Name	Definition	References
Data Source	Where the energy use information comes from.	EPRI, 2009; Hochwalliner & Lang, 2009; LaMarche et al., 2011; Karlin et al., 2014
Duration	How long the information is provided for.	Fischer, 2008; Karlin et al., 2014
Frequency	How often information is given.	Fischer, 2008; Fitzpatrick & Smith, 2009; Froehlich, 2009
Granularity – end-use	The resolution of the feedback data in terms of end use (i.e. whole home, circuit, appliance level).	Fischer, 2008; Fitzpatrick & Smith, 2009; Froehlich, 2009; Herter & Wayland, 2009; Hochwalliner & Lang, 2009
Granularity - temporal	The resolution of the feedback data in terms of time.	Froehlich, 2009
Immediacy	How soon after (or before) an action information is provided.	Darby, 2006; Ehrhardt-Martinez et al., 2010; EPRI, 2009; LaMarche et al., 2012; Stein & Enbar, 2006
Interface type	Whether the user interface is freestanding, integrated with existing hardware, or software.	Karlin et al., 2014; LaMarche et al., 2011; Rossell & Soler, 2011
Message Comparison	Whether feedback is measured against some standard.	Wood & Newborough, 2007; Fischer, 2008; Fitzpatrick & Smith, 2009; Froehlich, 2009; Herter & Wayland, 2009; GMT
Message Content	The unit of measurement the feedback is given in.	Fischer, 2008; Fitzpatrick & Smith, 2009; Froehlich, 2009; Herter & Wayland, 2009; Stein & Enbar, 2006
Presentation medium	The physical medium on which data is presented to the user.	Fischer, 2008; Froehlich, 2009; LaMarche et al., 2011
Presentation mode	The format feedback is presented in, i.e. ambient, numerical, graphical etc.	Fischer, 2008; Fitzpatrick & Smith, 2009; Froehlich, 2009; Wood & Newborough, 2007
Prompt source	Where the data for a demand response prompt comes from.	Ehrhardt-Martinez et al., 2010; Ford et al 2014; Strother & Lockhart 2013
Prompt type	Ability to send consumers demand-response promopts.	Ehrhardt-Martinez et al., 2010; Ford et al 2014; Strother & Lockhart 2013
Push/Pull	Whether the feedback is sent to the user or the user navigates to it.	Froehlich, 2009; Karlin et al., 2014

Control

Control is the other defining function of HEMS and refers to the ability to modify the energy consumption of a household appliance through remote or rule-based control. It can be provided as remote (aka manual, active, or user) control or as rule-based (aka termed automatic, passive, or system) control (Asare-Bediako, Kling and Ribeiro, 2012; Jaber, 2014).

Remote control is defined as the situation in which a user controls the operation of an appliance in the home via a user interface. This allows the user to manage that appliance's energy demands in real-time from a remote location, providing that their control request can be transmitted to the appliance via some network. It can also be called manual, active, or user control.

Rule-based control can be either scheduled or optimized. Scheduled control, often termed automation, is when users create priorities or settings to manage household appliances ahead of time (Asare-Bediako et al., 2012; Karlin et al., 2014). Optimization is a type of control in which usage or historical data is analyzed and used in algorithms, (such as machine learning) to create a more effective demand pattern within the constraints set by users, and thus improve output and efficiency (Heppelmann and Porter, 2014).

Control can be implemented by both the user and the utility (or third-party) so that multiple stakeholders can realize the benefits of HEM. This allows utilities to send signals direct to appliances in the home to shut them off during a demand response event (LaMarche et al., 2011; Ford et al., 2014). Control signals that come from the utility may include appliance delay, time-based pricing and notifications for load-shedding to meet spinning reserve requirements. (Association of Home Appliance Manufacturers, 2011).

Table 3. Control Characteristics

Name	Definition	References
Controlling source	Who is able to control the energy loads	Bojanczyk, 2013; Erol-Kantarci & Mouftah, 2010; Ford et al. 2014; Wacks, 1991; Ehrhardt-Martinez et al., 2010; Javaid et al 2013
Control type	Whether appliances can be controlled remotely and/or according to a set of rules	Bojanczyk, 2013; Erol-Kantarci & Mouftah, 2010; Ford et al. 2014; Wacks, 1991; Ehrhardt-Martinez et al., 2010; Javaid et al 2013
Loads controlled	Type of loads controlled by the HEM system	Bojanczyk, 2013; Ford et al. 2014
Control intelligence	The "smart" mechanism by which loads are controlled, responding to rules or settings, optimizing demand according to additional input, or automating use independently of users.	Ford et al. 2014; Rossell & Soler, 2011; O'Neill et al., 2010

3.4 Network Capabilities

Alongside the functionalities of information and control, the network is an important component to consider when identifying and characterizing home energy management systems. While networks are not a functionality of home energy management, they provide a fundamental service in enabling different technologies to be integrated into a home energy management system, as illustrated in Figure 6. The most common reference to networks in both literature and popular press is the term home area network (HAN), yet there is some ambiguity as to the distinction between home automation networks/systems and home area networks (HAN). Where these terms have been used interchangeably they tend to refer to systems that link appliances, sensors, controllers, and control panels, and that includes: (1) smart-devices with embedded/attached networking and/or communicating chips for automation; (2) advanced network systems and software using mesh networks to provide measurement and feedback of appliance specific data; (3) the potential for two-way communication with the utility; and (4) some kind of consumer interface for direct, real-time feedback (Wack, 1991; Donnelly, 2010).

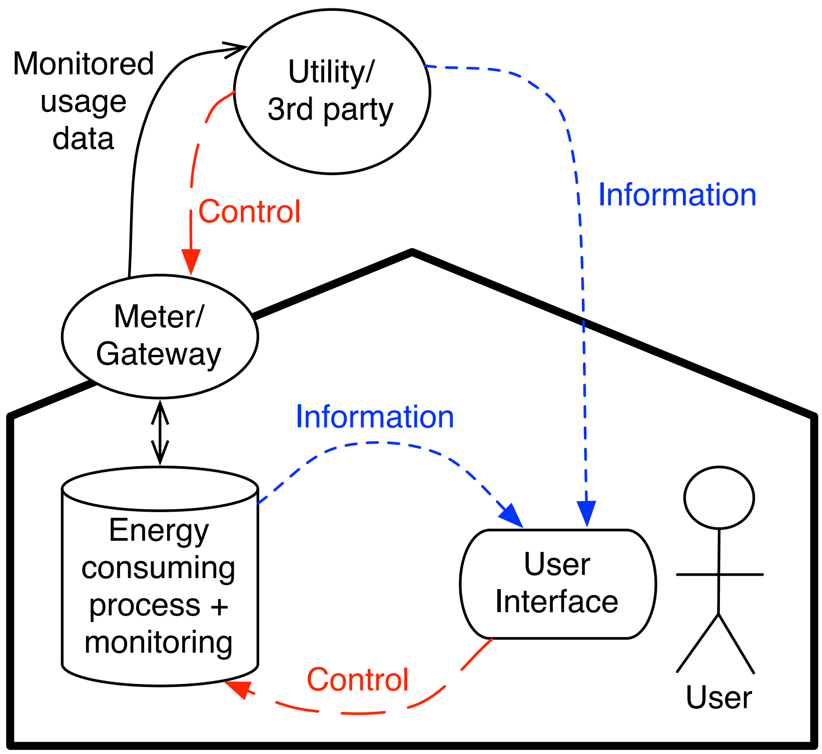


Figure 6. Home Energy Management Network Pathways

To keep clarity around the functionality provided by a home area network and its relationship to home energy management, we define a HAN 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 components of the HEMS (LaMarche et al., 2011; Aricent Group, 2013). Similar to feedback and control, networks can vary based on key characteristics, as seen in Table 4.

Table 4. Enabling HEMS Characteristics

Name	Definition	References
Communications	Whether or not the physical component or components of the system is able to communicate with each other and/or pre-existing electronic devices	Ford et al., 2014; Hochwalliner & Lange, 2009; Karlin et al., 2014; LaMarche et al., 2011; Rossell & Soler, 2011; Jaber, 2014
Communications Protocol	Whether or not the system uses a proprietary communications protocol	Erol-Kantarci & Mouftah, 2010; Karlin et al., 2014; LaMarche et al., 2011; Rosenberg & Liecau 2014; Williams and Matthews 2007
Integration	Details about any third party technologies that can be integrated into the network, including smart hardware and software platforms.	Bojanczyk, 2013; Ford et al. 2014; Strother & Lockhart 2013
Interoperability	Ability of the devices within the HEMS to exchange information and commands without conflict	Javaid et al., 2013; Rossell & Soler, 2011; Roth & Sachs, 2013

4. Technology Assessment

The HEMS market is expanding rapidly as information technology becomes an integral part of well-known household appliances; "embedded sensors, processors, software, and connectivity in products (in effect, computers are being put inside products), coupled with a product cloud in which product data is stored and analyzed and some applications are run, are driving dramatic improvements in product functionality and performance" (Heppelman & Porter, 2014).

The main components of HEMS include: sensing, monitoring and control devices; smart appliances; gateway devices; user interfaces and displays; and the enabling ICT (Bojanczyk, 2013; Asare-Bediako et al., 2012). Despite this broad range of components, a single system does not require all to be present, resulting in a variety of HEMS offering different benefits and demand management options. Although "HEMS can be strictly software, strictly hardware, or a combination of both" (Delphi participant), a smart home that connects multiple devices may bring customer convenience and energy savings beyond what has been possible before.

Past research suggests that effectiveness of HEMS varies according to the type of system and its capabilities (Erol-Kantarci & Mouftah, 2011; Strother & Lockhart, 2013; Williams & Matthews, 2007), so a meaningful conversation about HEMS opportunities required the distinction between product types. This chapter proposes, defines, and describes categories for HEMS products.

A review of academic and mainstream literature, coupled with a technology scoping study (see Appendix A), led to the proposition of 12 distinct product categories that make up a home energy management system. These fall into three groups: (1) user interfaces, (2) smart hardware, and (3) software platforms, depicted in Figure 7 and discussed in detail in the following sections.

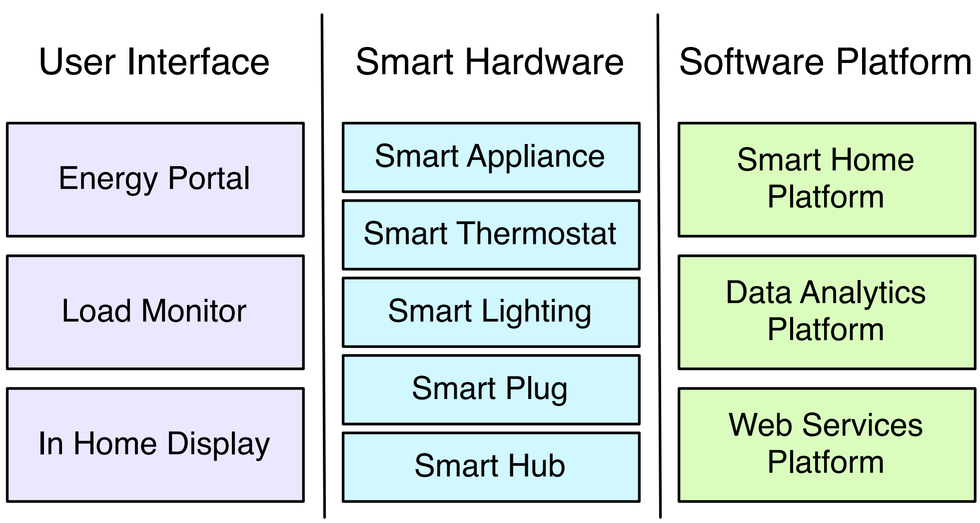


Figure 7. HEMS Categories

4.1 User Interface

This group of HEMS categories describes those products whose primary function is to incorporate the user into the home energy management process by providing them with information to help make more informed energy use decisions and/or enabling them to implement remote or rule-based control. The most common type of information provided back to the consumer is energy feedback, defined by Karlin et al. (2014) as “ information about actual energy use that is collected in some way and provided back to the energy consumer” (p. 381). This may be raw data, such as real time or historical usage data, or processed data, such as comparisons or goal settings (LaMarche et al., 2011). Other types of information, such as demand response prompts intended to trigger behavior-based demand management, may also be provided through the user interface. Ford et al. (2014) describe this type of information as coming from the utility, linked in some way to stress on the electricity grid, and being in the form of an economic incentive to encourage consumers to shift their power demand patterns.

Some user interfaces also allow consumers to remotely control or set rules to control connected appliances via the home area network. In these cases, energy feedback and prompts may also be present, as well as more general feedback about the state (i.e. whether the appliance is on or off, and its patterns of use) of the various connected appliances.

The user interface (often termed “display”) is a key enabler of home energy management, and used by Karlin et al. (2014) as one of the six characteristics critical to developing their taxonomy of home energy management technologies. In this work displays were described as either distributed (i.e. information presented via existing channels, such as a utility bill, website, computer software or phone), autonomous (i.e. an independent wall mounted or portable display), or embedded (i.e. built into the device that collects energy feedback).

These closely relate to the three types of user interface proposed here: *Energy portals* are those products that engage the user through distributed means; *In-home displays* are those products, sometimes termed energy consumption display (Wood and Newborough, 2007), and energy monitors (Van Dam, Bakker and Van Haal, 2010; Pierce et al., 2010) that engage users via a stand-alone piece of hardware generally located centrally in the home; and *Load monitors*, sometimes termed activity based displays (Wood and Newborough, 2007) are those displays embedded into a single piece of hardware that collects information about the energy consumed by a specific appliance or outlet. Each of these product categories are discussed in the following sections.

4.1.1 Energy Portal

This category describes products that integrate with existing hardware (e.g. utility meter or smart appliance) to collect and transmit data. They provide users with feedback about the use of connected devices and/or deliver energy saving prompts to the user and/or enable them to remotely control or automate to use of connected electronic devices. Energy portals provide these functionalities through existing media, such as smartphone apps, websites, or computer software. Although prior research has discussed non-computerized media such as enhanced energy bills (e.g., Karlin et al., 2014; Strother & Lockhart, 2013; Ehrhardt-Martinez et al., 2010) this is not common amongst current HEMS and is not included in our categorization.

The functionality provided by these Energy Portals tends to include the provision of more granular energy feedback than provided by traditional utility bills, displaying weekly, daily, or even hourly energy use. Many energy portal companies partner with utilities to provide additional information, such as generic and/or customized advice about how the user can save energy in the home, comparisons of the user's energy use to an average or similar customer, and demand response prompts, to consumers.

The control functionality of energy portals allows users to remotely control or automate the use of appliances in the home via a network that connects these portals to compatible devices. Some energy portals are designed to integrate with other home energy management products offered by the company (e.g. Green Energy Options Energynote) while others are designed to integrate with various smart products (e.g. EcoFactor: Proactive Energy Efficiency service).

One product on the market, SmartThings's mobile application, is a form of energy portal that enables users to interact with any connected device. Another example of an energy portal is Opower's Energy Efficiency Solution that enables users to view comprehensive energy and gas usage reports and track past and current energy reduction efforts. Lastly C3 Energy's Customer Analytics portal enables utility customers to gain energy use information and recommendations based on benchmarks, weather records and building characteristics with the end goal of enabling users to understand and reduce their energy use (see Appendix B).

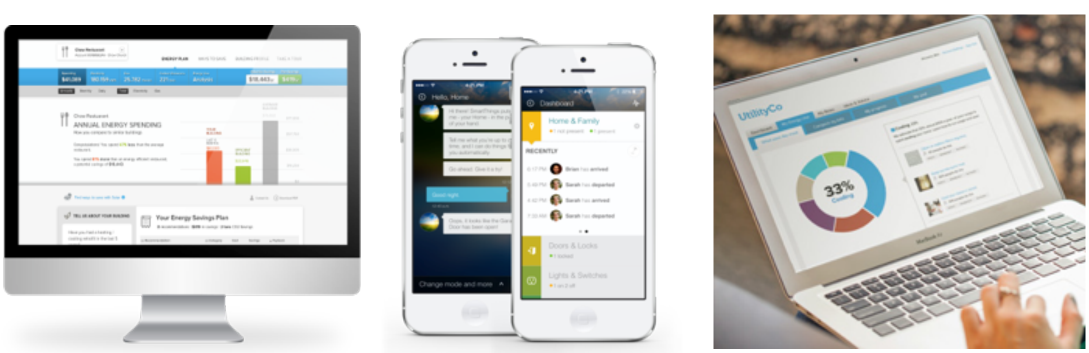


Figure 8. C3 Energy web-based portal and SmartThings mobile application

4.1.2 In-Home Display

We define an in-home display as a product that collects data from existing hardware, such as a meter, utility, or sensor, or smart device, and provides energy use feedback and/or prompts (such as energy pricing signals) in real (or near real) time via a physical display. It may also enable users to remotely control or automate to use of these connected electronic devices. Historically, in-home displays have dominated the market and been the most frequently discussed form of HEMS in the academic literature (Van Dam et al., 2010), where they are also referred to as in home energy displays (Ehrhardt-Martinez et al., 2010), home energy displays (LaMarche et al., 2011), direct displays (Darby, 2006), and graphical user interfaces/displays (Bojanczyk, 2013).

In-home displays may be standalone (e.g. a table-top portable display or a wall-mounted display) or embedded within an existing appliance (such as a fridge or thermostat). They typically communicate with other devices via the home area network to receive information about energy consumption, usually in kWh consumed. Many in-home displays couple with one or more pairs of current transformer (CT) clamps that sense the energy consumption of electricity circuits in the home via a network created by a transmitter to which the CTs are attached. Other in home displays collect and display the energy use of connected appliances via plug load sensors that communicate with the in-home display. They may also be able to receive feedback and prompts via the smart meter or from an external source, for example, Rainforest Automations' EMU-2 presents users with ambient pricing information in the form of lights, usually with green indicating times of low pricing and red indicating times of high pricing.

Newer in-home displays, such as Wink's Relay are starting to add in control functionality so that users can remotely control or automate household appliances. This is primarily because of the smart devices (appliances, lightings, plugs and thermostats) that are beginning to be adopted and, while most make use of energy portals to enable control, many companies are also exploring the use of integrating an in-home display to add additional benefits for users. Examples of in-home displays currently available in the US include Wink's Relay, Rainforest Automation's EMU-2, and Energy Inc.'s TED 5000 series (Appendix B).

Figure 9. Rainforest Automation's EMU-2, Wink's Relay, and Energy Inc.'s TED 5000 series

4.1.3 Load Monitor

We define a load monitor as a single, non-communicating piece of hardware that serves as a proxy between the energy source and energy-consuming device (i.e. between the wall outlet and an appliance), collecting and displaying data about the energy consumption of the connected appliance or appliances. The information they collect remains on the load monitor itself unless manually loaded onto a computer via a physical connection. In this way, the information collected by the load monitor may be shared upstream, but the actual load monitor does not communicate across a home area network. Information flow is one way, from the connected load (usually a regular appliance) to the monitor.

Most load monitors, sometimes called activity based displays (Wood and Newborough, 2007), plug in electricity usage monitors (Hochwallner & Lang, 2009), plug monitors, outlet level monitors and outlet readers (LaMarche et al., 2011), plug in devices (Fitzpatrick & Smith, 2009), and distributed direct sensors (Froehlich et al., 2011), are plug-in devices that consist of an outlet and a display. To measure and view the energy use of a device, the user simply plugs the device into the load monitor's outlet and information is displayed on a digital screen. The most basic load monitor displays power use of whatever device is plugged into it, while others might additionally show cost or greenhouse gas emissions.

Load monitors currently available include P3 International's Kill-a-Watt, Belkin's Conserve Insight Monitor, and Reliance Control's AmWatt (see Appendix B). P3 International's Kill-a-Watt has over 1800 customer reviews on amazon and is a number one best seller among "voltage testers." It collects data about the supply voltage and frequency, as well as the current drawn by connected devices, and uses this to calculate and display power demand (in kW) and energy consumption (in kWh) of whatever device is plugged into it. Belkin's Conserve Insight Monitor, which also displays the real time power demand and energy consumption of plug in devices, also estimates the cost of running the device as well as the associated carbon dioxide emissions.

Figure 10. Belkin's Conserve Insight Monitor P3 International's Kill-a-Watt, and Reliance Control's AmWatt

4.2 Smart Hardware

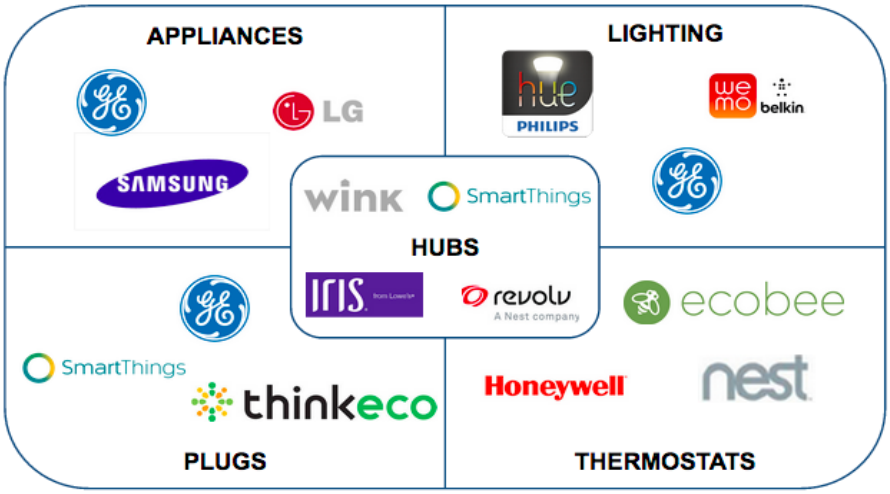


Figure 11. Smart Hardware

This group of HEMS categories describes those products that physically enable household energy demand to be controlled such that the energy demand patterns of particular appliances are modified to meet particular objectives. Devices are made smart by integrating monitoring and control, via the addition of sensors, storage, software and operating systems, and/or as ports and protocols to enable communication (Heppelmann & Porter, 2014).

While the most basic smart hardware contains sensing and/or communicating networking chips, enabling data collection and automation, more advanced options enable higher degrees of automation with more settings, wireless two-way utility communication for demand management control, delayed start functions, and pricing signal control (Donnelly, 2010). These novel sensing and control algorithms, characterized "by the autonomy of their programmed behavior, the dynamicity and context-awareness of services and applications they offer, the ad-hoc interoperability of services and the different modes of user interaction upon those services" are typical of these more advanced smart hardware products (Ferscha & Keller, 2003).

There are a number of devices in the home that have had "smarts" added to them in this fashion. *Smart appliances* and *smart thermostats* have been around for a few years now, though the level of intelligence implemented is continually improving, while smart lighting is a newer addition to most homes. *Smart plugs* enable "smarts" to be retrofitted to older non-smart appliances through the use of hardware that sits between the energy consuming appliance and the energy source. As more smart hardware is added into consumers' home, smart hubs enable these products to communicate across a single home area network. The following sections discuss these products in more detail.

4.2.1 Smart Appliances

A smart appliance is defined in the literature as one which "uses electricity for its main power source, which has the capability to receive, interpret and act on a signal received from a utility, third party energy service provider or home energy management device, and automatically adjust its operation depending on both the signal's contents and settings from the consumer." (Association of Home Appliance Manufacturers, 2010) In addition the embedded sensors, microprocessors may enable the smart appliance to collect information about its energy demand patterns, which can be transmitted across the HAN so that users can view on a connected display, and/or used to optimize demand through algorithms that are built into the appliance or reside in the product cloud.

A smart appliance may communicate either with the smart meter (via a home area network to which both are connected) to provide information back to the utility, or with a cloud based platform by sending energy usage information to be analyzed or receive control commands. A smart appliance may have an embedded display from which the user can control its setting and/or view energy use information. Additionally, many smart appliances utilize mobile apps that allow the users to view their status and control them from their smartphone or tablet and are thus broadly described as "domestic appliances with integrated intelligence and communication systems" (Asare-Bediako et al., 2012).

Smart appliances have long been envisioned by leading appliance manufacturers. Back in 1957, RCA-Whirlpool had detailed working products for their "Miracle Kitchen," where they outlined a home management vision yet to be realized. However, we are now starting to see manufacturers pursuing smart appliances with a market ready emphasis. Currently, the majority of smart appliances are kitchen and laundry appliances such as refrigerators, dishwashers, clothes washing, and drying machines. For example, in their latest showing at consumer electronics show (CES), appliance manufacturer Whirlpool describes connected appliances as ones we are familiar with but incorporate information and communication technologies; *"instead of you having a one-way interaction with your appliances, your washer could let you know the best times for energy usage and your fridge could send you food preservation notifications"* (Wollerton, 2014). This leads to both information gathering and control enabling features to benefit the end customer.

Manufacturers of smart appliances include major home appliances companies such as General Electric, LG, Samsung, and Whirlpool. Some of the smart appliances currently available to customers in the US include GE's Brillion Profile Oven, LG's ThinQ refrigerator, and Whirlpool's Smart Washer with 6th Sense Live technology. All three of these appliances can be monitored and controlled remotely by the user via a mobile app and are designed to run efficiently; Whirlpool's Smart Washer, for example, connects to the smart grid to optimize energy use and track how much energy it is using.

4.2.2 Smart Thermostats

In line with the definition used for smart hardware, a smart thermostat is defined as one that enables the power of the connected HVAC unit to be controlled using remote or rule-based mechanisms, such that the energy consumption used to heat and cool is modified to meet particular objectives. Some smart thermostats (often called programmable thermostats) enable on-board rule based control whereby the user can set a variety of time points each day for a different set-point temperature, enabling energy to be saved by reducing the use of heating and cooling equipment at times of the day when it is not needed (energystar.gov). Some smart thermostats add to this user-schedule control and offer optimization of energy use through the use of machine learning algorithms that are either built into the device or reside in the cloud. Many smart thermostats also utilize some type of communications protocol (often Wifi) so that users can view and adjust their settings remotely via a compatible smartphone app or website.

Thermostats receive a lot of attention amongst HEMS companies (Nest, Ecobee, Opower's Thermostat Management, etc.) because heating and cooling accounts for, on average, about 47% of a home's energy use in the US (eia.gov). Though California homes, on average, require less heating and cooling that the rest of the US, heating and cooling is still makes up a significant portion of the state's residential energy use at about 31% (eia.gov). The Consumer Electronics Association (Parks Associates, 2014) recently released a market survey report showing that smart thermostats are the most sought after smart home device. In addition Lowe's market survey (Loew's 2014) identified temperature control as the desirable control capability a user could perform while still in bed.

Smart thermostats have been a very active product category over the last 5 years. We have identified three market-leading products based on popular press and marketplace availability. Smart thermostats currently available to customers in the US include Nest's Learning Thermostat, Honeywell's Lyric, and Ecobee's Ecobee 3 (see Appendix B). All these have learning capabilities and can be monitored and controlled remotely via an energy portal.

Figure 12. Nest's Learning Thermostat and Ecobee's Ecobee 3

4.2.3 Smart Lighting

Smart lighting products are defined as those that incorporate sensors, microprocessors, and controllable switches or relays to offer automated control functionality, such as scheduling, occupancy control, and daylight harvesting, into traditional lighting solutions; eliminating over-illumination and unnecessary usage to reduce the lighting demand of a building. These systems may also enable communication such that users can view and adjust control settings or energy patterns of the lights remotely. Many systems support demand response programs, so that lights can be automatically dimmed or turned off in response to a signal from the utility.

Residential lighting makes up 14% of all residential electricity use within the US (eia.gov) and there is an industry trend towards energy efficient lighting. For example, many smart lighting products use LED bulbs, which are becoming more and more commercially available and affordable for the residential light market. Unlike incandescent bulbs that just consist of a simple electrical filament, LED bulbs require electronic circuits (drivers) to deliver the right voltage and current to the light emitting semiconductor diodes. Incorporating additional electronic circuits that also operate at similar voltage ranges of the LEDs is a natural engineering fit on top of the energy savings of this lighting technology. This is a core reason why most of the smart lighting products identified incorporate LEDs.

Another market trend among smart lighting is the added benefit of awareness, which enables both energy savings and enhanced convenience. Capabilities of aware lights include the ability to gradually turn on to gently wake up the user, sense room occupancy to turn on or off accordingly, sense ambient light and adjust brightness accordingly, and learn user behaviors over time to optimize usage. Additionally, many of the smart lights (Philips Hue, LIFX, etc.) can change color based on control functionalities. LIFX puts it as “going from black and white television to full-color HD… Imagine the ability to transform the ambience of your home or workplace using your smartphone.” (lifx.co) We are seeing color as an added benefit of such technology. Smart lighting currently available to customers in the US includes Belkin’s WeMo LED lighting Phillips's HUE, and GE’s Link (see Appendix B for more details).

Figure 13. Belkin’s WeMo LED lighting Phillips's HUE, and GE’s Link

4.2.4 Smart Plugs

A smart plug is defined as a separate piece of hardware that serves as a proxy between the energy source and energy-consuming device, which can control and/or provide feedback about the energy-consuming device. Smart plugs include outlets, switches, power strips that enable users to control devices and appliances plugged into them. They enable control signals to be sent to connected appliances via remote commands or algorithms that are built into the device or reside in the product cloud. Many smart plugs can additionally provide feedback about the energy consumption of connected appliances. Most smart plugs enable users to remotely control the devices plugged into them via a smartphone and accompanying mobile app or other via any Internet-enabled device.

Smart plugs turn an unconnected product into a connected one, enabling customers to receive many of the functionalities offered by smart appliances with their existing, traditional appliances at a much lower cost (smart plugs are usually sold for $25-$50 each). While smart plugs may not offer some of the more sophisticated features that smart devices/appliance can offer, such as learning capabilities, their wide range of applications make them critical component in the smart home ecosystem. Smart plugs currently available to customers in the US include Wink's Tapt Switch, Belkin's WeMo Switch, and ThinkEco's Modlet (see Appendix B). Aricent Group (2013) outlines smart switches as a crucial component for the future of HEMS, stating that such devices will eventually be built into home walls rather than sold separately as plug in devices.

Figure 14. Wink's Tapt Switch, Belkin's WeMo Switch, and ThinkEco's Modlet

4.2.5 Smart Hubs

We define a smart hub as a device that enables and manages interaction between existing smart hardware in the confines of a home. It is the central hub that facilitates smart home devices to be part of a network and take advantage of each other’s capabilities to provide new services to household. It can also act as a gateway to the worldwide web or to another network.

Fundamentally a box of radios, a smart hub allows consumers to connect their existing smart hardware across a common network such that they can be monitored or controlled via a single management portal on a smartphone, tablet, or PC (Higginbotham, 2014a), creating a networked smart home solution akin to the management networks described by Karlin et al. (2014). Over the past few years much of the smart home press has focused around the development of smart hubs (Higginbotham, 2014a), and there is also hype that Apple are getting into the game by adding remote access to Apple TV (Tilley, 2014). This, according to Tilley (2014), is a signal that Apple intends to use Apple TV in a smart hub capacity.

The smart hub market space has also been seeing some high profile acquisitions; summer 2014 saw Samsung purchase SmartThings for $200 million (Wroclawski, 2014), and in October 2014 Nest acquired Revolv (Davidson, 2014), a company with a commercially available smart hub. While this acquisition resulted in Nest retiring the Revolv smart hub (Davidson, 2014), it does point to a strong signal that the smart hub, and more importantly wireless communication interoperability, is crucially important to the connected home ecosystem and the big tech players (Google, Samsung, etc.) are actively developing their strategies through such acquisitions. Conglomerate General Electric (GE) has backed Quirky’s Wink smart hub, which supports Wifi, Bluetooth LE, Z-Wave, Zigbee, and Lutron’s Clearconnect wireless communication standards. Beth Comstock, GE's chief marketing officer, describes the company direction as having "launched a bevy of new connected devices, along with a couple of other initiatives all aimed at driving mainstream consumer adoption of the smart home” (Popper, 2014). Each smart hub supports a variety of protocols; certain products support more protocols than others. Some of the currently available smart hubs include Samsung’s SmartThings hub, Quirky’s Wink hub and Lowe’s Iris hub (see Appendix B for more details).

Figure 15. Lowe’s Iris hub, Samsung’s SmartThings hub, and Quirky’s Wink hub

4.3 Software Platforms

In recent years there has been tremendous growth in smart devices as appliance makers attempt to shift this market place forward; however, they have mostly ended up stumbling over each other in the process. In part this is because consumers don't purchase a "smart home," they buy end-point devices - a washing machine, a refrigerator, a heating system - and as a consequence the home energy management market has ended up with "a collection of appliances and home gadgets that offer enhanced functionality but won't work together in concert unless you happen to buy them all from the same manufacturer." (Kastrenakes, 2014)

As many smart devices have come onto the market in the past few decades, as have many wireless standards, this has resulted in a less than ideal solution for consumers who may end up with many smart devices each with their own set of rules about how they can be monitored and controlled. Many will also need to connect to devices in the cloud, which "adds latency, additional cost to the device manufacturer and means the programming will fail when the Internet goes down or APIs break" (Higginbotham, 2014wa).

As much of the functionality of HEMS is enabled through the transmission of information from a smart device, utility, or third party to the user, and through the signals sent by users, utilities, or third parties to smart devices to enable control, the addition of software platforms that can facilitate and improve the communication of information between users, utilities, and hardware in the home is a key aspect of HEMS. In this section we discuss the three software platforms that have enabled smarter home energy management: (1) *smart home platforms*, (2) *data analytics platforms*, and (3) *web services platforms*.

Figure 16. Lowe's Iris - an example of a smart home platform

4.3.1 Smart Home Platform

A truly smart home needs a way for hardware and interfaces communicate with one another, and the goal of many home energy management products is to integrate the various smart devices to enable control, cross device communication and a level of automation that wasn't before realized with silo-ed data exchanges. Whilst the Smart Hub provides physical hardware that enables communication between devices, it tends to offer these services only for those devices produced by a single manufacturer. However there are many devices from different manufacturers coming onto the market, each with an app to manage it and each which uses its own network protocol (Reardon & Tibken, 2014). A Smart Home Platform goes beyond the offerings of a Smart Hub, and provides a combination of "software, embedded systems and cloud expertise" to create a turnkey smart home solution across a variety of hardware partners (Wolf, 2014).

Therefore, we define a Smart Home Platform as a software platform that delivers a managed environment and provides core services to enable a standardized way for devices and appliances to interact and form a home energy management system. This type of platform can be used to run a variety of applications that solve different home needs, allowing users to group different smart hardware products together and manage them using single commands.

Across the marketplace we are seeing smart home platform companies partnering with a variety of smart hardware manufacturers to create smart home solutions that cover all key product categories (including smart lighting, smart thermostats, smart appliances, as well as home security products). This provides a benefit to consumers in enabling them to create a fully integrated smart home solution, whereby smart devices in the home can be managed in a more intelligent and autonomous manner. For example, one piece of smart hardware connected to the "Works with Nest" platform is the Nest thermostat, which has a number of different sensors built in (temperature, humidity, activity, ambient light). If another smart hardware, for example, smart lighting, was connected to the Works With Nest platform, that product should also be able to access the data collected by the sensors embedded in the Nest thermostat; if these two devices can interact, the smart thermostat could message the smart lighting system if it detects fire such that the building lights could flash. Additionally, because lighting is present in every room and could be capable of determining occupancy, they could provide more accurate activity information to the smart thermostat to enable smarter temperature control.

As outlined above, building out an elegant product ecosystem is critical to a company's smart home platform success. Apple is doing just that despite a current lack of commercially available products; they have partnered with microchip makers Broadcom and Texas Instruments which have started shipping WiFi and Bluetooth chips loaded with HomeKit firmware (Tilley, 2014). This is yet another signal that this tech giant is laying down the foundations (both hardware and software) for their Homekit product ecosystem. Other emerging smart home platforms include Quirky's Wink platform and Lowe's Iris platform (see Appendix B for more details).

4.3.2 Data Analytics Platform

This is another type of platform that can be integrated with existing HEM technologies. This platform typically has a data analytics engine at its core and is hosted on the cloud. Connected and powerful computer servers enable it to analyze large volumes of data collected from existing smart hardware and/or utility meters to provide additional insights about energy use patterns. These platforms also provide additional services such as data warehousing, data visualization, and web and mobile communication frameworks that are needed to build cloud based energy management solutions.

These analytic platforms do the heavy lifting for underlying products and services that are offered to homeowners. For example Opower's Flex 5.5 is an ideal data analytics platform that combines data and behavioral science to product insightful analytics that can then be delivered out across the many connected energy portals (web, mobile app, etc.). In this way data analytic platforms can be conceptualized as the engines that power the various user facing energy portals.

Another example of a data analytics platform is EcoFactor's "energy analytics" platform. The focus of EcoFactor's platform is minimize household heating energy usage through a set of cloud based optimization algorithms, demand response and performance monitoring services. The company has had great success with their pilot programs. A similar heating based data analytics demand response service is offered by Nest. This service is call Nest Rush Hour Rewards and automatically adjusts thermostat settings based on the data analytics around peak use times in order to save the user money (see Appendix B for more details).

Figure 17. EcoFactor's "energy analytics" platform, Opower's Flex 5.5, and Nest's Rush Hour Rewards

4.3.3 Web Services Platform

Both smart home platforms and data analytics platforms tend to be targeted toward the development community and consequently the APIs (application programming interfaces) are not visible to end-users. A new web services platform called IFTTT puts more control in the hands of the end-user. The San Francisco based start-up provides automation service for small tasks between Internet-connected products and services. Once smart hardware products create IFTTT channels in their products, users are to create connections between these channels (and products) to implement additional control functionality through the use of conditional programming statements. This service provides event driven control functionality. For example, the conditional statement <<*If raining then blue light*>> will trigger the user's smart light to change its color to blue if it's raining.

Another web services platform is Intamac's Enso. Enso is a cloud-based platform that connects smart home devices to the Internet so that users can monitor and manage their devices remotely. Enso utilizes an API library to enable smart hardware companies to integrate almost any product into Enso's web services. Users are then able to set up notifications and alerts, as well as manage full two-way control of connected devices via an energy portal, such that they can automate devices and control them remotely (see Appendix B for more details).

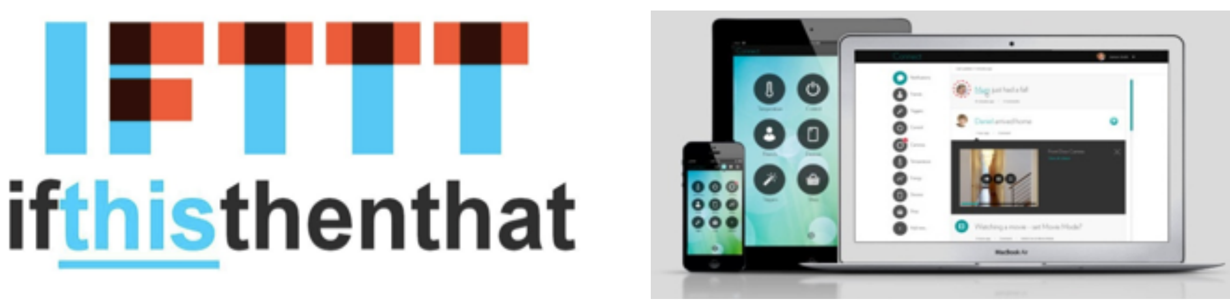


Figure 18. IFFFT and Intamac's Enso.

4.4 Protocols and Players

A home area network (HAN) to which smart hardware can connect is a key aspect of home energy management (LaMarche et al., 2011). While not all HEMS include every type of product category described in the sections above, Figure 19 illustrates how these different components may be connected together in a fully integrated smart home. A HAN enables devices to communicate with one another within the home and allows them to connect beyond the home to leverage additional functionalities.

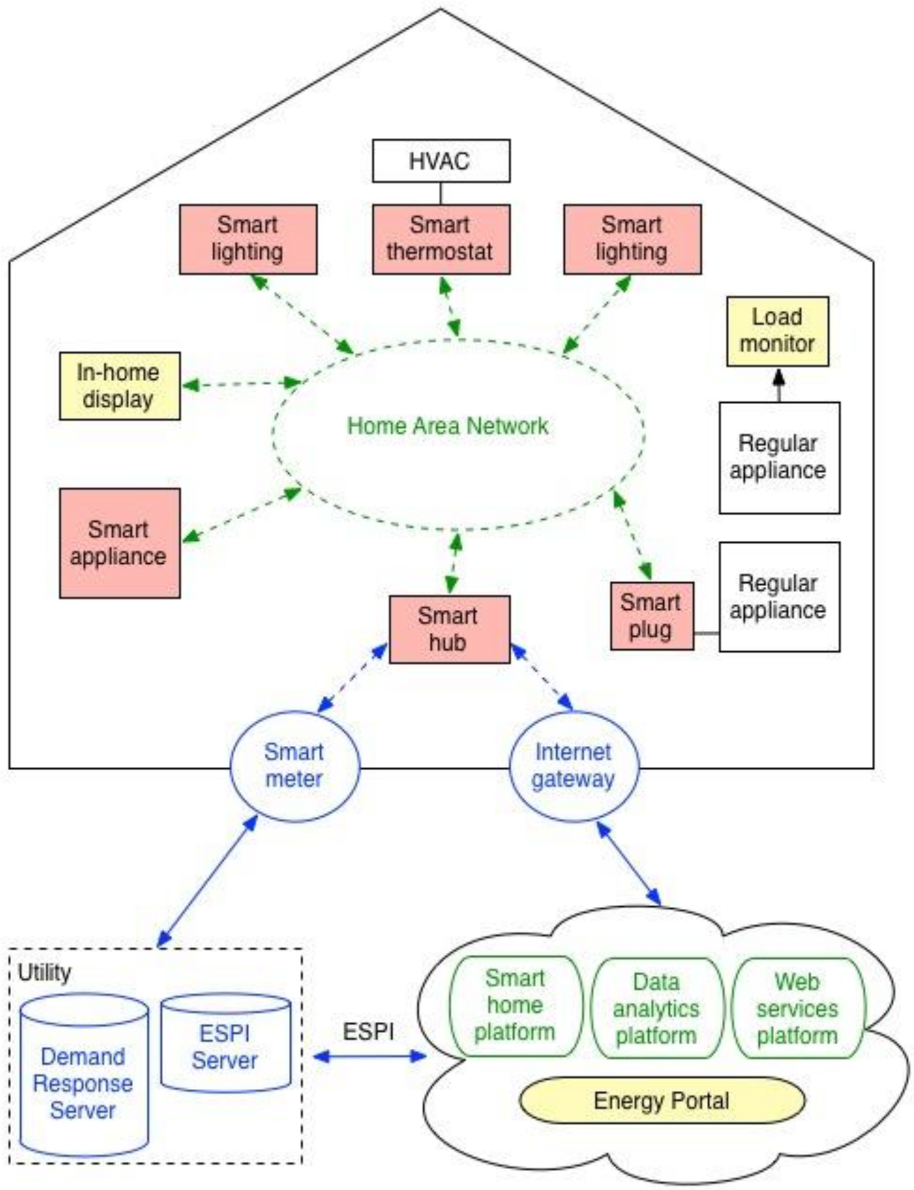


Figure 19. A fully integrated smart home

A common language of communication is required to enable multiple types of hardware to talk to one another across a home area network. This common language is called a protocol; it describes the set of rules governing communication between two networked devices.

WiFi and Bluetooth are the two most prevalent HAN protocols in today's home, used primarily for Internet connectivity and multimedia streaming purposes. However, both these protocols are power-hoggers and the radios required for their use are expensive, so they are not entirely suitable for emerging smart home applications that may involve multiple battery operated devices that communicate intermittently over long periods of time.

Bluetooth Smart (also known as Bluetooth LE) helps to overcome this by utilizing lower power consumption than traditional Bluetooth, though it also operates over a reduced distance (10m instead of 100m). Other protocols (Zigbee, Zwave) also consume less power for their operation and can support the lower data rate required by home energy management and thus may be more appropriate for smart home applications that involve distributed monitoring and control.

Other protocols, such as Thread and Insteon have been developed to fit smart home applications by companies that have been trying long and hard to break into smart home market from multiple directions including security, energy management, lighting, telecommunication, entertainment, kitchen appliances etc. They have taken this route due to technological limitations of existing protocols or to strategically establish marketplace dominance; however, a consequence of this is an abundance of different protocols that now exist in the HEM space (see Appendix C).

This abundance of protocols to choose from has resulted in different smart home solution providers using different protocols in their products, such that devices from two different vendors may not be able to communicate with one another. An important technological requirement to building a cohesive smart home solution is device interoperability across vendors' solutions, and to address this concern several companies and organizations with vested interest in smart home market have formed alliances to promote interoperability among solutions. For example, SmartThings, who have developed a hub and platform to enable interoperability, have partnerships across Zwave and Zigbee protocols with companies including Leviton, GE, Aeon Labs, Danalock, Kwikset, 2Gig, Schlage, Fibaro, Dropcam, ecobee, Ecolink, Everspring, FortrezZ, Philips, Intermatic, Sylvania, Jawbone, CentraLite, Evolve, Sonos, Honeywell, Yale, RCS, SmartenIT, First Alert, Remotex, and Enerwave. These products span thermostats, dimmer switches, door locks, smoke alarms, and so on, enabling SmartThings to enable consumers to create themselves a fully connected smart home.

However, there is little allegiance within any of these alliances - typically, companies are part of multiple alliances. For example, SmartThings is in many of the alliances including Thread, Zigbee and Zwave and has built products that support Z-wave, Zigbee and (see Figure 20).

	Wifi	Bluetooth LE	Thread	Zigbee	Zwave
Apple	☑	☑			
Nest	☑		☑		
SmartThings	☑		☑	☑	☑
Loes (Iris)	☑			☑	☑
Quirky (Wink)	☑	☑	☑	☑	☑

Figure 20. Protocols supported by 5 major Smart Home Platform Developers

As various alliances start to emerge this opens up the opportunity for platform manufacturers to engage with a variety of developers to start creating integrated home management solutions that more fully meet the needs of their customers. To explore the progression of this market we select 5 major players in the home energy management space and examine their performance according to the following criteria: (1) device interoperability, (2) developer community, (3) product scope, (4) user experience, and (5) brand awareness (Figure 21).

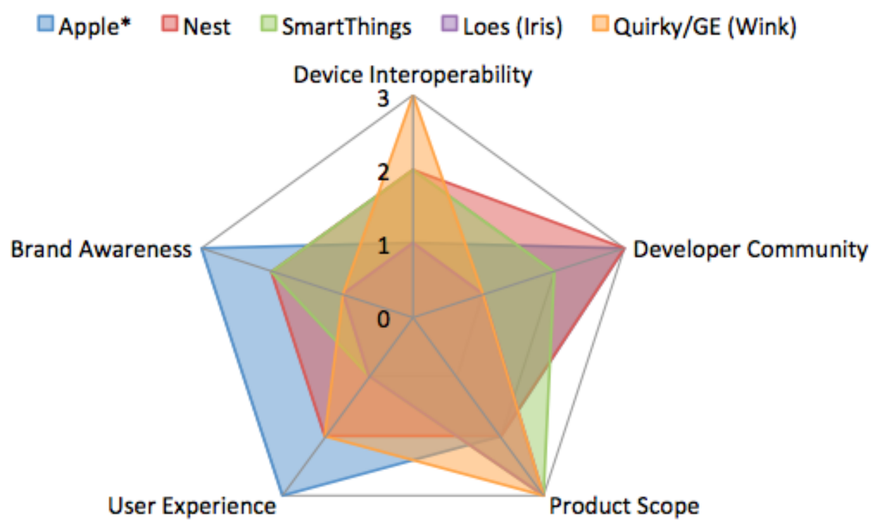


Figure 21. HEMS Market Progression

As seen in Figure 21, there is substantial variation between players in terms of their progression along each axis. This could impact on the ability of the HEMS to meet the needs and objectives of consumers (and utilities) and may also impact on the potential savings and adoption rates of different home energy management solutions.

5. HEMS Savings Potential

In this chapter we review past literature on HEMS saving potential and both synthesize past findings from pilot studies and qualify these findings in terms of their methodological limitations, with suggestions for future research. We consider the savings potential of distinct HEMS categories as well as the implications of HEMS functionalities and characteristics for energy savings. This analysis takes a user-centric approach to savings, concentrating on the potential household level savings rather than grid-level, without invoking adoption rates or market projections. The goal of this approach is to highlight the savings potential as it may be applied to and perceived by individual consumers.

5.1 Savings from Information-based HEMS

As outlined in Chapter 3, HEMS have two primary information functionalities: feedback and prompts. 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. Several reviews of this literature have appeared in recent years. Four of these reviews (Darby, 2006; Ehrhardt-Martinez et al., 2010; EPRI, 2009; Fischer, 2008) analyzed past empirical studies of energy feedback through the methods of qualitative literature review, where a set of empirical studies on a topic are "digested, sifted, classified, simplified, and synthesized" (Manten, 1973, p. 75). They have concluded that feedback is generally effective, but its effectiveness is immensely variable, ranging from negative (i.e. increase in energy consumption) to up to 20% in energy savings. To explain some of this wide variation, reviews suggest that there are characteristics of feedback that moderate (influence) its effectiveness.

While these reviews suggest significant potential savings, results must be interpreted with caution because effect sizes are not calculated, reported effects are not weighted, and inferential tests are not performed to determine whether observed effects are statistically significant across studies (Rosenthal & DiMatteo, 2001). Additionally, differences between studies related to research settings, methodology, and characteristics of the feedback provided (i.e. feedback format, type, frequency, etc.) were not analyzed inferentially to determine whether they significantly moderated the effectiveness of the interventions.

To address these limitations, members of the current research team conducted a meta-analysis of 42 feedback studies in order to assess the overall effectiveness of energy feedback as well as the moderating effects of specific feedback characteristics on savings outcomes (Karlin, Zinger, & Ford, under review). Since both differences in effects and the number of studies that included each level of a variable may be relatively small (especially as compared to overall effect sizes), the techniques of meta-analysis are useful because they estimate the statistical significance of the differences. These key differences lead to more reliable conclusions than "eyeballing" self-reported findings or "vote counting" (Cooper & Hedges, 1994).

Previous qualitative reviews (Darby, 2006; Ehrhardt-Martinez et al., 2010; EPRI, 2009; Fischer, 2008) reported average savings of 8-12%, but meta-analysis results suggests 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% 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. The fixed effects model obtained a mean effect size of .0397 and the random effects analysis obtained a mean effect size of .0712; both were significant at the $p < .0001$ level. These analyses suggest that feedback results in statistically significant energy savings, but that the true effect is typically in the range of 4-7% savings.

While analysis revealed a significant positive effect for feedback, the studies varied greatly both in terms of the information provided and their effects on energy savings. A statistical test of the heterogeneity among the effects was significant ($p < 0.001$), suggesting that these effects vary significantly based on key variables related to the study and/or treatment. We therefore tested for moderating effects of characteristics related to the way that information was provided. The following statistically significant findings emerged:

1. Goal comparisons were most effective. The four studies with goal comparisons had the highest average effect size, followed by the seven studies with historical comparison, and finally by the two studies with social comparison (p=.016).
2. Combining feedback with other interventions increased savings. Three studies were identified where feedback was combined with a goal-setting and two combined feedback with an incentive; effect sizes for these "combined" interventions were significantly higher than studies using feedback alone. ($p = .037$).
3. Computerized feedback had higher effect sizes. The feedback medium in the studies included billing, door hangers/cards, in-home displays, and computer applications. Feedback provided via computer was more effective than feedback provided via any of the other medium ($p = .083$).
4. The shortest and the longest studies were most effective. Study duration ranged from less than a month to more than two years. When analyzed, studies of less than three month and more than one year were more effective than those from 3-12 months (p<.0756).

These suggest that significant more research should be conducted into what types of energy information are most effective, rather than continuing to test HEMS vs. control in simple RCTs. The next section discusses specific findings for various types of HEMS that serve a primarily information function.

User Interfaces

User interfaces (load monitors, in-home displays, and energy portals) have historically offered primarily information (feedback), although some are evolving to include control functionalities. Research conducted to-date on each type of interface is presented here.

Energy Portals. Opower is the largest provider of residential energy portals and the majority of studies on energy portals have used their platform. Their platform, and others like it, employs a Software as a Service (SaaS) model, in which they provide energy use data to utility customers over the Internet and via Home Energy Reports (HERS). In these presentation formats, energy use feedback is provided alongside social comparison data and energy savings tips, or prompts. They cite the average electricity savings across all their programs as 1.5-2.5% (Opower, 2014).

Load Monitors. Load Monitors like the Kill A Watt are advertised as having the potential to "save $100's on electric bills" (P3 International, 2014). Studies indicate that appliance-level feedback can yield savings from 12-20% (Dobson & Griffin, 1992; Haakana, Sillanpää, & Talsi, 1997; Mansouri, & Newborough, 1999; Wood & Newborough, 2003; Ueno et al., 2005; Ueno et al., 2006). In some of these studies, the appliance-level feedback was offered for multiple appliances on a single interface at one time or offered in conjunction with an in-home display. However, most of these were pilots of concept products or technologies developed specifically for the respective studies rather than products on the market. Therefore, little is known about the potential unique contribution of commercially available load monitors to energy savings.

In-home Displays. Of all HEMS categories, in-home displays (IHDs) have been investigated the most in field studies. Their effectiveness ranges from 0-18% savings (Allen & Janda, 2006; Harrigan, 1992; Hutton et al., 1996; Matsukawa, 2004; Mountain, 2007; Parker et al., 2008; Sipe & Castor, 2009; Wood & Newborough, 2003). Some research indicates that IHDs are most effective in the short-term, when consumers experiment with energy use to determine and address inefficiencies, and that usefulness can dwindle over time (e.g., Van Dam et al., 2010), but this claim has not been empirically validated. Studies of IHDs with demand response prompts have been found to be effective in shifting use from peak to off-peak times, but evidence is inconclusive in terms of overall energy savings (Sexton, Johnson, & Konakayama, 1987; Martinez & Geltz, 2005).

IHDs also include displays embedded in smart hardware, such as thermostats and refrigerators; savings from these displays may be attributed to feedback and prompts provided, such as mobile notification when appliances are left on or when washing or drying cycles are completed to avoid forgetting and re-running. One report (Sastry, Pratt, Srivastava, & Li, 2010) estimates 3-6% savings across smart refrigerator/freezers, clothes washers, clothes dryers, room air-conditioners, and dishwashers. However, this estimate was based on the qualitative reviews of feedback studies mentioned in the previous section, which assessed feedback effectiveness in the context of user interfaces or non-technological feedback (e.g., enhanced billing) and not actual smart appliances. Therefore, future research is required to validate these claims and understand the savings potential associated with this specific type of IHDs.

5.2 Savings from Control-based HEMS

While research on information-based HEMS significantly pre-dates that of control, most emerging HEMS include control functionalities, which are enabled by smart hardware (e.g., appliances, thermostats, lighting, plugs). 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 achieve 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. Instead, we discuss findings from smart hardware studies based on simulations, estimates, laboratory tests, and self-studies by manufacturers. They are presented to illustrate potential savings, though we note that limitations in methodology prevent us from drawing firm conclusions about savings potential.

Smart Hardware

Smart Appliances. Smart appliances have mainly been studied in terms of demand shifting, rather than energy reduction, potential. A series of reports by SCE (2012a, 2012b) involve laboratory tests of demand response (DR) savings potential of smart appliances. Findings include demand reduction of 100 W for a smart refrigerator during Spinning Reserve events with demand reduction of approximately 100 watts (W), but power actually increased a little during Delay Load events (SCE, 2012a). They also demonstrated that a smart dishwasher can achieve demand reduction up to 1 kW (SCE, 2012b). These findings are somewhat inconsistent with one pilot test of a networked HEMS (a smart hub providing a home area network to which multiple smart appliances and smart plugs connect, and an in home display and/or energy portal enabling customers to control the appliances and respond to DR signals) deployed in five homes in SCE territory (i.e., dishwasher only resulted in a reduction of 140 W; NegaWatt, 2013). Given such diverse methodologies and findings, in addition to the very small real-world sample and conflation of multiple HEMS categories in the one field study, it is impossible to draw firm conclusions about the DR savings potential of smart appliances.

Smart Thermostats. Little research is yet available regarding the effectiveness of smart thermostats. Some manufacturers have conducted their own analyses or hired third parties to assess effectiveness. However, these findings are presented on manufacturer websites and in popular media without details of the methodologies involved for critique and comparison. For example, Greentech Media (Aug. 26, 2014) reports that the Nest thermostats leads to load reductions of 1.18 kW per thermostat during demand response events and average AC runtime reduction of about 5%. The same article reports that EcoFactor helped utility NV Energy in Nevada roll out a program consisting of smart thermostats coupled with demand response programming and HVAC performance monitoring that independent researchers claim led to even greater savings than Nest (e.g., cutting residential AC usage by 11%). This supports the theme that more networked HEMS generally produce more savings, but comparison of such distinct pilot studies is insufficient to draw firm conclusions, especially when the details about respective methodologies are unavailable. Systematic, comparative, replicable research is required.

Programmable Thermostats. We also briefly review the evidence of savings associated with programmable thermostats here as a less evolved sub-category of smart thermostats for which the control features are always user-based (never third party) and there are no advanced intelligence features such as machine learning. Studies into the effectiveness of programmable thermostats in homes date back to the 1970s when they generated a rule-of-thumb that expected energy savings are 1% for each degree Fahrenheit of temperature in an 8-hour nighttime setback period (Nelson & MacArthur). These studies, however, were based on simulations and gas or oil-based space conditioning systems. Later research revealed much lower, even non-significant, savings for electricity-based systems, especially with heat-pumps (Nevius & Pigg, 2000). User behavior is critical to achieving savings with programmable thermostats. For example, Peffer, Pritoni, Meier, Aragon, and Perry (2011) reviewed user studies and concluded that almost half of programmable thermostat owners do not use the available programming features, suggesting usability factors impede savings. Nevius and Pigg (2000), however, found that owners of non-programmable and programmable thermostats used about the same amount of energy for space conditioning, suggesting motivated users are as likely to set non-programmable thermostats daily as they are to use programming features when available. These studies exemplify the potential problems with assumptions underlying simulation studies of HEMS savings potential that fail to account for differences in user behavior in both the implementation of new technologies and the implementation of older technologies as a baseline for comparison.

Smart Lighting. The unique savings potential of smart lighting has not been studied in the residential sector, but considerable studies have quantified its potential in the commercial sector. The Electric Power Institute (EPRI, 1993) and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE, 1989) estimate that smart lighting in commercial buildings results in an average savings of 30%. The savings potential is proportional to the degree of sophistication in the sensor systems (Garg & Bansal, 2000; Guo, Tiller, Henze, & Waters, 2010). A study based on simulations of residential buildings (Chua & Chou, 2010) suggests that CFLs coupled with smart lighting may allow up to 7% reduction of total electricity consumption at home, but they did not provide a statistic for the unique contribution of smart lighting to savings and their estimations were based on assumptions of user behavior. Future real-world studies of savings associated with smart lighting in the residential sector are needed.

Smart Plugs. One report for San Diego Gas & Electric (SDG&E) by NegaWatt Consulting (2012) installed smart plug strips with DR potential in six homes and found an average instantaneous drop of 5.5 kW in response to a simulated DR event. They noted that the drop would be less for homes where high intensity energy consuming devices (A/C and/or pool pumps) were not plugged into the strips and the drop would not likely last throughout the entire DR event (e.g., A/C change in setpoint only delays it turning on). NegaWatt Consulting concluded that "energy and demand savings with this technology will inherently occur unless the customer opts out of load reduction during a DR event" and that "the level of the load reduction directly depends on number and type of DR enabled devices, the consumption of each device, and the degree to which the homeowner wishes to reduce load (i.e., PCT setpoint offset)" (p. 27).

There has been sparse quantitative investigation into the effectiveness of smart plugs in the commercial sector—particularly smart plug strips. Acker, Duarte, and Van Den Wymelenberg (2012) installed occupancy sensor plug strips (WattStopper Isole) and load sensing plug strips (BITS Limited) in office buildings and found an average savings of 0.60 kWh per square foot of office space per year (savings up to 163 kWh/yr per plug strip and up to 85.4 kWh/yr per device controlled by plug strip). More in-depth studies of smart plugs in homes are needed.

5.3 Savings from Integrated Solutions

Many scholars project that HEMS savings potential is positively related to the degree of connectivity (Strother & Lockhart, 2013). Williams and Matthews (2007) estimate that programmable thermostats save around 3% whereas 26% can be saved with "an integrated system that includes monitoring and control of appliances, plus zone heating/cooling" (p. 239). These estimates are based on assumptions about household behavior and inefficiencies derived from the DOE Residential Energy Consumption Survey (RECS).

Companies are also involved in perpetuating the concept that integrated solutions offer greater savings than single smart hardware/user interface solutions. For example, EcoFactor (2014) advertises that their Proactive Energy Efficiency Service saves 10-15% more energy than programmable communicating thermostats. Nest claims that their portal with demand response prompts, Rush Hour Rewards (RHR), has "helped achieve an incredible 55% reduction in energy use during peak times" (Nest, 2014, ; not noted whether per household or per thermostat or per total participation), with low instance of consumer overrides (reported as 14% of participants). According to Greentech Media (2014), EcoFactor reports that their Automated Demand Response Service contributes to load reductions up to 3kW per home and 2.4kW per thermostat, noting that these results are 25% greater than other DR programs. It is difficult to assess this information because the sources provide few methodological details.

5.4 Limitations of Savings Estimates

While the literature to-date presents evidence supporting potential energy savings from HEMS, further research is still needed to answer the questions of how and for whom HEMS works best. As seen in the previous sections, the results of past studies have varied, with effects ranging from negative (i.e. increase in energy consumption) to large effect sizes (over 20% savings). These results suggest that the effectiveness of HEMS varies based on how and to whom they are given.

Since literature review (as presented above) serves to aggregate findings from the results of multiple studies, results are often referred to as *synthesis-generated evidence*, as opposed to the *study-generated evidence* that comes from the individual studies which are analyzed (Cooper, 2010). While only study-generated evidence is able to make causal attributions (due to variation between study samples and procedures), synthesis-generated evidence can be useful for exploring associations not tested in individual studies and providing suggestions for future research. Based on the current review of HEMS studies, we identified five primary suggestions:

1. Integration of **theory** into hypothesis generation and design to better interpret results;
2. Testing of multiple variables via **factorial designs** to identify and isolate variation;
3. Greater attention to the **physical design** of HEMS to reflect user needs;
4. **Improved reporting** of methods and results to enable replication and interpretation; and
5. Additional **data collection** to allow testing of how and for whom HEMS are effective.

Integration of Theory

One major limitation of HEMS research conducted to-date is a lack of theoretical integration and failure to test hypotheses through isolating variables within treatment conditions. To understand the effects of an intervention such as HEMS on behavior, it is important that studies are designed in order to isolate and test key variables of interest. This task is generally accomplished through the development and testing of theory. Linking research to theory is vital to be able to tie findings back into the ideas that inspired the study in the first place and explain variations between conditions. If the underlying theories or hypotheses of a research design are not fully articulated, then the results do little more than explain how the presence of an intervention is better than the lack of said intervention. While interesting, this approach does little to further knowledge.

Factorial Designs

In addition, the study designs themselves often failed to test the hypotheses or ideas presented. Over half tested a simple treatment (HEMS) vs. control (no HEMS) group, which means we can't determine what variables led to the treatment effect, or which technologies are most effective. Among those that did have more than one intervention group, conditions were often confounded (e.g., HEMS & goal-setting), preventing us from determining which strategy was responsible for savings. Although there was a great deal of variety in the interventions employed *between* studies, just over half included more than two groups to assess variation *within* studies.

Of those that had more than one intervention group, most featured designs in which treatment groups received different conditions (e.g., control, feedback, feedback plus rebate) but without fully crossing conditions to isolate the treatment effect of each variable. To correct for this, factorial designs are recommended in future research to test research hypotheses and to isolate treatment conditions. To fully understand the interaction between HEMS and incentives, for example, it is important to not only have a group that receives HEMS technology and incentives, but also a group who receives only incentives and one that receives only HEMS. Completely balanced designs allow for the variables themselves as well as the interactions between variables to be better understood. Only five of the reviewed studies utilized a complete multi-factor ANOVA design or multivariate regression model to isolate and analyze the relationship between conditions. Four of them (Kurz, Donaghue, & Walker, 2005; Mansouri & Newborough, 2003; Seligman, Darley, & Becker, 1978; Winett et al., 1982) tested a factorial design with feedback and another intervention and one (Robinson, 2007) included a factorial design of comparison message (historic vs. social) vs. medium (email vs. mail); more like this are greatly needed.

Improved Reporting

We also identified a need for more comprehensive presentation of methodology and results to enable greater replication and interpretation of findings. Many studies failed to present a clear and comprehensive report of the methodologies employed as well as the specific details of the intervention strategies tested. The way that participants were recruited and assigned to treatment conditions was unclear or not specified in many reports; methods featured broad statements about populations consisting of “city residents” or “low-income customers” being recruited by a “postal survey” or “invitation”. Additionally, specific details of the treatment were not explicitly described in such a way that would enable replication. Few details were given about design features or the specific information provided to subjects. Such omissions result in parsimonious reports but also decrease scientific rigor. Replicability is a core facet of the scientific method and refers to the inclusion of all critical methodological details when presenting study findings. It enables findings to be substantiated or refuted and is a basic principle of scientific writing.

Additionally, the presentation of statistical data was inconsistent. Echoing a previous meta-analysis of energy conservation interventions (Abrahamse et al., 2005), only a handful of studies reported means and standard deviations for the treatment groups, which is standard practice in the presentation of experimental research. Several studies failed to provide any specific statistics at all, simply reporting whether the findings were “significant” or the intervention “worked.” The presentation of any statistical (or qualitative, for that matter) findings should be clear and comprehensive, in order to allow transparency in assessing study findings. Simply saying that an intervention was “effective” is not nearly as precise as providing the means and standard deviations for the treatment and control conditions or telling the reader which inferential tests were used (e.g., *t*-test, ANOVA), along with provision of the test statistics and associated *p*-value. More than a suggestion, this is a strong request of all future researchers in this area.

Design and Presentation

As suggested above, several characteristics related to the design and presentation of HEMS can impact the way in which they are perceived, interpreted, and acted upon. However, there has been limited work investigating responses to different types of user interfaces or control technologies beyond style of energy measurement and comparison messages. Less than half of the reviewed studies included a graphic or description of the user interface or physical HEMS technology and even fewer compared different display formats using (e.g., controlling for) the same technology. The few studies that have investigated displays did find differences in response based on the type of graph used (Egan, 1998; Ford & Karlin, 2013) and comparing ambient (e.g., light changing color) to factual (numbers indicating kWh consumption) feedback (Ham & Midden, 2010). As indicated by these studies, successful design of HEM technologies can greatly benefit from psychological testing of the designs being used most in practice so that design can take into account principles drawn from cognitive and social psychology. As such, it is suggested that psychologists work more closely with designers and design researchers to test theoretically derived design parameters in experimental settings.

A recent market forecasting (Strother & Lockhart, 2013) suggests that IHDs are on their way out because of the cost-effectiveness of energy response portals that require no hardware and can offer similar functionalities. However, it is important to recognize that existing research into the effectiveness of any type of HEMS is (a) limited by the products available to assess and (b) not purely a function of technological capabilities, but also enabled or constrained by design features, which Froehlich, Findlater, and Landay (2010) note have been understudied in eco-feedback research. The majority of IHDs that have been studied are very utilitarian in design, offering text-based digital feedback, but more recent models include ambient feedback (e.g., Wattson, Joule, and Ambient Energy Orb) that some research suggests is more effective in promoting conservation (Ham & Midden, 2010) contribute to longer lasting effects.

Data Collection

Finally, part of the limited understanding of HEMS savings is due to the way studies are typically evaluated. Most use the amount of energy use (measured in kWh) as the dependent variable for measuring effectiveness. Although this may be an ideal measure of *whether* energy interventions work, additional information collected could add significantly to our understanding about *how* and *for whom* they work. While the ultimate goal of these interventions is energy savings, it is important to understand why behavior is (or isn't) changing and what (if any) relationship between the intervention and behavior change exists. In their review of intervention studies, Abrahamse et al. (2005) found that "underlying determinants of energy use and energy-related behaviors have hardly been examined". Although this situation has improved in recent years with increased evaluation research, significant variation remains in the variables collected and questions used, making comparisons across studies difficult.

Reviewing the HEMS literature, while three quarter of the studies collected some data beyond energy (kWh) savings data, we found little consistency in the way that these data were collected or measured. Data were collected primarily through surveys (65%), interviews (31%) and focus groups (6%) and were collected on demographics (64%), behavior (62%), user experience (58%), attitudes (27%), and knowledge (21%), but there was significant variation in the way that data was collected. Specific scales were only found in five articles (10%) and no standard tools or metrics currently exist to conduct such an assessment comprehensively and consistently. Evaluation consistency would improve our overall ability to account for variation in treatment effects and to verify savings.

Such standardization is common in related fields such as education and psychology, but have yet to take hold in energy program evaluation. Such measurement would complement rather than replace traditional measures of program effectiveness; they could yield useful insights into effective program design and increase our ability to move beyond testing individual intervention strategies for their effectiveness to modeling and predicting the effectiveness of future interventions based on an understanding of *how* and *for whom* they are effective. Such knowledge is essential for behavior-based programs like HEMS to take their rightful place in utility energy efficiency and DR programs.

6. HEMS Adoption

Chapter 5 discussed HEMS savings potential of HEMS but the overall impact of HEMS depends upon not just savings but also HEMS adoption. In general terms, the total energy savings resulting from HEMS is equivalent to the number of adopting households multiplied by average savings per household (Figure 22). Adoption is a critical part of the equation; therefore, in this chapter we review current knowledge about HEMS adoption.

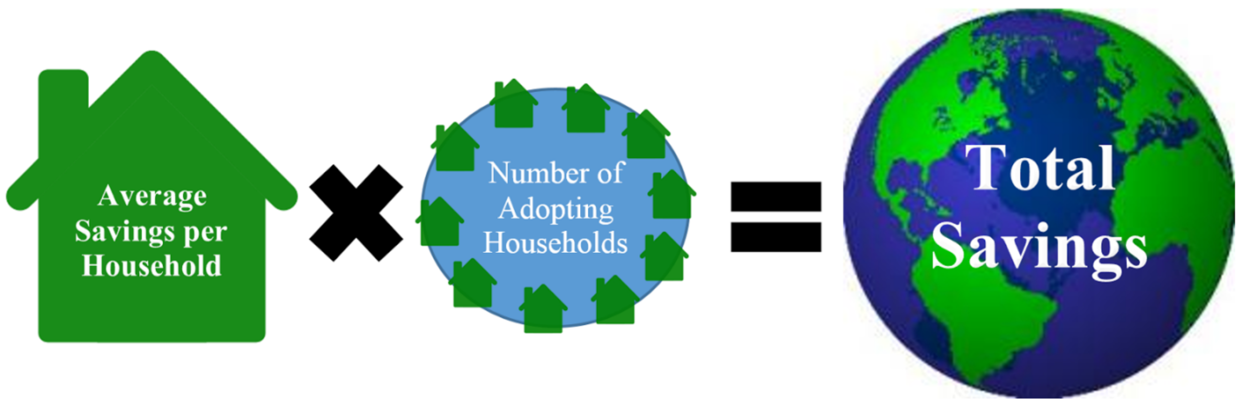


Figure 22. The HEMS Savings Equation

6.1 Diffusion of Innovation: An Overview

We situate our analysis of HEMS adoption within the context the innovation-decision process, a conceptual model in Rogers (2003) Diffusion of Innovation theory (see Figure 23). Diffusion of innovation details both the general process by which a technology cluster spreads among individuals as well as the intrapersonal process by which an individual learns about, assesses, and decides to adopt or reject an innovation. A technology cluster consists of one or more distinguishable elements of technology that are perceived as being closely interrelated (e.g., HEMS). We will discuss HEMS adoption in terms of the five stages of the innovation-decision process (knowledge, persuasion, decision, implementation, and confirmation), as well as two additional influential factors: individual characteristics and communication channels.

The knowledge stage refers to the consumer's awareness of the existence of a technology and how it works. Some awareness necessarily precedes the persuasion stage, which is when a consumer forms an attitude toward the technology or cluster, influenced by how they perceive it to align (or not) with their own needs and values. If it is initially appealing, further knowledge-seeking may follow and eventual decision to adopt, wait, or reject the technology (decision stage). The implementation stage follows, as the consumer puts the technology into use. As this occurs, the consumer seeks to confirm her decision by assessing how well it performs in terms of her expectations (the confirmation stage). Through implementation and confirmation, knowledge and persuasion with respect to the technology can change based on her experience with it.

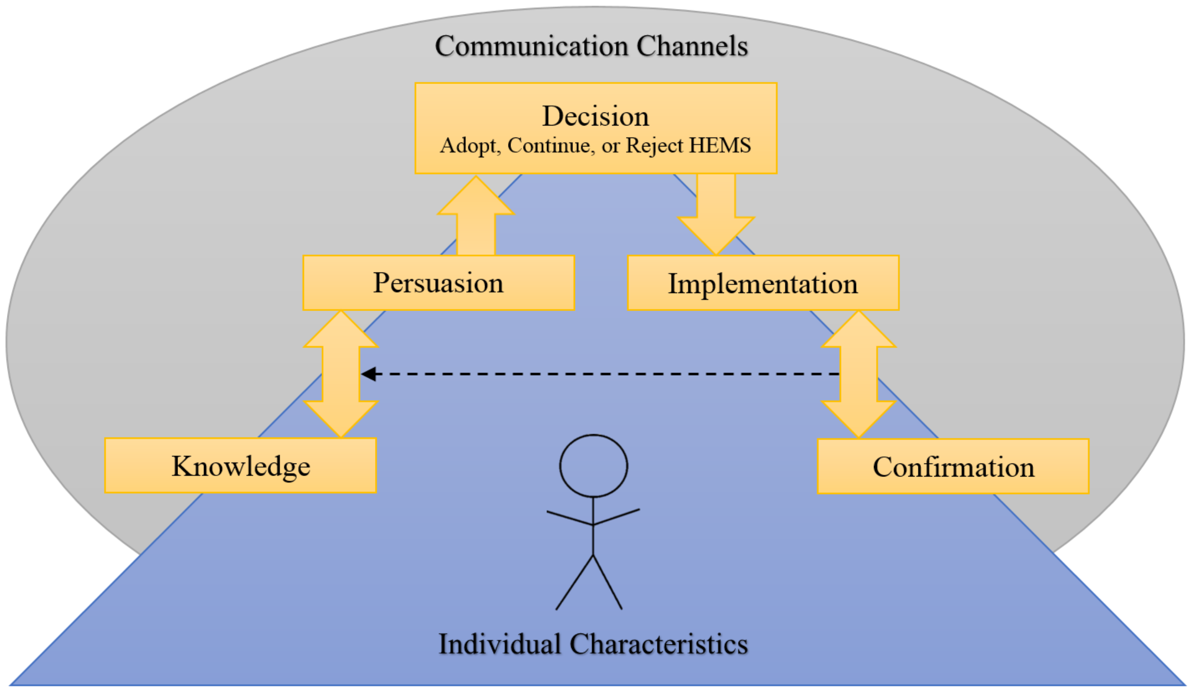


Figure 5. The HEMS Innovation-Decision Process.

Both individual characteristics and communications channels also influence all elements of the innovation-decision process (knowledge, persuasion, decision, implementation, and confirmation). Individual characteristics include personal and household demographics and general attitudes and values. Communication channels are interpersonal or mass media sources by which consumers learn about, receive evaluative messages about, or acquire the technology. Communication channels are emphasized most in the knowledge, persuasion, and decision stages, but they are relevant in all of the innovation-decision stages as they represent the social environment of the adopter.

This chapter aims to review existing literature on HEMS adoption —those who independently and actively adopt HEMS. Where such literature is sparse, we also include relevant findings from studies where HEMS users were recruited and studies of naturalistic adopters of similar technologies (e.g., home energy audits). We also include some findings from a recent study conducted by two of the study authors (Karlin et al., in press), which we refer to as the *feedback diffusion study*. While we analyze data in reference to Diffusion of Innovation Theory, in many cases, ours in the only research that was informed by the conceptual framework presented above and is the only dataset we could identify that collected data about all stages of the entire innovation-decision process. We hope to extend this work to address the adoption of HEMS, more, with a more recent and strategic sample (i.e., ratepayers within a specific utility territory).

6.2 The Knowledge Stage

Knowledge refers to consumer awareness of the technology, including awareness of its existence and how and why it works, and is generally considered the first stage in the innovation-decision process. Lack of consumer awareness and knowledge is cited as a barrier to HEMS adoption (Williams & Matthews; 2007) and energy efficiency adoption more broadly (Geller & Nadel, 1994). Researchers have just recently begun to conduct much-needed market-scoping surveys focusing on "smart homes" (Lowe's, 2014; Parks Associates, 2014), which are reviewed in this section. While useful, it is still preliminary and further research is needed to assess consumer knowledge of HEMS and specific HEMS categories.

King Brown Partners (2011) ran focus groups on perceptions of *smart home*, and concluded that awareness of smart home technologies is "far from universal" (p. 4). Nearly all participants focus groups had heard the term *smart home* but could not easily attempt to define it. They most associated the term with "futuristic, Jetsons-like homes" (p. 4) and more specifically with the concepts of energy management and home automation. "Many perceived the technology as something that would need to be built into new homes and nearly all thought that the technology would be complex and costly to implement" (p. 4). Similarly, Park Associates (2014) found that 10% and 11% of their respondents were very familiar with smart home services and products, respectively, whereas 62% were not familiar. Even fewer (8-9%) were very familiar with where to buy smart home services and products.

Our feedback diffusion study (Karlin et al., in press), found that only 27% of respondents were aware of at least one specific feedback-only HEMS. A slightly larger segment, 35%, was generally aware of the existence of energy feedback, but not aware of specific feedback HEMS. The largest segment, 37% of our sample, was unaware that any feedback HEMS existed, as shown in Figure 24.

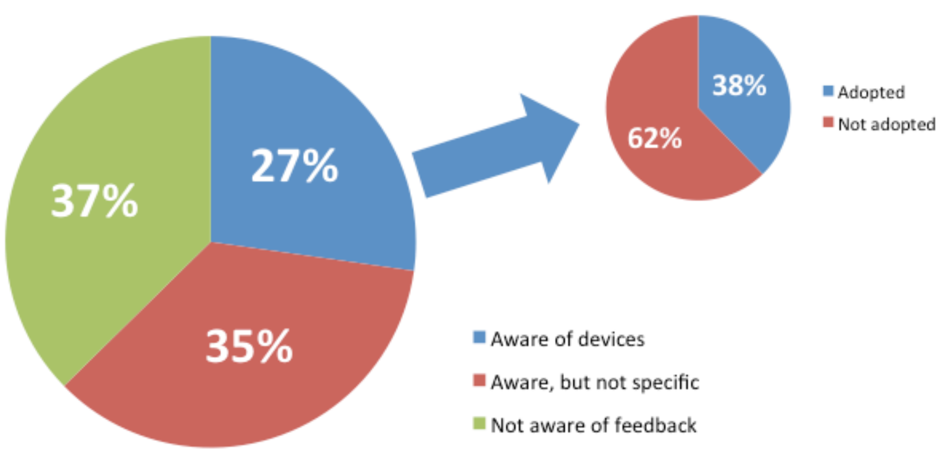


Figure 24. Awareness of and adoption of devices, feedback diffusion study

There is much yet to be discovered about the knowledge stage in the process of HEMS adoption. It is generally assumed that knowledge of HEMS in the general population is low, but there is a need for greater quantitative and qualitative understanding of consumer knowledge. For example, how many ratepayers in a given utility territory are aware that HEMS are available? Of those who are aware, how extensive is their knowledge of how and why HEMS work? How many actually know what demand response is and why it is important?

6.3 The Persuasion Stage

Persuasion refers to consumer attitudes toward the technology, which importantly align (or not) with their values and needs to create motivation to adopt. In so far as HEMS align with consumer values the likelihood of adoption is increased.

Early Impressions. Some knowledge (i.e., awareness of HEMS existence) is prerequisite to persuasion, but the two can occur in tandem and iteratively. A consumer survey by Navigant (2013) found that 64% of U.S. respondents had an interest in HEMS for their homes. Given that one year later Parks Associates (2014) found that roughly that same percentage (62%) was not familiar with smart home products, many of Navigant's respondents had likely only just heard about HEMS while participating in the survey and the idea was initially appealing, which is an affective response. This indicates that persuasion and knowledge may occur virtually simultaneously.

In our feedback diffusion study (Karlin et al., in press), we asked participants about their general or specific impressions of feedback HEMS. Given that their knowledge of feedback HEMS was so low, it is unsurprising that 48% were ambivalent. Almost as many (42%) had positive impressions, implying that knowledge is indeed a barrier to adoption. A small segment (10%) had negative impressions, as shown in Figure 25.

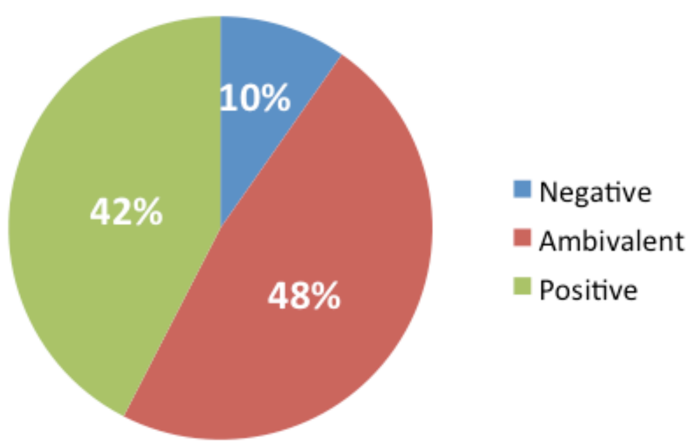


Figure 25. Impressions of Feedback

Energy Objectives. For some consumers, motivation to adopt HEMS may relate to specific objectives. For example, in Liikkanen (2009), 20 load monitor renters were motivated primarily by gathering information, technological curiosity, or a general sense of curiosity about energy use. Three specific types of motivation were identified: (1) determining the "truth" about their home energy use by doing an extensive walk-through of all appliances in the home; (2) attributing blame to a cluster or group of energy-intensive appliances; and (3) acquiring information on a singular new or suspicious appliance. Voluntary participants in home energy audits (Ingle, Lutzenhiser, & Diamond, 2012) were in some cases motivated to solving particular energy use problems.

Comfort, Convenience, Control, and "Cool" Factor. Park Associates (2014) asked respondents for words that describe what they value in smart home products. The responses varied widely, but the most frequently reported words were "easy", followed by "control", "safety", and "convenient". Home energy audit participants (Ingle et al., 2012) reported some similar motivations for requesting an audit and subsequent adoption of recommended efficiency measures, including improved comfort and issues of health and safety. A survey of 2088 adults administered by Lowe's (2014) found that the key cited benefits to having a smart home were included home security, home monitoring, and greater convenience.

In the Lowe's study (2014) participants generally desired control and automation features, with 70% wishing they could control something from their phone or tablet from bed (e.g., thermostat, lights, coffee pot) and 49% and 37% wishing the temperature would be perfect or lights would turn on automatically when they arrive home, respectively. The top three things participants wished to control remotely were the three things they were most likely to forget doing before leaving home (turning off lights, adjusting thermostat, and locking the door), nicely illustrating the importance of compatibility between HEMS and user needs.

Adopters of smart home technologies reported novelty as their primary motivation for adoption (King Brown Partners, 2011). Similarly, respondents in the Lowe's (2014) survey said smart home technologies would make them feel more tech-savvy. These findings reflect a potential social status or fun factor motivation for HEMS adoption among some segments.

Money: Costs and Savings. Also listed as a key benefit of smart homes in the Lowe's (2014) study was saving money on energy bills. The potential for cost savings was also a motivation for early adopters of smart home technologies in a focus group study by King Brown Partners (2011) for PG&E and voluntary participants in home energy audits (Ingle et al., 2012). Feedback studies have also ranked financial savings as a primary motivation for feedback use (Hargreaves, Nye, and Burgess, 2010; Parker et al., 2008)

Another finding in the Lowe's (2014) study was that 56% of respondents cited cost or fees as the most important deciding factor in purchasing smart home products. Burson-Marsteller (2009) surveyed 1003 Americans in 2009 to assess consumer demand for green energy technologies. They found that the general population was willing to pay $48 on average for a one-time installation fee and $13 on average in monthly fees for the benefits of smart grid technology. In our feedback diffusion study (Karlin et al., in press) we asked participants how much they were willing to pay for feedback devices. About half of respondents were willing to pay up to $20 (27%) or even $50 (26%) for a feedback device.

Environmental and Altruistic Values. Other consumers may be attracted or repelled by HEMS because they align (or don't align) with their core values. For example, Toft, Schuitema, & Thogersen (2014) analyzed consumer acceptance of smart grid technologies in Europe using the Technology Acceptance Model and Norm Activation Model and found that acceptance of these technologies was higher when individuals viewed them as useful to society and the environment. Being "green" and energy savings ranked as a benefit among smart home technology adopters (King Brown Partners, 2011) and energy savings and increased efficiency were mentioned as motivating energy audit participants (Ingle et al., 2012). Studies that inquired about motivations for adopting energy feedback (Hargreaves et al., 2010; Parker et al., 2008) found environmental concern ranked second only to financial savings.

Individual Characteristics. All the motivations listed are doubtless related to some individual characteristics of the consumer, even the relatively more universal concerns of convenience, comfort, control, and money. An illustrative case comes from Demiris et al., (2004), who conducted focus groups with 15 older adults to determine areas in which advanced, including smart home, technologies would benefit older adults. Participants had a positive attitude toward smart home technologies overall and discussed issues related to emergency help, prevention and detection of falls, and monitoring of physiological parameters as potential motivations to adopt. They expressed concerns about user-friendliness of devices, lack of human response, and receiving training tailored to their needs as possible barriers to adoption.

Overall, only four of these studies assessed motivations of actual HEMS adopters specifically. Assessing the attitudes and motivations regarding HEMS without connecting that information to the other stages and factors in the innovation-decision process, such as whether they adopt, individual characteristics and communication channels through which they learned about HEMS, limits the utility of the information. Replicating our feedback diffusion study with a systematic sample and focus on current HEM technologies would enable a more systematic assessment of factors related to motivation to adopt specific types of HEMS. See Table 5 for a summary of factors related to motivation to adopt HEMS and related technologies from the literature to-date.

Table 5. Motivation Factors in the Persuasion Stage of HEMS Adoption

HEMS or Related Technology	Motivation Factors in Persuasion Stage
Home Energy Audit (adopters) (Ingle, Lutzenhiser, & Diamond, 2012)	Save energy Reduce costs Increase efficiency Improve comfort Solve particular problems Issues of health and safety
Smart Grid Technologies (Toft,Schuitema, & Thogersen, 2014)	Useful to society and the environment
Smart Home Devices (intending adopters) (Parks Associates, 2014)	Interoperability Easy Control Safety Convenient
Smart Home (adopters) (King Brown Partners, 2011)	Novelty Cost savings Reduction in electricity use Being green
Smart Home (mostly non-adopters) (Lowe's, 2014)	Safety: Home security, hazard protection (floods, fire, etc.), Information: Home monitoring Convenience Feel more tech savvy Financial: Monthly fee, cost of equipment, Savings on energy bills, insurance discount Ease of use
Automation (mostly non-adopters) (Lowe's, 2014)	Lighting Temperature
Load monitor (adopters) (Liikkanen, 2009)	Curiosity Gathering information Attributing blame to appliances/devices
Feedback (recruited users) (Hargreaves et al., 2010; Parker et al., 2008)	Financial savings Environmental concern
Smart home and advanced telemedical technologies (mostly non-adopters; older adults) (Demiris, 2003)	Emergency help Prevention and detection of falls Monitoring physiological parameters User-friendliness Lack of human response

6.4 The Decision Stage

The decision stage consists of the decision to adopt or reject the innovation, and also includes activities that immediately lead to this decision, such as adopting the innovation on a trial basis. Rogers (2003) specifies five adopter categories and the portion of the population of potential adopters each represents: innovators (first 2.5% of population to adopt), early adopters (next 13.5% to adopt), early majority (34%), late majority (34%), and laggards (16%).

Navigant (2013) estimates a 1% market penetration rate for the latest smart grid-enabled HEMS, which indicates that these technologies have yet to even reach early adopters. In our feedback diffusion study (Karlin et al., in press), about 10% reported adopting a feedback device; however, this is an overrepresentation of true market saturation because we oversampled population segments more likely to have adopted HEMS. This indicates that feedback HEMS, which have largely preceded control-capable HEMS, are still just reaching early adopters.

Park Associates (2014) found that 20.7 millions of units of smart home devices have been sold in the US (including smart thermostats, networked cameras, smart door locks, smart water leak detectors, smart smoke detectors, smart carbon monoxide detectors, smart light bulbs, smart light switches, smart plugs and outlets, and smart power strips). They claim 10% of all US households have at least one of these smart home devices, with no single device in more than 6% of homes. About one third of smart product owners also have a centralized controller, but the remainder acquired their device as a stand-alone product. This indicates early adopters are acquiring some HEMS, but more networked HEMS have only reached innovators.

Individual Characteristics

Much of the research on HEMS has actively recruited participants for studies that involve imposing HEMS on them in order to assess usability and/or effectiveness, therefore little is known about the characteristics of individuals and households who have actively and independently adopted HEMS on their own (i.e., naturalistic users).

Park Associates (2014) identified a number of individual characteristics that distinguish early adopters of smart home technologies, including a dramatically stronger propensity to buy new technologies as soon as, or soon after, they become available. Pride of ownership and concern for the safety of family members are also salient with adopters and Park Associates predicts these factors will be more important for early majority adopters. Smart device owners also tend to have higher education and income than the national average. They are younger than non-owners but older than adopters of other “pure tech” products, credited by Park Associates to the family-focus rather than individual-focus of motivations to adopt, which include safety, security, and convenience.

Liikkanen (2009) studied naturalistic feedback adopters; specifically, she interviewed 20 consumers that had independently rented a load monitor from their energy service provider. Consistent with Hargreaves et al. (2010), the majority of these consumers were male (13). The majority belonged to a two-adult household (three had children). Education and age varied widely. This study is unique in its provision of information on naturalistic HEMS adopters, but the sample size is small and no comparisons are made to non-adopters in the same population.

Positive attitudes toward energy conservation (Kurz, et al., 2005) and previous energy conservation behavior (Battalio, Kagel, Winkler, & Winett, 1979) have also been found to predict feedback adoption. Other studies comparing voluntary participants in feedback studies with a blind control group found no significant differences for conservation commitment, energy awareness, or conservation behavior (Robinson, 2007; Winett, Neale, & Grier, 1979). These assessments were within the context of studies that recruited participants, so it is not clear whether these participants would have adopted energy feedback on their own.

Although not pertaining specifically to HEMS, Ingle et al. (2012) identified individual characteristics of voluntary participants in home energy audits, many of which subsequently adopted energy efficiency measures. Participants were more wealthy, more educated, and older than the average local population. The findings related to income and age are consistent with our data pertaining to naturalistic adopters of energy feedback.

In the feedback diffusion study (Karlin et al., in press), we analyzed three types of individual characteristics for differences betweeen HEMS adopters and non-adopters: demographics, housing characteristics, and attitudes. Our data indicate that HEMS adopters were significantly more likely to be male (54% vs 30%), older (46 vs 40), married (65% vs 51%), and have a higher income ($106k vs. $88k) compared to non-adopters. In terms of household characteristics, they were significantly more likely to be homeowners (83% vs 57%) and live in detached single-family houses. They were also significantly more likely to be concerned about the environment and motivated to protect it, and to be price conscious and motivated to save money.

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Park Associates (2014) assessed the market for smart home products. They found that 20.7 millions of units of smart home devices have been sold in the US (including smart thermostats, networked cameras, smart door locks, smart water leak detectors, smart smoke detectors, smart carbon monoxide detectors, smart light bulbs, smart light switches, smart plugs and outlets, and smart power strips). They claim 10% of all US households have at least one of these smart home devices, with no single device in more than 6% of homes. About one third of smart product owners also have a centralized controller, but the remainder acquired their device as a stand-alone product. This indicates early adopters are acquiring some HEMS, but more networked HEMS have only reached innovators.

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In our feedback diffusion study (Karlin et al., in press), we analyzed the demographic and housing characteristics that distinguish HEMS adopters from non-adopters. Our data indicate that feedback-only HEMS adopters are significantly more likely to be male, older, White, married, liberal, and have higher income compared to non-adopters and in terms of household characteristics, they are significantly more likely to be homeowners and live in detached single-family houses (Table 6).

Table 6. Demographic Characteristics of Feedback Users Compared to Non-users

	Feedback users	**Non-users**
Gender***	46% female 54% male	70% female 30% male
Age**	45.5 years	39.9 years
Race	80% Caucasian 1% Hispanic 8% Asian 1% African-American 10% Other/Decline	82% Caucasian 7% Hispanic 6% Asian 2% African-American 3% Other/Decline
Marital status*	65% married 35% not married	51% married 49% not married
Political affiliation*	3.96	3.67
Education	18.0 years	17.4 years
Income*	$106,000	$88,000
Homeownership**	83% own 17% rent	57% own 43% rent

$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Communication Channels

Characteristics of communication channels involved in the diffusion of an innovation are highly influential on the innovation-decision process, perhaps especially for the decision stage. HEMS companies are taking a variety of routes to market, including: utility-centric, non-utility service provider, home builder, and direct-to-consumer (Aricent, 2013). Each of these routes has distinct characteristics that appeal to the company. The utility-centric route is the lowest cost and easiest deployment method for a new product. The non-utility service provider route leverages existing security or cable services by offering bundling deals. The home builder route leverages the special opportunities for innovation and integration that new construction offers. The direct-to-consumer route may be preferable for products that are easy to install and use. These characteristics are important for companies to consider, but they should also consider implications of communication channels from the user's perspective, not to mention evidence of the effectiveness of these various channels.

Peterson (2011) found that the limited knowledge most people had about smart homes came from popular media, including Disneyland exhibits such as Epcot Center and the Home of the Future. In our feedback diffusion study, we asked participants who were aware of feedback devices where they heard of them. The most prevalent communication channel by which participants heard of devices was friend or family (20%), followed by utility company (17%), work-related (14%), other (14%), online shopping (8%), article/publication (7%), environmental group (7%), environmental event (6%), home audit (3%), and environmental store (2%).

According to a recent CEA market research report (2013), home improvement stores are the top choice of consumers for 'where to go get' these devices and services. Delphi experts agreed that more affluent customers gravitate to companies that provide home automation directed at entertainment and security features, while the retail distributors are important for "more utilitarian...needs of the smart home", such as "lighting, HVAC, thermostats, water heaters, garage doors, light switches, outlets, smart plugs, water softening, irrigation, smoke [detectors], CO_2, fire alarms, outdoor cameras, door locks", etc.

Park Associates (2014) found that national or local retailers were the most prevalent acquisition channel (> 20%) for US broadband households that acquired a smart device in the past year, followed by 'received as a gift' (~20%), online retailer (>10%), broadband service provider (~10%), and a security dealer. The Lowe's (2014) survey also indicates most consumers prefer a DIY approach (50%) without a monthly fee over professionally installed products with a monthly service fee (21%).

In our feedback diffusion study (Karlin et al., in press), we asked feedback adopters where they acquired the device. The most prevalent source of acquisition to be the Internet (29%), followed by friend or family (14%), utility (14%), store (13%), other (12%), manufacturer (11%), and 7% did not know. At least 13% of devices were borrowed, which is consistent with previous findings that some feedback users prefer renting feedback products rather than owning them (Hutton et al., 1986; Van Houwelingen & Van Raaij, 1989).

We also asked survey respondents about factors likely to influence purchase of a feedback device and gave them a set of fixed choice responses related to communication channels. The most frequent response was "available at my local drugstore or supermarket", followed by "provided by my utility company", then "somebody to help me install/use the device". Given that the newest HEMS are more diverse and often more complex than the feedback devices we focused on in our survey, it is important to replicate this research to assess communication channel preferences for specific HEMS categories among consumers within a given utility territory.

Aside from our own study cited above, we were unable to find research on sociodemographic characteristics of adopters of HEMS and the communication channels via which they acquire them. Replicating our study with a more meaningful sampling strategy (i.e., ratepayers in a particular utility territory) and including (and comparing) distinct types of HEMS would be enormously powerful to help guide utility program design and marketing strategies.

6.5 The Implementation Stage

The innovation-decision process does not end with the purchase or otherwise acquisition of a HEMS. The implementation stage refers to the overt process of putting the innovation to use following the decision to adopt. As Rogers (2003) notes, "It is one thing for an individual to decide to adopt a new idea, quite a different thing to put the innovation to use, as problems in exactly how to use the innovation crop up at the implementation stage" (p. 179). Research on the usability of HEMS is relevant to the implementation stage.

Brush et al. (2011) studied 31 naturalistic adopters of home automation systems (remote lighting control, multi-room audio/video systems, motion detectors, or security camera systems) in 14 households. They recruited participants via Microsoft mailing lists for home automation, including Microsoft employees. Users identified some issues with the implementation of their products, which included inflexibility in terms of interoperability and structural changes required that made it difficult to relocate the products. They also discussed issues of poor manageability, which included unreliability, complex interfaces, iterations required to get it right, reliance on experts, and difficulty achieving security. King Brown Partners (2011) found that most of the smart home technologies were installed by early adopters who expressed issues with system complexity and a lack of integration.

Problems with usability have also been reported in feedback studies, mostly pertaining to the display of information. Feedback delivered via mail or email was found to be unclear and not useful (Robinson, 2007), in-home display users reported difficulty reading and interpreting numerical information and graphs provided (Allen & Janda, 2006; Hargreaves et al., 2010), and users of plug load monitors reported accessibility issues with certain appliances (e.g., refrigerator) whose size would block any information displayed by the device (Liikkanen, 2009).

Some studies of energy feedback also identified individual characteristics that relate to feedback use among recruited participants. In a study in the UK, Hargreaves et al., (2010) found that men were more interested and engaged with feedback displays compared to women.

6.6 The Confirmation Stage

Confirmation refers to the tendency of adopters to seek information that reinforces their decision to adopt, avoiding or reducing any dissonance between expected and actual outcomes. This is complementary to the persuasion stage, as consumers assess the performance of the technology in terms of the anticipated outcomes that motivated adoption. Insofar as energy savings is valued by the consumer and expected from the HEMS, this will be assessed in the confirmation stage.

In the focus groups of early adopters of smart home products, King Brown Partners (2011) found the most cited benefit of products to be convenience (e.g., due to remote control capabilities). In Brush et al. (2011), three themes emerged in discussions of most valued outcomes of home automation systems: convenience, peace of mind, and centralized control. Even among adopters of more traditional energy efficiency measures as recommended in home energy audits, the most cited tangible benefit was increased comfort (Ingle et al., 2012).

In energy feedback research, user satisfaction has been high across a variety of technologies including utility billing (Arvola et al., 1994); in-home displays (Hargreaves et al., 2010; Mountain, 2007), appliance monitors (Mansouri & Newborough, 1999), and plug load monitors (Likkanen, 2009). Participants reported that using energy feedback devices improved their ability to manage and curtail energy use overall, with gains in both knowledge and conservation behavior. Knowledge gains include a general increased awareness of energy use patterns (Allen & Janda, 2006; Haakana et al., 1997; Hutton et al., 1986; Van Houwelingen, & Van Raaij, 1989); learning that their energy use was either more (Mountain, 2007) or less (IBM, 2007; Hargreaves et al., 2010) than expected; and specific knowledge about how to reduce energy use (Kasulis et al., 1981; Parker et al., 2008; Vollink & Meertens, 2006). Feedback users also reported specific changes in their behavior, including replacing light bulbs (Mountain 2007; Robinson, 2007), lowering thermostat and hot water settings (Haakana et al., 1997; Mountain, 2007; Winett et al., 1979), closing the refrigerator more quickly (Kurz et al., 2005), identifying and disposing of "greedy appliances" (Hargreaves et al., 2010), shifting use to off-peak hours (Nexus, 2005), and turning off lights when not in use (Haakana et al., 1997; Mountain, 2007).

6.7 Limitations of Adoption Research

While the reported findings above shed some light on various aspects of HEMS adoption, most studies have focused on one aspect of the adoption process rather than systematically evaluating naturalistic adopters. In addition, much of the work lacks ties to the theoretic concepts underlying the adoption process, and while this may identify how a single technology is perceived or adopted by a particular group of users, it doesn't help to more broadly advance our understanding of how Home Energy Management might be adopted in the wider marketplace. Further research, grounded in theory, and which systematically attempts to identify multiple aspects that influence the adoption process, is required.

7. Conclusion

Having defined and described Home Energy Management, reviewed the technology landscape, and assessed potential savings and adoption, we conclude with a brief discussion of how the market is evolving, key barriers (and ways to address them), and the potential role(s) of the utility in the HEMS market.

7.1 Market Evolution

Popular press favors a few key HEMS players, primarily Google's NEST, Apple's Homekit, and Samsung, but according to the experts on our Delphi panel, products like NEST have "over priced, overstated benefits" and operate based on "optimum temperature control algorithms that have been [around] for years". In fact, one expert suggested using a "home centric hub and a thermistor/temperature sensor", focusing on "getting the cost and complexity out of the temperature sensor and putting the smarts and flexibility into the whole home controller, lighting, actual controls (smart plugs, smarter appliances), security, and enhanced safety". Others felt that what separates technologies like NEST is the "user interface and presentation" and that the product could "still drive meaningful shifts in public psychology and how residents interact with their energy use". Another aspect that separates innovative HEMS companies from their competition is how well they market themselves and appeal to consumer lifestyles.

Knott (2014) takes the marketing claim a step further by stating that key players pay for all the "hype," but may only reap the benefits of growing visibility for the market. Converging business models from Internet companies, hardware firms, cable companies, retailers, and even security companies will have an overall positive effect on the market but may never become the first choice for consumers. According to Knott, these companies are targeting the affluent consumer but neglect to consider the 69 million households earning under $200,000 each year.

Because consumer awareness of HEMS technologies is low, distribution partners are among the most important players "as a sales channel and possibly as an installer resource". In fact, several Delphi panel experts commented on the importance of retail partners, such as Lowe's, Home Depot, Best Buy, Sears, and other home improvement stores with "Wal-Mart and Target...likely right on the heels of bringing [in their own products]". "The merchandising must be worked out in order to tell the right story to the consumer."

While discussion of current technology is necessary as we move forward, it is also important to note that the HEMS market is changing rapidly and the market forecasts to-date have been both highly variable and somewhat inaccurate. A 2009 report in Smart Grid news predicted the market would be worth $3 billion annually by 2012 (Berst, 2009). By 2012, Navigant Research made a more conservative prediction that the HEM market would grow from $300.7 million to $1.8 billion by 2022 (Navigant, 2012). More recently, GTM Research predicted a market value of $4.1 billion by 2017 (Bojanczyk, 2013). At this point, industry researchers agree that there is high potential in the HEMS market, but no one agrees about just how much.

The product landscape in the market is also changing rapidly. As evidence, we reviewed the list of 208 HEMS feedback products identified by Karlin et al. (2014) and only found 48 that met the criteria for the current HEMS technology assessment. Of those that did not meet the criteria, 31 were out of business, 50 products were retired, and 43 were not available in the US market.

7.2 Key Barriers

Our analysis identified three key barriers to HEMS uptake: (1) interoperability, (2) data privacy and security, and (3) consumer engagement.

7.2.1 Interoperability

Rossell and Soler (2011) state that "HEMS should provide seamless interaction between devices" but that this can be challenging to achieve as there are a variety of home energy management technologies from different producers and with different communications standards (p.251). As with other industries, key players in the HEMS market are competing for a majority share of consumers without much concern for interoperability outside of their own "suite" of devices. As one expert put it, "the major tech companies are really busy trying to outdo each other and we may not get consensus in the near term if left up to them." While many discuss a lack of interoperability as a key challenge to HEMS (Rossell & Soler, 2011; Roth & Sachs, 2013; Javaid et al., 2013), it is unlikely for companies to address this challenge unless consumers demand it. One expert said, "Interoperability will remain an issue for the foreseeable future as it will take mass adoption of devices by consumers to weed out tier 2 and tier 3 technologies. Once consumers show a clear preference for the type of technology they want in their homes, the industry (OEM's, utilities, etc.) will follow the consumer." Major players in the market are pushing products out to consumers to see "what will stick," but learning what consumers want and how they use their devices will help shape the future of HEMS.

Experts agree that consumers want products that operate much like the smart devices with which they are already familiar. For instance, a recent study conducted by Pew Research Center's Internet and American Life Project finds that, for the first time, a majority of American adults (56%) own smartphones (Farivar, 2014). The smartphone may be a key to introducing HEMS to a broader market who would not have to learn a new platform to control their home.

What was clear from our study was that whichever systems do get integrated into the home, they must work together. One Delphi expert stated, "I see a natural evolution of these devices to where nearly every appliance or piece of consumer electronics sold will be Wifi-enabled and contribute to the 'Internet of Things'. Then, manufacturers and vendors will have to start figuring out how they talk to each other." This is exactly what Google is aiming to do with their project of transforming how devices communicate with consumers and each other. Google recently unveiled a new project, Thread, that aims to make the "Internet of Things" (IoT) interaction completely "app-less" (Etherington, 2014). This new "interaction on demand" may mean that energy systems could function together without the use of a centralized management system, even when purchased from different retailers.

Others have discussed an evolution of the HEMS marketplace where users are almost entirely removed, creating autonomously systems that communicate with one another and manage their own behavior with no user interaction. Heppelmann & Porter (2014) define autonomy as the scenario in which appliances can operate without human intervention, using data analytics that enable products to "learn about their environment, self-diagnose their own service needs, and adapt to users' preferences." One of our Delphi respondents listed "predictive and adaptive technology that does not actually require the user to proactively manage or make constant decisions regarding their energy consumption" as a component of HEMS, stating that "the best HEMS will require minimal user interaction after initial implementation." According to our expert, "autonomy is the future of HEMS" and the key to market growth.

Although experts agree the HEMS market has a great potential for growth, the participants in our Delphi study agree there is much left to discover about how consumers would interact with the products and which products would integrate with how they currently live in their homes. We don't "know enough about user behavior, preferences, motivation, and tipping points to implement intelligent control," but "intelligent control is perhaps unavoidable. Its effectiveness is limited and addressing user's behavior and creating awareness remains essential."

However, whether the HEMS marketplace moves in a direction reliant on users or independent of them, it is increasingly evident that fully connected products capable of communicating broadly and leveraging data across devices is a key aspect.

7.2.2 Data Privacy and Security

Data privacy and data security are often cited as barriers to consumer engagement in smart grid technologies (Park et al., 2014). Rossell & Soler (2011) cite data privacy as one of the features required for an effective HEMS**.** Hewlett Packard released a security report in 2014 revealing that 70% of the most common Internet connected devices contain vulnerabilities (Miessler, 2014). The list of vulnerabilities included password security, encryption, and lack of granular user access permissions. As more Internet connected devices enter the smart home, privacy and data security will become a bigger concern for the everyday person. Data security could have an impact on HEMS adoption, and utilities may be in a strong position to show leadership in this space. Both the regulatory bodies and utilities have been active in this space to ensure standards are in place when dealing with data security, but "as a nexus of devices begins to interact, it becomes increasingly important that the necessary firewalls and vaults are in place to ensure the consumer is protected from the unknown threats." (Rawlinson, 2014)

With an estimated 50 billion devices connected to the Internet by 2020 (Etherington, 2014), consumers will increasingly integrate technology into their lives, with the next frontier likely being their homes. While Park et al. (2014) note that stronger standards for privacy and security are important, they suggest that concern over data insecurity can be mitigated via greater transparency and increased public education. For instance, transparency on what data that companies are collecting and what they are doing with data is key. An expert posed, "Why not just tell people what you're collecting and going to be doing with their data? If they wouldn't like it, you probably shouldn't be doing it." Participants in the Delphi study agreed full disclosure could "eliminate data and privacy concerns" and the explanations should be simple, not complex and hidden in fine print. As one participant put it, "the number of people who decide never to create a Facebook account due to privacy is pretty darn small," but if products are "excellent and convenient," consumers will begin to adopt them. The key is knowing what consumers deem as excellent, and simultaneously developing transparent customer data security processes.

7.2.3 Consumer Engagement

A HEM device is only successful if it is being used as intended, and many experts think simplification can increase implementation. Park et al. (2014) state that to make products more compatible and thus enhance customer engagement, "energy data should be made more enjoyable and easier for smart grid users to interface" (p. 217). If "Grandma can simply plug in and go," HEMS adoption will be easier for the average consumer. One expert believes the reason why Apple and Google capture the market isn't simply marketing, but that "it's their simple and customer-centric industrial design and user interfaces that make them appealing." Industry experts seem to agree that the best user interfaces will most likely dominate the HEMS market, but we must first know what interfaces consumers prefer in their homes. Experts on our panel stated they would "like to see more studies about how people interact with their energy currently and what is motivating their use." They believe the more that consumer behavior around HEMS adoption and use is understood, the "better we can provide the simplest possible interface to get the job the household needs done."

The panel of experts in our Delphi study believe there is potential for the market to correct itself and "weed out the bad companies," but they note this must be done with caution given how quickly the market changes. For example, one Delphi expert said, "backlash from early prototypes may in turn set the entire industry back. It will be important to avoid major pitfalls in early products and services, because the market will not be easily moved past initial negativity."

Another step in overcoming the barriers of HEMS adoption is simplifying and clarifying the terms. Even among the experts, the definitions vary from person to person. For example, when asked about their feelings on intelligent control based on behavior, one participant talked about "big brother and big data" while another mentioned "sending push notifications to [his] smartphone" and how a smartphone is "critical to HEMS success." Our definition of intelligent control is applied to a device which develops algorithms based on consumer behavior to manage energy efficiently and autonomously, but some of our experts equated "intelligent" with "smart" and began commenting on integration with existing mobile technology. If the HEM industry remains market-dominated (instead of regulated) as it is today, it is incredibly important to ensure that consumers understand and engage with HEMS, and because energy is often an abstract and complex concept, this may require some facilitation.

7.3 The Role of the Utility

Past literature provides very little indication that utility companies are considered key players in the HEMS industry, but the current analysis suggests that they are in a great position to be a central player in the HEMS market. It seems that utilities can create a central role to better take advantage of the full energy savings, demand response, and customer convenience benefits of HEMS in the following five ways:

1. Supporting research and testing;
2. Serving as a gateway to provide connections and leverage data across devices;
3. Serving as the trusted energy advisor;
4. Promoting market growth with energy efficiency and demand response programs; and
5. Developing customer data security processes.

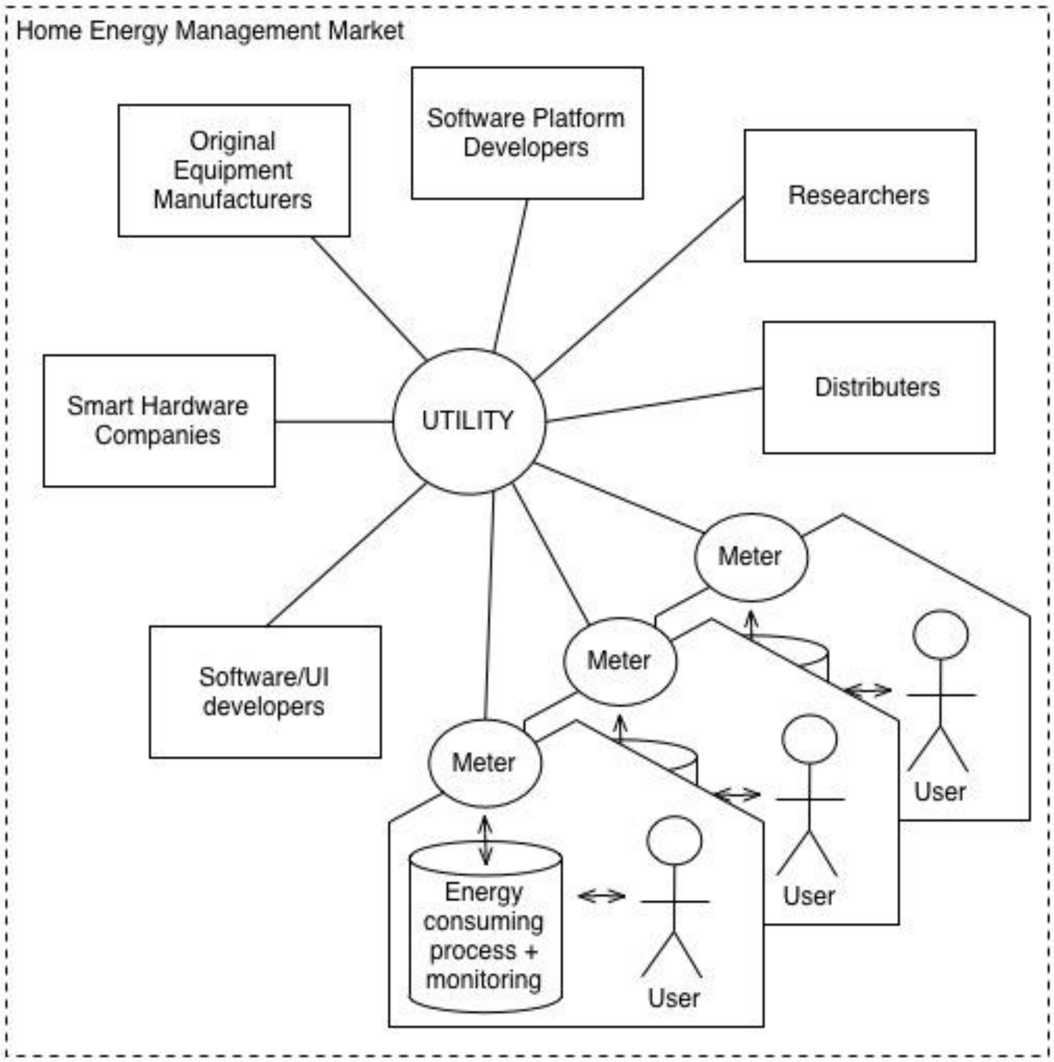

Figure 27. Potential Utility Role in the HEMS Landscape

Our expert panelist suggests that "utilities need to set the pace" and "not watch from the sidelines" by expanding HEMS involvement and "set[ing] standards for user interaction." If utilities don't actively devote resources to HEMS, according to another, "it will allow a small number of companies who have built integrations to keep others out, thus decreasing competition and creating a dismal customer experience." Similar sentiments were echoed by several participants and the potential for utility leadership is reinforced by findings that consumers are likely to get information about HEMS and to acquire HEMS products from their utility.

Final Thoughts

It is clear that HEMS is an ever-changing market and every prediction is a moving target. The creation of a supportive environment that promotes energy efficiency and demand response initiatives can help facilitate the further development and evolution of a strengthening HEMS market. Additionally, further research to help better understand consumer uptake, behavior, and interaction with HEMS will assist in piecing together a more accurate market forecast. It seems that many market predictions to-date have overshot the market potential, which may mean that the products are not as attractive to consumers as preliminary researchers and product developers think and further research focused on the user experience could be fruitful. However, if they are able to attract consumers, it seems that Home Energy Management Systems have a great deal of potential for energy efficiency and demand side management within the residential sector.

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Appendix A: HEMS Product List

Company	Product	Description	Product Category
Aclara	Customer Care Solutions	Unique content and analytics that improve the effectiveness of customer care and billing, enhances customer energy management and increases customer satisfaction by helping customers better understand and manage their bills	Energy Portal
ADT	ADT Pulse	The ADT Pulse® portal provides secure access so you can monitor and manage your home's eneryg and security via most web-enabled devices.	Smart Home Platform
Alarm.com	Energy Management	Alarm.com Energy Management learns your activity patterns and adapts to your needs, automatically. Controls connected thermostats and lights.	Smart Home Platform
AlertMe	SmartEnergy	Provides real-time and historical energy use information	Smart Home Platform
Allure Energy	Eversense	Thermostat that automatically adapts to the user's daily schedule	Smart Thermostat
Ambient Devices	Energy Joule	In Home display that commincates energy price and usage data thorugh digital and color feedback.	In-Home Display
Apple	Homekit	HomeKit is a framework in iOS 8 for communicating with and controlling connected accessories in a user's home.	Smart Home Platform
Apple	Homekit Platfrom	Home automation platform to connect and control all of your smart home devices	Smart Home Platform
AT&T	Digital Life Energy Package	Remotely adjust lighting, thermostats and small appliances.	Smart Home Platform
Ayla Networks	Ayla Platform	An end-to-end cloud platform for OEMS to build internet connected products	Smart Home Platform
AzTech	in-Home Display	home display allows you to take charge of energy usage	In-Home Display
Belkin	Conserve Insight	Electric load meter and energy monitor	Load Monitor
Belkin	WeMo LED Lighting	Smart LED bulbs connected to the WeMo Link	Smart Lighting
Belkin	Conserve Insight	A smart plug that can provide load and cost projections as well as instantaneous usage information to a small display	Smart Plug
Belkin	Conserve Smart AV	A plug board that eliminates standby power by automatically switching on/off peripheral components when the user turns on/off their TV	Smart Plug

Company	Product	Description	Product Category
Belkin	Conserve Socket	Plug that eliminates standby power by switching off power to electronics after a time interval	Smart Plug
Belkin	WeMo Insight Switch	Smart Switch with control and monitoring capabilities	Smart Plug
Bidgely	EE Solution	Energy disaggregation allows us to show customers how to save. We make it easy, which gives consumers the confidence to act.	Energy Portal
BITS	Energy Saving Smart Strip Surge Protectors	A plug board that eliminates standby power by automatically switching on/off up to four peripheral components (green) when the user turns on/off a control device (blue)	Smart Plug
Black and Decker	Power Monitor	In home display for energy management by B&D	In-Home Display
Blue Line Innovations	PowerCost Monitor	Home energy monitor that wirelessly reads a meter and provides information on real-time electricity consumption, real-time cost consumption, and peak electricity in a 24 period, as well as the time, the temperature at meter location, signal strength and the battery strength of both the display and sensor units	In-Home Display
Brand Electronics	Digital Power Meter	Plug in meter with Watts, kWh, Elapsed Time, Cost per month, Total Cost	In-Home Display
Brultech	ECM-1240	Net metering energy monitor	Energy Portal
C3	Residential Solution	C3 Residential is a loyalty-based customer engagement and energy efficiency solution that educates residential customers about their energy use and motivates them to conserve energy, save money, and earn rewards.	Energy Portal
Calico Energy Services	HomeSMART Energy Management	Consumer engagement portal for monitoring, budgeting, control, DR opt-in	Energy Portal
Carrier	ComfortChoice	Programmable thermostat designed for ZigBee applications	Smart Thermostat
Ceiva Energy	HomeView	CEIVA Homeview puts home energy control right at your customer's fingertips, full disclosure. Your customers can decline DR events, receive alerts on their mobile device(s), view their home's energy demand instantly, and develop their own strategies for conservation and reducing peak-time demand.	Data Analytics Platform
Comcast	XFINITY Home	Home security and home control system	Smart Home Platform
Comverge	InteliPEAK	Load control unit for demand response applications	Data Analytics Platform
Comverge	SmartConsumer	customer service solution for utilities	Energy Portal

Company	Product	Description	Product Category
Control4	Control4 HC-800 Controller	Integrates music, shades, locks, climate control and video for a smart home solution	Smart Hub
Cooper Power Systems	Load Control Switches	Switches for demand response applications with multiple communications options	Load Monitor
Cooper Power Systems	In-home Peak Indicator	In-home peak indicator requests homeowners reduce load and costs given a dynamic pricing system	Smart Plug
Cooper Power Systems	Programmable Communicating Thermostats	Programmable thermostat with demand response capability	Smart Thermostat
Creston	TSW	Touch screen display to control your networked home	In-Home Display
Current Cost	The Classic	A simple monitor for home energy consumption	In-Home Display
Current Cost	TREC	A small device display for energy consumption monitoring	In-Home Display
Current Cost	ENVI	Similar to the classic with advaced metering cabilities	In-Home Display
Current Cost	EnviR	Individual appliance monitoring capabilitys and utility metering cabilities	In-Home Display
DreamWatts	DreamWatts	A web-enabled portal for automating commercial and residential buildings to better manage energy consumption	Energy Portal
EarthNetworks	WeatherBug	Customer energy use information and a comprehensive set of analytics, WeatherBug® Home provides personalized insights and reduces energy use. Homeowners can finally stay comfortable and save energy at the same time — and utilities can harness the power of big data to improve operations and boost efficiency.	Energy Portal
Ecobee	ecobee3	The smarter wi-fi termostat with remot sensors (for homes with more than one room)	Smart Thermostat
EcoFactor	Optimized Demand Response Service	A service to maximum load shed can be achieved with high consumer participation. Offering a unique combination of powerful, cloud-based analytics and inexpensive internet-connected thermostats, we help utilities and energy retailers launch industry leading, high yielding DR programs.	Data Analytics Platform
EcoFactor	HVAC Performance Monitoring	With the EcoFactor's HVAC Performance Monitoring service, our sophisticated analytics algorithms and pattern recognition can be used to identify lapses in HVAC performance and notify consumers as soon as a problem is detected.	Energy Portal

Company	Product	Description	Product Category
EcoFactor	Proactive Energy Efficiency Services	A service uses data collected from Internet-connected thermostats to run patented energy algorithms, and automatically minimizes homeowner energy consumption.	Energy Portal
EDF Energy	EcoManager	Wireless appliance monitor/controller	In-Home Display
Efergy	True Power Meter	Power meter energy monitor displays in kilowatts based on true power consumption reaching 99% accuracy.	In-Home Display
Efergy	Elite Classic	The elite classic is our latest and renewed version of our elite wireless power monitor updates every 10 seconds so you can instantly see the impact of turning a light on or off, using the stove top burner, or your electric clothes dryer.	In-Home Display
Efergy	E2 Classic	The e2 classic is a renewed version of our third generation of energy monitors, and includes 9 new features. The e2 will help you understand better how much energy and money you consume in your home.	In-Home Display
Efergy	Elite IR	The elite IR energy monitor is our optical generation of wireless electricity monitors. It includes an optical sensor which reads in a very accurate way the electricity consumed in your home or business.	In-Home Display
Efergy	Engage Hub	The engage hub is all the hardware you need to start monitoring your home energy use online in real-time through the engage,.	Energy Portal
eGauge	eGauge Kit	Home consumption/generation monitor with built in web-server	Energy Portal
EGO	Home Automation	Technology and manufacturer-independent HEMS	Smart Appliance
Emberlabs	Wristify	Adjusts local enviornment to determined temperatures	Smart Thermostat
Embertec	Emberplug & EmberCeptor	Fully automated power-saving plug boards	Smart Plug
Energate	Energate Home Energy Management Suite	In home display & Thermostat to create a home area network and provide energy management services to consumers and utilities	In-Home Display
Energy Inc	TED 5000 Series	Single phase residential electricity monitor	In-Home Display
EnergyAware	Neurio	Neurio is a home intelligence™ technology that makes your ordinary appliances smart and your home more efficient. Using a WiFi power sensor and a cloud service with some smart pattern detection algorithms, Neurio monitors your home's electricity to figure out what your appliances are up to - without the need to install sensors on every device.	Energy Portal

Company	Product	Description	Product Category
EnergyHub	Mercury software platform	Software to help utilities remotely monitor and manage thermostats	Data Analytics Platform
EnergySavvy	Optix Engage	Optix Engage, our innovative residential online audit, provides homeowners with an engaging, user-friendly experience and provides utility program marketers with in-depth customer intelligence.	Energy Portal
EnTek	DR load controllers	Load control unit for demand response	Load Monitor
Eyedro	Home Electricity Monitoring	Eyedro and MyEyedro are always working together to measure, analyze and store your electricity usage and cost information. The MyEyedro electricity monitoring cloud service presents your electricity data in ways that are engaging, informative and easy to understand. See real-time electricity usage and gain access to many helpful features that help you uncover waste, manage costs and take control of your electricity use.	Energy Portal
FutureDash	EnergyBuddy	Monitor energy and control smart plugs and appliances from your computer	Smart Plug
GE	Link	Connected LED light bulb at a very affordable price.	Smart Lighting
GE	In-Wall Outlet	This double outlet is designed to replace a traditional electrical outlet and connects to the existing wiring in your home. This outlet contains one Z-Wave AC outlet and one standard AC outlet. The Z-Wave outlet supports incandescent lamps, fluorescent lamps, and small appliances, and the objects you plug in extend the range of the Z-Wave network.	Smart Plug
GE Appliances	GE Brillion Profile Seriers 30"	Wirelessly control oven functions from your smartphone	Smart Appliance
Green Energy Options	Solo	Energy monitor for grid electricity, smart plugs and micro-generation	In-Home Display
Green Energy Options	Chorus	The Chorus is easy to install and works with systems where both the generation and the import meter are modern electronic meters with an LED output (a flashing light on the front of the meter, usually with ‘imp/kWh’ written next to it).	In-Home Display
Green Energy Options	Energynote	Visualise and engage with your household consumption using an easy-to-use, regularly updated and welcoming interface.	Energy Portal

Company	Product	Description	Product Category
Green Energy Options	GEO Smart Plug	You can also keep a close eye on the true cost of running appliances, as scheduling, consumption and control can all be viewed from the home PC or on the move using a smartphone.	Smart Plug
Greenwave Systems	Energy Management	HEMS for monitoring and control of devices in the home	Data Analytics Platform
GridPoint	GridPointCustomer Engagement Platform	A software-based dashboard with tools for utilities to extend customer relationships and engage customers in utility energy efficiency programs	Energy Portal
Honeywell	Lyric	Geofencing temperature control, smart cues keep you informed, motion sensing, control from anywhere, self learning	Smart Thermostat
iControl	OpenHome Platform	Enables utility-controlled demand response and consumer energy management services	Smart Home Platform
iFactor	iFactor Mobile	iFactor Mobile™ apps for smartphones provide your customers with a convenient way to manage their energy anytime, anywhere. Our	Energy Portal
IFTTT	IFTTT	Automation service for small tasks between internet-connected products and services	Web Service Platform
Insteon	Insteon Energy Display	Home energy monitor displays consumption information from up to 3 transmitting plugs	In-Home Display
Insteon	Insteon Hub	Control INSTEON light bulbs, wall switches, outlets, and thermostats at home or remotely	Smart Hub
Insteon	SynchroLinc + ApplianceLinc	Automatically shut down peripherals or to implement custom automation	Smart Plug
Intamac	Enso Platform	Smart home services can be built on the Enso platform	Data Analytics Platform
Intelligy	Intelligy System	Allows the consumer to monitor and manage consumption in the home as well as utility demand response implementation across a variety of devices	In-Home Display
Interactive Voice	IVEE voice controlled home assistant	Internet-enabled voice controlled personal assistant	Web Service Platform
Leviton	Lumina Home Control System	Energy management and lighting control	In-Home Display

Company	Product	Description	Product Category
LG	Smart ThinQ Washer Dryer	Energy conservation is important to all of us. Smart Grid technology in every LG Smart ThinQ appliance is designed to detect when power consumption in your area is at its lowest, so your appliance can operate at lower energy rates	Smart Appliance
LG	Smart ThinQ Refrigerator	Energy conservation is important to all of us. Smart Grid technology in every LG Smart ThinQ appliance is designed to detect when power consumption in your area is at its lowest, so your appliance can operate at lower energy rates	Smart Appliance
Lowes	IRIS Smart Hub	Wireless home Management Network controls a thermostat and appliances via smart plugs	Smart Hub
Lowes	IRIS Smart Plug	Add convenience of turning lamps, electronics and appliances on and off remotely	Smart Plug
Lowes	IRIS Smart Thermostat	7-Day Touch Screen Programmable Thermostat (Works with Iris)	Smart Thermostat
Lowes	Iris Platform	Home automation platform to connect and control all of your smart home devices	Smart Home Platform
Makad Energy	DreamWatts	The DreamWatts Energy Management System is a web-enabled, user-friendly system for automating commercial and residential buildings to better manage energy consumption.	Energy Portal
MiCasaVerde	Vera3 home control system	A ZigBee and Wi-Fi enabled hub to create a home area network	Smart Hub
Nest	Rush Hour Rewards	DR solution based on thermost adjustment	Data Analytics Platform
Nest	Nest Learning Thermostat	Self-optimising learning thermostat	Smart Thermostat
Nuri Telecom	AiMiR Home Energy Management Portal	HEMS to monitor and control home energy consumption with real-time usage monitoring, budgeting, thermostat and appliance control and demand response notifications from the utility	Smart Hub
Onzo	Onzo Display	Onzo offers powerful analytics tools for electricity providers and energy monitoring for their customers	Energy Portal
Opower	Flex5	Opower 5: Flex combines cutting-edge importers and analytics engines with design-driven products to provide an end-to-end customer experience. Now with more visibility, flexibility, and personalization for utilities.	Data Analytics Platform

Company	Product	Description	Product Category
OPower	Demand Respons Solution	Opower's demand response solution allows utilities to deploy cost-effective and reliable demand response programs across everyone in their territory, with or without in-home devices.	Data Analytics Platform
OPower	Smart Thermostat Solution	Utility-integrated thermostat platform designed to engage customers, deliver measurable results, and increase program participation.	Data Analytics Platform
OPower	Energy Efficiency Solution	Opower delivers large-scale energy savings quickly and reliably, yielding more kWh across a territory than other approaches and allowing utilities to meet ambitious energy efficiency mandates while maintaining cost effectiveness.	Energy Portal
OWL	micro+	Home energy monitor	In-Home Display
OWL	Intuition Family	A modular, internet connected monitoring and control system that can manage electricity supply, solar PV generation, central heating and hot water	Energy Portal
P3 International	Kill A Watt CO2 Wireless MSRP	displays energy use of things plugged into smart plugs	In-Home Display
P3 International	Kill A Watt	Appliance energy monitor for determine usage of plugged devices.	Load Monitor
P3 International	Save A Watt Phantom Power Indicator	Displays standby power levels for plugged in devices	Load Monitor
P3 International	Save A Watt Edge	Programmable standby killer with occupancy sensor	Smart Plug
Panasonic	SMARTHEMS	Panasonic is developing smart houses with SMARTHEMS technology	Smart Home Platform
People Power Co	Presence Pro Energy	Mobile real-time, whole home energy monitoring and smart plug control.	Energy Portal
Phillips	Hue	Smart lighting with advaced control and color capabilities	Smart Lighting
Plugwise	Plugwise Home	Monitor and control home appliances from your computer	Smart Plug
Powerhouse Dynamics	eMonitor	Energy monitor with data analytics and thermostat control	Smart Thermostat
PowerWatch	PowerWatch HEMS	Home energy Management Portal	Energy Portal
Rainforest Automation	EMU2	Links wirelessly to the smart meter to show consumption information and messages from the utility	In-Home Display
Rainforest Automation	EAGLE Home Energy Gateway	Links wirelessly to your smart meter to provide access to energy information	Smart Hub

Company	Product	Description	Product Category
RCS Technology	RCS Whole home energy monitoring and control	Home energy monitoring and control with demand response capability	Smart Thermostat
Reliance Controls	AmWatt Appliance Load Tester	This tester displays a quick readout of the amps or watts used by plug-in appliances	Load Monitor
Revolv	Revolv Device	Smart Hub to connect all your connected home things	Smart Hub
Revolv	Revolv Hub	Smart Hub to connect all your connected home things	Smart Hub
Revolv Inc.	Revolv Smart Home Automation Solution	Smart phone app to control and view your Revolv home control system	Energy Portal
Rosewill	RHSP-130001	Electric load meter and energy monitor	Load Monitor
Savant	Savant Automated Home	Enable homeowners to monitor and reduce energy consumption via home automation	Smart Home Platform
Schneider Electric	Wiser In-Home Display	Allows homeowners to easily monitor and control home energy use through informative displays and color changing screens that alert users of changes in home energy use and pricing.	In-Home Display
Schneider Electric	Schneider Wiser Home	Home demand Management Portal for utilities and consumers	Energy Portal
Schneider Electric	Wiser Smart Plug	The Wiser™ Smart Plug is a part of Schneider Electric's growing family of energy management products.	Smart Plug
Schneider Electric	Wiser Smart Thermostat	The Wiser™ Smart Thermostats are programmable communicating thermostats that manage HVAC home energy use.	Smart Thermostat
Secure	Puffin	Electricity usage information is displayed via a large high resolution graphical back-lit touch-screen display.	In-Home Display
Secure	Pipit 500	Pipit 500 is an in-home display that will allow you to save up to 12% off your energy bill. The Pipit 500 collects energy usage information from your Smart Meter and displays it on a LCD touch screen.	In-Home Display
Sequentric	Senquentric System	Management Network to allow demand response applications	Smart Home Platform
Silver Spring Networks	CustomerIQ Energy Portal	CustomerIQ provides tools for residential and commercial customers to reduce consumption, save money, and help the environment and supports the Green Button initiative for simple data access.	Energy Portal
Simple Energy	Engagement Platfrom	The Simple Energy engagement platform offers a range of experiences to engage more people.	Energy Portal
Smartenit	Harmony Gateway	A home area network to integrate smart energy devices	Smart Hub

Company	Product	Description	Product Category
SmartThings	SmartSense	Extreme temperatures and humidity levels can freeze pipes, create leaks, encourage mold, and cause thousands of dollars worth of damage.	Smart Appliance
SmartThings	SmartThings Hub	The Brain of the smarthings platform	Smart Hub
SmartThings	SmartPower Outlet	Plug lamps, electronics, and small appliances into this protable zipbee based outlet	Smart Plug
SmartThings	SmartThings Mobile	Smartphone app for contorlling the SmartThings connected devices	Energy Portal
SmartThings	SmartThings Platform	Home automation platform to connect and control all of your smart home devices	Smart Home Platform
SolarCity	PowerGuide	Energy monitoring service	Energy Portal
STACK	Alba	A lightbulb that is smarter than you	Smart Lighting
SunPower	Residential Monitoring	See solar output and house energy usage	Energy Portal
swisscom	myStrom	Control and schedule a smart plug network	Smart Plug
swisscom	BeSmart	Opt-in demand response in exchange for energy management services	Energy Portal
Tendril	Tendril Energy Services Management	Energy providers rely on the Tendril Energy Services Management (ESM) Platform to reduce peak loads, lower costs and maintain grid reliability.	Data Analytics Platform
Tendril	Demand Respons Solution	Demand response solution that enables energy reduction during peak loads	Energy Portal
Tendril	Energy Efficiency Solution	EE solution for behavior change and leading to reduce energy consumption	Energy Portal
Tenrehte	PICOwatt	Plug load control and monitoring	Smart Plug
Thinkeco	Gateway	Connect your modlets and smartACs to the ThinkEco cloud with a USB or Ethernet Gateway. Each Gateway can manage up to 23 ThinkEco devices in any combination of modlets, modlet BNs, and smartAC remotes.	Smart Hub
Thinkeco	Smart AC	ThinkEco's smartAC kit brings modlet smarts to all plug-in air conditioners. In addition to minute-level energy data capture and setting a customized schedule to automatically turn A/Cs on and off, set your desired room temperature using the smartAC thermostat to stay cool while saving energy.	Smart Plug

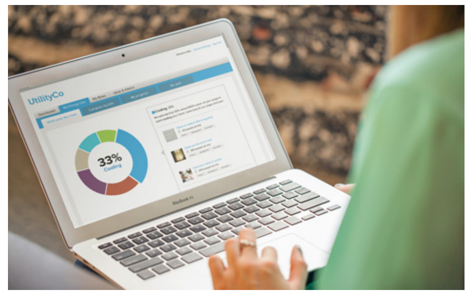
Company	Product	Description	Product Category
Thinkeco	the modlet BN	The modlet BN, pronounced "bean", is the single socket version of the modlet. Like the modlet, the modlet BN measures minute-level power use and can be programmed to turn on and off according to your personalized schedule.	Smart Plug
Thinkeco	Modlet	Provides remote metering of plug power consumption in real time and enables users to set saving schedules to better control their energy use and quantify savings	Smart Plug
Thinkeco	Monitoring App	Energy use, modlet configurations and demand response participation	Energy Portal
Tri Cascade	i-bright7	Smart Surge Protector	Smart Plug
Tri Cascade	Powerstrip+	Smart Powerstrip with IR and Movement sensors.	Smart Plug
U-Vue	Single Socket	Monitor energy usage of the socket	Load Monitor
Vera	Smart Contorller	VeraLite is a powerful control gateway designed to connect to your existing Wi-Fi router. VeraLite runs the same home control engine with all the capabilities of the larger Vera3, and it is perfect for users with small to medium sized homes.	Smart Hub
Vera	Smart Energy Switch	The Smart Energy Switch measures the energy used by any device you plug it into (washing machine, DVD player, floor lamp, etc.). T	Smart Plug
Vivint	Vivint Energy Management	Home energy management and security network	Smart Home Platform
Watts Up?	Watts up? Plug Load Meters	With simple its simple operation, one can quickly and accurate monitor different plug load to determine their power consumption.	Load Monitor
Wattsclever	Wireless Energy Monitor	Energy-Control Monitors allow you to monitor the electricity consumption of your home and office and the equipment and appliances you and have.	In-Home Display
Wattstopper	Isole IDP-3050 Power Strip	Turns plug load devices on and off based on occupancy	Smart Plug
Wattvision	Wattvision 2	Easy to use hardware and software to get your real time energy use data on the web and phone	Energy Portal
Whirlpool	Smart Washer	Makes it easy to know when your clothes are clean, manage energy usage and even control every load–anytime, anywhere	Smart Appliance
Whirlpool	Smart Dryer	Makes it easy to know when your clothes are clean, manage energy usage and even control every load–anytime, anywhere	Smart Appliance

Company	Product	Description	Product Category
Whirlpool	Smart Refrigerator	Lets you know if the power goes out, helps manage your drinking water and control your temperature settings	Smart Appliance
Whirlpool	Smart Dishwasher	Lets you know when your dishes are done, helps you manage energy usage and control your console	Smart Appliance
Wink	Relay	Wall mount touchscreen display to provide control on all wink devices connected to your home. Also it has 2 light switches.	In-Home Display
Wink	Connected Home Hub	Connects all home wink devices for control and feedback apllications	Smart Hub
Wink	GE Tapt Switch	Smart light switch that is very similar to traditional light switches but enables control from wink portals	Smart Plug
Wink	Wink App	Home automation mobile app to manage wink connected products	Energy Portal
Wink	Wink Platform	Home automation platform to connect and control all of your smart home devices	Smart Home Platform

Appendix B: Brief Product Reports

Energy Portal

Opower: Energy Efficiency Solution



Target Market: Utilities
User Interface: Web portal, Mailed report
Requirements: A utility partner and integration with the smart meter
Protocol/Platform: N/A
Cost: Contact company

About Opower
Opower partners with utility companies to provide enhanced billing information to custo reduce energy consumption. Opower currently works with 95 utilities and has ov employees across offices in Arlington, Virginia, San Francisco, London, Singapore and T

Product Description
Opower's energy efficiency solution is web portal that provides more detailed consumption information to residential customers and small businesses in the form of a r mailed statement and utility website. The utility will supply the information to Opower analytics engine will allow for "batch analysis," the capability for millions of homes usi AMI and standard metering data to obtain the most accurate energy-use assessments.

Feedback Features
Reports show energy and gas usage over the past year and compare it to others neighborhood. Dollar amounts are also available in terms of amount saved. Targets can set and the reports will reflect the progress working towards those goals. Repo customizable per the utility's needs and goals.

Control Features
None

Sources: http://opower.com/solutions/energy-efficiency - November, 2014
http://www.opower.com/company - November, 2014
Image Credit: http://opower.com/solutions/energy-efficiency

C3 Energy: Residential Solution

Target Market: Utilities
User Interface: Web portal
Requirements: Utility Partner
Protocol/Platform: N/A
Cost: Contact company

About C3 Energy
C3 Energy offers several services designed to enhance the benefits of the smart grid to utilities and their customers. Services offered by C3 Energy integrate large amounts of disparate data and provide real-time information via display portals.

Product Description
C3 Energy's residential solution aggregates data from all relevant grid operational systems to provide customers with digital portals that give energy use information and recommendations. C3 Energy Customer Analytics provides utility customers with energy usage data that includes industry benchmarks, weather records, and building characteristics to enable customers to better understand and reduce their energy use

Feedback Features
From the web portal, utility customers can view detailed energy use information and receive recommendations. C3 Energy also helps utilities track the impact of targeted energy savings recommendations and rebates.

Control Features
None

Sources : http://www.c3energy.com/ - November, 2014
Image Credit: http://www.c3energy.com/

SmartThings: SmartThings Mobile

Target Market: Residential Customer
User Interface: Mobile app
Requirements: Compatible household devices, SmartThings Hub
Protocol/Platform: N/A
Cost: Free

About SmartThings
SmartThings is a technology company owned by Samsung that specializes in smart home technologies based in Washington, DC.

Description
SmartThings Mobile is a mobile app that uses the SmartThings smart hub to connect with SmartThings enabled devices and appliances in a user's home, allowing them to monitor and control those devices and appliances from their smartphone or tablet. The app is compatible with both Apple and Android smartphones.

Feedback Features
The app works with the SmartThings hub SmartSense Presence sensor to enable users to receive notifications when someone arrives or leaves the home, when doors or windows are opened or closed, or when valuable items are moved.

Control Features
Users can use the app to remotely control household devices and appliance connected to compatible sensors.

Sources: https://itunes.apple.com/us/app/smartthings-mobile/id590800740?mt=8 - November, 2014
http://www.smartthings.com/ - November, 2014
Image Credit: http://techcrunch.com/2013/12/05/smartthings-new-iphone-app/

Belkin: Conserve Insight Energy-Use Monitor

Target Market: Residential Users
User Interface: Display on device
Requirements: None
Protocol/Platform: None
Cost: $29.99

About Belkin
Belkin is a consumer electronics manufacturer based in Los Angeles, California. Their product mix includes wireless home networking devices, mobile accessories, energy management devices, and more.

Description
The Conserve Insight Energy Use Monitor by Belkin is a load monitor that displays the energy use, cost, and CO_2 emissions of plug in appliances. To view the energy use, cost, or CO_2 emissions of a plug-in appliance, the user plugs the appliance into the Conserve Insight's plug and usage information appears on the screen of the attached display.

Feedback Features
The Conserve Insight can show predicted monthly or yearly CO_2 emissions and cost associated with powering the connected appliance based on the power being consumed at a given moment. If an appliance is left plugged into the Conserve Insight for over 75 minutes, the monitor will go into averaging mode, calculating cost and CO_2 values based on the average power consumed over the time the appliance as been plugged in.

Control Features
None

Sources: Conserve Insight Energy Use Monitor Users Manual - November, 2014
http://www.belkin.com/conserve/insight/ - November, 2014
Image Credit: http://www.belkin.com/conserve/insight/

Reliance Control: AmWatt Appliance Load Tester

Target Market: Residential Users
User Interface: Display on device
Requirements: None
Protocol/Platform: None
Cost: ~$30

About Reliance Control
Reliance Control is an electronics company based in Racine, Wisconsin. Reliance Control's product mix includes inverters, heavy duty time clocks and controls, generator accessories, power cords, and home monitoring systems.

Description
Reliance Control's AmWatt Appliance Load Tester is a load monitor that measures the amps and watts of any appliance plugged into it. To view the energy use of a plug-in appliance, the user plugs the appliance into the back of the AmWatt's display.

Feedback Features
The display shows the numeric reading of either amps or watts in real time. A slide-switch action instantly converts the reading between Amps and Watts. The cord that connect AmWatt's display monitor to its plug cord can reach up to 26 inches long.

Control Features:
None

Sources: http://www.amazon.com/Reliance-Controls-THP103-Generator-Appliance/dp/B000G7TKCG - November, 2014
http://www.reliancecontrols.com/ProductDetail.aspx?THP103 - November, 2014
http://www.northerntool.com/shop/tools/product_200321255_200321255 - November, 2014

Image Credit: http://www.northerntool.com/shop/tools/product_200321255_200321255

P3 International: *Kill-A-Watt*

Target Market: Residential Customers
User Interface: Display on device
Requirements: None
Protocols/Platforms: None
Cost: $20-$30

About P3 International
P3 International is an electronics manufacturer based in New York, NY.

Description
P3 International's Kill-A-Watt is a loaf monitor that is designed to measure and display the energy use of plug in appliances. The Kill-A-Watt simply plugs into a wall outlet. To measure energy use, appliances are plugged into the Kill-A-Watt's outlet.

Feedback Features
The Kill-A-Watt displays energy use information numerically on an LCD screen. The user can configure the Kill-A-Watt to display energy either in units of volts, amps, Hertz, kilowatts, or kilowatt hours by using the buttons on the display. The Kill-A-Watt can also be used to calculate the running cost of appliances and to check the quality of an appliance's power.

Control Features
None

Sources
http://www.p3international.com/brochures/p4400.pdf - November, 2014
http://www.amazon.com/P3-P4400-Electricity-Usage-Monitor/dp/B00009MDBU - November, 2014

Image Credit
http://www.amazon.com/P3-P4400-Electricity-Usage-Monitor/dp/B00009MDBU

Rainforest Automation: *EMU-2*

Target Market: Residential Customers
User Interface: Display on device
Requirements: Zigbee certified smart meter
Protocols/Platforms: Zigbee
Cost: $69.99

About Rainforest Automation
Rainforest Automation is a private company based in Vancouver, Canada that specializes in energy management products and software for utility customers.

Description
Rainforest Automation's EMU-2 is an in-home display that shows whole-home energy use in real time. EMU-2 can be plugged into a standard AC outlet or run on two AAA batteries. It connects wirelessly to the user's smart meter to measure and display energy use information and works with all certified Zigbee smart meters.

Feedback Features
The EMU-2 displays current whole home energy use and updates every 4-30 seconds. Users can also use the buttons at the side of the display to view total daily energy, total monthly energy use, the current price of electricity, as well as messages from the utility. The monitor also includes "stoplight" indicators, which can be programmed to alert the user of peak-use events and other pricing information. The back of the EMU-2 has built in magnets and a keyhole so that it can be mounted to a wall or metal surface

Control Features
None

Sources: http://rainforestautomation.com/wp-content/uploads/2014/02/emu2_datasheet_6.pdf - November, 2014
http://rainforestautomation.com/wp-content/uploads/2014/02/emu-2_product_summary_1.3s.pdf - November, 2014
http://www.amazon.com/Rainforest-EMU-2-Energy-Monitoring-Unit/dp/B00BGDPRAI - November, 2014
Image Credit: http://rainforestautomation.com/wp-content/uploads/2014/02/emu2leftsmall.jpg

Wink Inc: *Relay*

Target Market: Residential Customers
User Interface: Touchscreen
Requirements: Wink Hub, Wink App, and wink compatible appliances/devices
Platforms/Protocols: WiFi, Z-wave, Zigbee, and Bluetooth
Cost: $300

About Wink
Wink is a subsidiary of Quirky that specializes in energy management software and products for the home.

Description
Wink's Relay is an in-home display that runs the Wink App to enable the user to monitor and control all their Wink-connected devices. Relay communicates with all compatible devices in a home. Compatible devices are connected to the Wink App via the Wink Hub. Any devices or appliances that use one of these communications protocols can be connected to the Wink Hub. Wink also sells compatible appliances, thermostats, lighting, etc. on their website.

Feedback Feature
Relay can be used to track costs and view the usage of connected appliances

Control Features
Relay includes two switches that can act either as light switches to turn on or off wink compatible lighting, or can be configured to turn on and off other connected devices/appliances in the home. Because Relay used the Wink App, it has the same capabilities as the app, which includes the ability to set timers and create schedules for device/appliances.

Sources: http://www.wink.com/products/wink-relay-touchscreen-controller/ - November, 2014
http://www.wink.com/products/wink-hub/ - November, 2014
http://www.wink.com/about/ - November, 2014
Image Credit: http://relay.winkapp.com/img/products/03-benefits-01-app.png

Energy Inc.: *TED 5000-C*

Target Market: Residential Customers
User Interface: Display on device, computer software
Requirements: None
Platforms/Protocols: None
Cost: $239.95

About Energy Inc.
Energy Inc. is a manufacturer of in-home energy displays and energy management software based in Charleston, South Carolina.

Description
The Energy Detective (TED) 5000-C, is an in-home display that is installed through the electrical panel rather than the meter, and so is compatible with any utility in the United States.
There are four components to the TED 5000-C: CT clamps, the MTU, the gateway, and the display. The CT clamps and the MTU are installed in the electric panel where they measure household energy use. The MTU send data to Gateway through the powerline and Gateway, in turn, transmits data to the display via Zigbee.

Feedback Features
TED 5000-C displays whole home energy use in real time and can connect to wireless routers or directly to computer via Ethernet so that energy use data can be view on a personal computer using Footprints software. Gateway's built in web server also allows it to connect to any internet source.

Control Features
None

Sources: http://www.theenergydetective.com/b-5000c.html - November, 2014
https://www.theenergydetective.com/downloads/QuickStartInstallation%20v110711.pdf - November, 2014
Image Credit: http://www.theenergydetective.com/5000c

GE: Brillion Profile Oven

Target Market: Residential Customers
User Interface: Display on device, Mobile app
Requirements: WiFi
Platforms/Protocols: WiFi
Cost: $3,500

About GE
General Electric (GE) is a diversified technology and financial services company based in New York, NY. Their products and services range from aircraft engines, power generation, water processing, and household appliances to medical imaging, business and consumer financing and industrial products.

Description
GE's Brillon Profile Oven is a smart appliance that can be monitored and controlled remotely by the user via GE's Brillon mobile app. The oven also has embedded control panels displays.

Feedback Features
Users can receive notifications via GE's Brillon mobile app when items in the oven are ready

Control Features
Users can remotely change the temperature of the oven or turn it on or off via GE's Brillon mobile app

Sources: http://www.geappliances.com/connected-home-smart-appliances/ - November, 2014

Image Credit: http://www.geappliances.com/connected-home-smart-appliances/

Whirlpool: Smart Washer

Target Market: Residential Customers
User Interface: Touchscreen
Requirements: WiFi, Mobile app
Protocols/Platforms: WiFi
Cost: ~$1,700

About Whirlpool
Whirlpool is a manufacturer of household appliances based in Benton Charter Township, Michigan

Description
Whirlpool's Smart Washer with 6th Sense Live technology is a smart appliance with a built in touchscreen display. Users can remotely view and control the status of the washer via Whirlpool's mobile app. The washer also connects to the smart grid to optimize energy use and track how much energy it is using.

Feedback features
Users can access information about the status and usage of washer via the mobile app. The app also allows them to receive laundry tips and reminders about the status of the washer.

Control Features
Users can remotely control the washer on their smartphone or other compatible device via the mobile app

Sources
http://www.whirlpool.com/-[WFL98HEBU]-1021442/WFL98HEBU/ - November, 2014

Image Credit
http://www.whirlpool.com/-[WFL98HEBU]-1021442/WFL98HEBU/

LG: Smart ThinQ Refrigerator

Target Market: Residential Customers
User Interface: Touchscreen
Requirements: WiFi, Mobile app
Protocol/Platform: WiFi
Cost: $3,500

About LG
LG is a conglomerate corporation based in Seoul, South Korea.

Description
The ThinQ refrigerator is a smart appliance that allows the user to monitor expiration dates of their refrigerated food, find recipes based on ingredients they already have, and create shopping list via its embedded touchscreen display. Users can also access this information on an internet enabled device via LG's Smart Access refrigerator mobile app.

Feedback Features
Users can view energy usage of the refrigerator via the touchscreen display. Users can also check the contents of the refrigerator and track expiration dates remotely via the Smart Access mobile app.

Control Features
User can adjust the settings of their refrigerator via the Smart Access mobile app.

Sources
http://www.lg.com/us/discover/smartthinq/refrigerator- November, 2014
http://www.cnet.com/products/lg-smart-thinq-lfx31995st-refrigerator/ - November, 2014

Image Credit
http://www.lgnewsroom.com/ces2012/view.php?product_code=95&product_type=95&%20post_index=1828

Nest: Nest Learning Thermostat

Target Market: Residential Customers
User Interface: Display on device, Mobile app
Requirements: WiFi
Protocols/Platforms: WiFi
Cost: $249

About Nest
Nest is a manufacturer of programmable thermostats and smoke detectors based in Palto Alto, CA and owned by Google.

Description
The Nest Learning Thermostat is a smart thermostat that self-programs based on user behavior. Nest communicates via WiFi so that users can control and view information about the thermostat remotely.

Feedback Features
The Nest Learning Thermostat will display a leaf when the user sets it to an efficient temperature. Additionally, users can view their Nest's heating and cooling schedules as well as its historical energy usage via Nest's mobile app.

Control Features
The Nest Learning Thermostat self-programs in about one week after installation and continually adapts to user behavior. For example, the Nest Senses can sense user occupancy and will automatically adjust to avoid heating or cooling when no one is home. Nest can also be controlled remotely via the mobile app.

Sources
https://store.nest.com/product/thermostat/ - November, 2014

Image Credit
http://www.androidcentral.com/nest-thermostat

Ecobee: *Ecobee 3*

Target Market: Residential Customers
User Interface: Touchscreen , Mobile app
Requirements: WiFi
Protocols/Platforms: WiFi
Cost: $240

About Ecobee
Ecobee is a manufacturer of programmable thermostats based in Canada.

Description
The Ecobee 3 is a smart thermostat that self-programs based on user behavior and communicates via WiFi so that users can control and view information about the thermostat from any internet enabled device. The Ecobee 3 uses remote sensors to measure the temperature in multiple part of the home to prioritize heating and cooling in rooms that are more frequently occupied.

Feedback Features
Users can view Ecobee 3's heating and cooling schedules via the Ecobee mobile app.

Control Features
The Ecobee 3 self-programs based on user behavior and can sense user occupancy to automatically adjust to avoid heating or cooling when no one is home. Users can also remotely control Ecobee 3's heating and cooling schedules via the mobile app.

Sources
http://shop.ecobee.com/products/ecobee-3 - November, 2014

Image Credit
http://shop.ecobee.com/products/ecobee-3

Honeywell: *Lyric*

Target Market: Residential Customers
User Interface: Touchscreen, Mobile app
Requirements: WiFi
Protocols/Platforms: WiFi
Cost: $280

About Honeywell

Honeywell International Inc. (Honeywell) is a diversified technology and manufacturing company, based in Morristown, NJ.

Description

The Lyric is a smart thermostat that can be remotely controlled by users and self-program based on learned user-behavior. Lyric can automatically regulate temperature when the user leaves the home, optimize the home for comfort based on both temperature and humidity, and keep the user informed of routine maintenance (e.g. change HVAC air filter).

Feedback Features

Users can view Lyric's heating and cooling schedules via Lyric's mobile app.

Control Features

The Lyric self-programs based on user behavior and can sense user occupancy (geofencing) to automatically adjust to avoid heating or cooling when no one is home. Users can also remotely control Lyric's heating and cooling schedules via the mobile app.

Sources
http://lyric.honeywell.com/ - November, 2014

Image Credit
http://cdn1.appleinsider.com/gallery/9553-1325-App_Thermostat-l.png

Belkin: WeMo LED Lighting Set

Target Market: Residential Customers
User Interface: Mobile App
Requirements: WiFi
Protocols/Platforms: WiFi
Cost: $99.99

About Belkin
Belkin is a consumer electronics manufacturer based in Los Angeles, CA. Their product mix includes wireless home networking devices, mobile accessories, energy management devices, and more.

Description
Belkin's WeMo LED lighting set is a smart lighting system that is energy efficient and can be control remotely via the compatible WeMo app, which utilizes the user's existing Wi-Fi network.

Feedback Features
Users can view the status of their WeMo lights from any internet enabled device via the WeMo app.

Control Features
The WeMo lights can be turned on and off, dimmed, and scheduled remotely via any internet enabled device via the WeMo app.

Sources: http://www.belkin.com/us/F5Z0489-Belkin/p/P-F5Z0489/ - November, 2014
Image Credit: http://www.belkin.com/us/F5Z0489-Belkin/p/P-F5Z0489/

Phillips: HUE Lighting

Target Market: Residential Customers
User Interface: Mobile app
Requirements: None
Protocols/Platforms: WiFi
Cost: $199.95

About Phillips
Royal Phillips (Phillips) is a technology company based in the Netherlands whose products are focused in the areas of healthcare, consumer lifestyle, and lighting.

Description
Phillips's HUE lighting set is a smart lighting system that can dim, flash, and pulse and can be used in a standard light fittings. The lights work with the HUE Bridge, which connects to the user's WiFi, along with the HUE mobile app to allow users to remotely control their lights via their smartphone or tablet.

Feedback Features
Users can view the status of their lights via the mobile app.

Control Features
The lights can be turned on and off, dimmed, and scheduled remotely via the mobile app.

Sources
http://www2.meethue.com/en-us/what-is-hue/the-system/ - November, 2014
http://store.apple.com/us/product/HA779VC/A/philips-hue-connected-bulb-starter-pack - November, 2014
http://www.philips.com/about/company/companyprofile.page - November, 2014

Image Credit
http://www2.meethue.com/en-us/what-is-hue/get-started/

GE/Wink: Connected Light Bulb

Target Market: Residential Customers
User Interface: Mobile app
Requirements: Wifi or Zigbee, Wink Hub or Relay
Protocols/Platforms: Zigbee, WiFi
Cost: $15.00 - $25.00

About GE
General Electric (GE) is a diversified technology and financial services company based in New York, NY. Their products and services range from aircraft engines, power generation, water processing, and household appliances to medical imaging, business and consumer financing and industrial products.

Description
GE's Link light bulbs are smart lights that connects to the Wink App via Wink's smart hub so that users can control the lights from their smartphone. Users can sync the Link lights with other smart products as well as dim and automate them.

Feedback Features
Users can view the status of their lights via the mobile app.

Control Features
The lights can be turned on and off, dimmed, and scheduled remotely via the mobile app and Wink's in-home display (Relay).

Sources
http://gelinkbulbs.com/ - November, 2014
http://www.wink.com/products/ge-link-connected-led-bulbs/ - November, 2014

Image Credit: http://www.wink.com/products/ge-link-connected-led-bulbs/

Wink: Tapt Switch

Target Market: Residential Customers
User Interface: Mobile app
Requirements: Wink Hub or Relay, WiFi, and Wink compatible devices
Protocol/Platform: WiFi
Cost: $60

About Wink
Wink is a subsidiary of Quirky that specializes in energy management software and products for the home.

Description
Wink's Tapt is a smart switch that is designed to replace a traditional, basic single-pole wall switch with two smart switches that give the user one-touch control over connected devices. Tapt Switches can be set to control any compatible devices within in a home and are compatible with the Wink app.

Feedback Features
Users can use Wink's mobile app to view the status of devices connected to the Tapt Switch.

Control Features
The Tapt Switch can be set to automatically turn connected devices on or off via the mobile app.

Source
http://www.wink.com/products/quirkyge-tapt-light-switch/ - November, 2014

Image Credit
http://www.wink.com/products/quirkyge-tapt-light-switch/

Belkin: WeMo Switch

Target Market: Residential Customers
User Interface: Mobile app
Requirements: WiFi
Protocols/Platforms: WiFi
Cost: $49.99

About Belkin
Belkin is a consumer electronics manufacturer based in Los Angeles, California. Their product mix includes wireless home networking devices, mobile accessories, energy management devices, and more.

Description
Belkin's The WeMo Switch is a smart switch that uses an existing WiFi network to provide wireless control of whatever household device or appliance is plugged into it. The compatible WeMo app enables users to remotely view, control, and schedule devices plugged into the WeMo switch.

Feedback Features
Users can view the status of device Devices plugged into the WeMo Switch from any internet enabled device via the WeMo app.

Control Features
Devices plugged into the WeMo Switch can be turned on and off remotely by users via any internet enabled device via the WeMo app.

Sources: http://www.belkin.com/us/p/P-F7C027/ - November, 2014

Image Credit: http://www.belkin.com/us/p/P-F7C027/

ThinkEco: *Modlet*

Target Market: Residential Customers
User Interface: Mobile app, Web portal
Requirements: WiFi or Zigbee, ThinkEco Gateway or USB
Protocols/Platforms: Zigbee, WiFi
Cost: $50 (USB gateway) or $155 (ethernet gateway)

About ThinkEco
ThinkEco is a green technology company based in New York, NY. They developed the Modlet to bring energy awareness and device-level energy management to home and office environments.

Description
The ThinkEco Modlet is a smart plug that fits into a standard 120V/15A outlet. The Modlet contains two sockets, each of which has individual minute-level power measurement and is individually programmable for stopping plugged-in device power waste.

Feedback Features
Users can view the status and energy consumption of devices plugged into the Modlet at minute level data via ThinkEco's web portal (mymodulet.com) and the ThinkEco mobile app.

Control Features
Devices plugged into the Modlet can be turned on and off remotely by users via the web portal via the ThinkEco app.

Sources
http://www.thinkecoinc.com/products/the-modlet/ - November, 2014
http://www.thinkecoinc.com/products/software/ - November, 2014

Image Credit
http://www.thinkecoinc.com/products/the-modlet/

Lowes: Iris Smart Hub

Target Market: Residential Customers
User Interface: Mobile app, email, text
Requirements: Z-Wave, Zigbee, or Wifi, Compatible Iris device(s)
Protocols/Platforms: Z-Wave, Zigbee, Wifi
Cost: $99

About Lowe's
Lowe's is a chain of home improvement stores with headquarters in Mooresville, NC. Lowe's 1,745 stores serve homeowners, renters, and commercial business customers.

Description
The Iris Smart Hub is a smart hub that makes up the centerpiece of the Iris line of smart home devices that enables communication and intelligence among those devices.

Feedback Features
Users can view the energy use and settings of their connected household devices and appliance via the Iris mobile app and receive notifications about the status of their connected devices via text or email.

Control Features
Users can remotely control connected household devices and appliance via the mobile app.

Sources
http://www.lowes.com/pd_388556-41166-HUB520_0__?productId=3735301 - November, 2014
http://www.lowes.com/cd_Services_945017324_?cm_sp=NoDivision-_-IrisLP|A3-_-Other|Services_Plan – November, 2014

Image Credit
http://www.lowes.com/pd_388556-41166-HUB520_0__?productId=3735301

Wink: Wink Smart Hub

Target Market: Residential Customers
User Interface: Mobile app
Requirements: WiFi or Zigbee, Wink devices
Protocols/Platforms: WiFi, Zigbee
Cost: $50

About Wink
Wink is a subsidiary of Quirky that specializes in energy management software and products for the home.

Description
The Wink Smart Hub is device that makes up the communication centerpiece of the Wink product ecosystem. It connects all wink enabled devices via zigbee to form a streamlined home automation platform. It is essential for wink smart home devices and enables communication and intelligence among those devices.

Feedback Features
Users can view the energy use and settings of their connected household devices and appliance via Wink's mobile app.

Control Features
Users can remotely control connected household devices and appliance via the mobile app.

Sources
http://www.wink.com/products/wink-hub/ - November, 2014

Image Credit
http://www.amazon.com/Wink-Connected-Home-Hub-PWHUB-WH01/dp/B002YVHYF

SmartThings: SmartThings Hub

Target Market: Residential Customers
User Interface: Mobile app
Requirements: ZigBee, Z-Wave, or WiFi, compatible sensors
Protocols/Platforms: ZigBee, Z-Wave, WiFi
Cost: $99

About SmartThings
SmartThings is a technology company owned by Samsung that specializes in smart home technologies based in Washington, DC.

Description
SmartThings's SmartThings Hub connects all SmarthThings compatible sensors around the user's home so that they can receive notifications and remotely control their home's security and energy usage. The SmartThings Hub ships with all necessary hardware and requires no wiring.

Feedback Features
The hub can be paired with SmartThings's SmartSense Presence sensor so that the user can receive notifications via the SmartThings app when someone arrives or leaves the home. The hub can also be paired with SmarthThings's SmartSense Multi sensor so that users can receive text notifications when doors or windows are opened or closed or when valuable items are moved.

Control Features
Users can remotely control household devices and appliance connected to compatible sensors via the mobile app.

Sources: https://shop.smartthings.com/#!/products/smartthings-hub - November, 2014

Image Credit
http://ecx.images-amazon.com/images/I/31g14%2Bt1mEL._SY355_.jpg

Apple: HomeKit

Target Market: Residential Users
User Interface: iOS devices
Requirements: iOS 8 (or later)
Protocol/Platform: WiFi, Bluetooth
Cost: Bundled with iOS device

About Apple
Apple is a multinational corporation based in Cupertino, California that designs, manufactures, and markets mobile communication and media devices, personal computers, and digital music players, and a variety of related software, services, and peripherals.

Product Description
Apple's Homekit is an in-development home automation framework built into iOS 8 for communicating with and controlling connected accessories in a user's home. Users can configure HomeKit devices in their home and create actions to control those devices.

Feedback Features
HomeKit can be used to get feedback on any HomeKit enabled device.

Control Features
HomeKit enables advanced control features using actions controls as well as group action controls. Users can also control their HomeKit devices via Siri.

Sources
https://developer.apple.com/homekit/ - November, 2014

Image Credit
https://developer.apple.com/homekit/

Quirky: *Wink*

Target Market: Residential Users
User Interface: Mobile app
Requirements: WiFi, Bluetooth, Zigbee, or Z-Wave, Wink hub, Wink app
Protocol/Platform: WiFi, Bluetooth, Zigbee, Z-Wave
Cost: Free

About Quirky/Wink
Wink is a subsidiary of Quirky that specializes in home automation products.

Product Description
Wink is a home automation service that enables users to manage the lights, power, and security within their home. Wink connects all smart home devices via the Wink app, enabling users to monitor and manage all their smart devices.

Feedback Features
Users can view the status of their connected smart devices via the Wink app or Wink's in-home display, Relay.

Control Features
Wink enables advanced control features using actions controls as well as group action controls. Users can remotely turn on or off or adjust the settings of their connected smart devices via the app or Wink's Relay display.

Sources: www.wink.com - November, 2014
Image Credit: www.wink.com

Lowe's: *Iris*

Target Market: Residential Users
User Interface: Mobile app
Requirements: WiFi, Z-Wave, or Zigbee, Iris Smart Hub
Protocol/Platform: WiFi, Z-Wave, Zigbee
Cost: $0.00 - $9.99 per month

About Lowes
Lowe's is a chain of home improvement stores with headquarters in Mooresville, NC. Lowe's 1,745 stores serve homeowners, renters, and commercial business customers.

Product Description
Iris enables users to monitor and maintain their connected household devices via the Iris mobile app. Users can adjust the lights, control the climate, manage the security system, and lock and unlock doors all from any internet enabled device.

Feedback Features
Users can view the status of their connected devices via the mobile app. Users can also receive email, text, and voice notifications when devices settings change.

Control Features
Users can turn on or off or adjust the settings of their connected devices via the mobile app. Users can also use voice control to manage their devices via the Iris app.

Sources
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https://www.google.com/finance?q=lowes&ei=RRV8VJHrIObiiwKqqoG4BA - November, 2014
Image Credit
http://www.engadget.com/2012/11/14/verizon-brings-wireless-monitoring-service-to-lowes-iris-smart/

Tendril: Energy Services Management Platform (ESM)

Target Market: Energy Providers
User Interface: Web Portal, mailed report
Requirements: Utility Partner
Protocols/Platforms: None
Cost: Contact company

About Tendril
Tendril is an energy platform company that specializes in open, cloud-based software platforms that are designed to help energy utilities give their customers better insight into their energy use.

Description
Tendril's Energy Service Management Platform (ESM) is a data analytics platform that enables utilities to provide more detailed and personalized energy use information to their customers. ESM combines meter data with customer-specific information, such as their home's square footage, age, their existing energy efficiency upgrades, and their usage history, to provide energy use information via paper or e-mailed reports and web portals. Utilities can integrate ESM with their existing web portals.

Feedback Features
Via the utility web portal, customers can view their energy use relative to other households, track top performers in their community, and ask questions to residential energy experts. ESM also employs gamification strategies; customers can earn points for completing goals and realizing energy savings

Control Features
None

Sources: http://www.tendrilinc.com/ - November, 2014
Image Credit: http://www.tendrilinc.com/how-we-do-it/engagement-channels/assessment-tools

Opower: Opower 5.5 Flex

Target Market: Utilities
User Interface: Smart device, Web portal, Mobile app, Mailed report
Requirements: A utility partner and WiFi thermostat
Protocol/Platform: WiFi
Cost: Contact company

About Opower

Opower partners with utility companies around the world to provided enhanced billing information to customers to reduce energy consumption. Opower currently works with 95 utilities and has over 500 employees across offices in Arlington, Virginia, San Francisco, London, Singapore and Tokyo.

Product Description

Opower's Flex is a cloud-based data analytics for utility customers. Flex imports large, diverse datasets into one system to provide utilities and their customers with insight into their energy use. Flex can determine and predict energy use patterns and provide personalized information to customers using specialized behavior change strategies designed to drive customer action.

Feedback Features

Customers can view their highly personalized energy use information via a variety of mediums as Flex content can be synchronized and viewed across email, mailed reports, web portals, smartphones, smart devices, and so on.

Control Features

None

Sources
http://opower.com/platform/computer-science - November, 2014

Image Credit
http://www.opower.com/

Nest: Nest Rush Hour Rewards

Target Market: Utilities and Residential Customers
User Interface: Display on device, Mobile app, Web portal
Requirements: Nest Thermostat, Partnering Utility
Protocols/Platforms: WiFi
Cost: Contact Nest

About Nest
Nest is a manufacturer of programmable thermostats and smoke detectors that is based in Palto Alto, CA and is owned by Google.

Description
Nest's Rush Hour Rewards is a data analytics platform that works with the user's Nest thermostat and utility to automatically adjust its settings based on peak use times in order to save the user money on his or her utility bill.

Feedback Features
Users will receive a notification on their Nest Thermostat, Mobile app, and/or web portal when a peak event is approaching. The day after an event, users can also view the temperatures that Rush Hour Rewards adjusted to.

Control Features
Rush Hour Rewards enables the user's Nest Thermostat to receive information from the utility and adjust its settings accordingly. The Nest will either reduce heating and cooling during a peak usage event or shift heating/cooling to before/after the event. The user can also override the settings by manually adjusting their Nest Thermostat.

Sources
https://nest.com/support/article/What-is-Rush-Hour-Rewards - November, 2014

Image Credit
https://nest.com/support/article/What-is-Rush-Hour-Rewards

IFTTT: *IFTTT*

Target Market: Residential Users
User Interface: Internet browser
Requirements: None
Protocol/Platform: None
Cost: Free

About IFTTT
If This Then That (IFTTT) is a San Francisco based start up that provides automation service for small tasks between internet-connected products and services. IFTTT has raised $37 million from tier 1 venture capitalists and has over 150 connected channels.

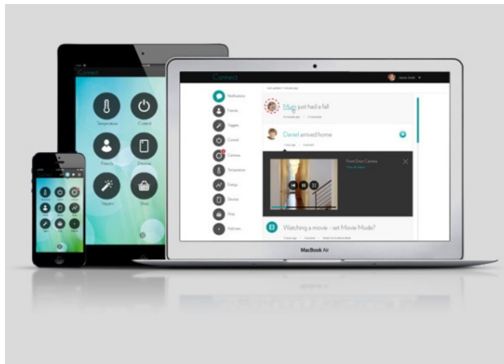
Product Description
IFTTT is a service that enables users to create connections with "if this, then that" statements which IFTT refers to as "recipes." The "this" part of the statement refers to a trigger, such as "I check in on Foursquare." The "that" part of the statement refers to an action, such as "send me a text message." Recipes can be turned off and back on. When turned back on, they will pick up as if just created. IFTT connects with 151 channels, including Facebook, LinkedIn, Nest Thermostat, Revolv, and more.

Feedback Features
IFTTT recipes can provide users with feedback for any of the 151 connected channels on the service.

Control Features
IFTTT recipes can provide control for any of the 151 connected channels on the service. The service provides event driven control functionality. For example, "If raining then blue light" will trigger the user's smart light to change its color to blue when it's raining.

Sources: https://ifttt.com/wtf - November, 2014
https://ifttt.com/channels - November, 2014
Image Credit: www.ifttt.com

Intamac: *ENSO*



Target Market: Developers, Residential Users
User Interface: Web portal, Mobile app, Computer software
Requirements: None
Protocol/Platform: None
Cost: Contact company

About Intamac
Intamac is an information and technology services company based in the UK. Intamac's web-based smart home services are offered globally.

Product Description
Intamac's Enso is a cloud-based platform that connects smart home devices to the internet so that users can monitor and manage their devices remotely. Enso is "product and RF protocol agnostic" because it utilizes an API library to enable developers to integrate almost any product

Feedback Features
ENSO enables users (and operators) to monitor connected devices via web portals and mobile apps for service propositions. Users can also set up notifications and alters.

Control Features
ENSO enables full two-way control of connected devices via a web portal and/or mobile app. Users can automate devices and manually control them from any location.

Sources
http://www2.intamac.com/what-we-do - December, 2014
http://www2.intamac.com/how-we-do-it - December, 2014
https://www.linkedin.com/company/144989 - December, 2014

Image Credit
http://www2.intamac.com/

Greenwave Systems: *Energy Management*

Target Market: Developers, Residential Users
User Interface: Web portal, Mobile app, Computer software
Requirements: None
Protocol/Platform: None
Cost: Contact company

About Greenwave Systems
Greenwave Systems is a global software and information technology services company with locations in California, Singapore, and Denmark.

Product Description
Greenwave Systems' Energy Management platform interfaces with Meter Data Management systems, smart meters, or meter readers to create in-depth energy reporting for customers and provide social comparisons of energy use. The platform supports Z-Wave and ZigBee standards and so can integrate of a variety of controls and sensors.

Feedback Features
The platform enables users to monitor connected devices via web portals and mobile apps for service propositions.

Control Features
The platform can integrate with smart thermostats to enable users to schedule and turn on or off their thermostat remotely via a mobile app or web portal.

Sources
http://www.greenwavesystems.com/referenceapps/#energy- December, 2014

Image Credit
http://www.greenwavesystems.com/#whatwedo

Appendix C: Protocols Description

Protocol	Description	Alliance	Access	Technical	Status
Insteon	A peer-to-peer dual-mesh network protocol using both powerline and radio to communicate between devices, and optimized for home command and control.	Most products are made by Insteon with some external partners to manufacture controllers	Proprietary technology, commercial license needed.	131 KHz powerline + wireless 915MHz (US), 858MHz (Europe). X10 compatible	Limited product choice because of single manufacturer. Partnered with Microsoft in 2014 to sell kits in Microsoft store and integrating with windows phone OS to enable touch and voice commands.
Zigbee	A low-power mesh network protocol allows low power devices to natively interact with IPv6-enabled Ethernet, wifi devices. This protocol is part of Zigbee Smart Energy 2.0 Profile.	Zigbee Alliance boasts several big name companies in media (Comcast), consumer electronics (Samsung), Smart Home Devices (Philips, GE, Honeywell, Lutron) and semiconductors (Freescale, Texas Instruments, ARM).	Open membership policy with an annual fee	IEEE 802.15.4 Physical Radio supporting 2.4GHz + 915MHz (Americas), 868MHz (Europe) and 920MHz (Japan)	Active ecosystem; multiple profiles were created for various applications and are not fully inter-operable, partially defeating the purpose of having a common standard. In an attempt to remedy this, Zigbee recently announced unification of its wireless standards into a new Zigbee 3.0 standard, expected to be ratified before Q4 2015.
Thread	A low-power mesh network protocol for smart home with native internet connectivity (via 6LoWPAN based Ipv6 support)	Threadgroup.org; Nest Labs, Samsung, ARM, Freescale, Silicon Labs, Big Ass Fans, Yale locks	Open and inclusive membership policy	IEEE 802.15.4 Physical Radio @ 2.4GHz	Formed in July 2014. A version is already running on Nest thermostats and will be compatible with other 250 products.
Z Wave	A low power wireless protocol for home automation applications	Sigma Designs; 250 manufacturing partners including ADT	Closed standard controlled and chip only built by Sigma Designs	Operates in the sub-1GHz band; impervious to interference from other wireless technologies in the	1100 different products supported as of 2014 but not many from major manufacturers.

				2.4 GHz range.	
Bluetooth	A wireless protocol that is compatible with a large installed base of smartphones and tablets.	Bluetooth SIG	Open membership policy	2.4 GHz radio frequencies transmitted over short distances (100m)	Most modern phones and tablets are bluetooth smart ready devices. It doesn't support IPv6 and mesh network natively but solution in the works. This is the primary network protocol supported by Apple Home Kit
Bluetooth Smart	A lower power version of the Bluetooth protocol.	Bluetooth SIG	Open membership policy	Same 2.4GHz radio frequencies as BT Classic, allowing the 2 standards to share same radio but short range (<10m)	Same as Bluetooth
Cellular	Telecommunications technology that allows mobile electronic devices to use services and networks	International Telecommunications Union	Open membership to governments	3G, 4G/LTE	Huge cellular networks blanket the earth. There is over 5 billion mobile cellular subscriptions in the world
WiFi	A local area wireless protocol that allows electronic devices to exchange data or connect to the internet	WiFi alliance, 600 member companies	Open membership policy	IEEE 802.11 standard based 2.4GHz, 3.6GHz and 5GHz bands	Huge ecosystem and the most prevalent network protocol in a home, with more than 20,000 products in market. Very high power consumption compared to other smart home protocols

Sources:
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http://en.wikipedia.org/wiki/Mobile_telephony
http://www.wi-fi.org/