Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities

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FOREWORD

Energy efficiency programs and policies in the U.S. have emphasized use of energy-saving technologies and design practices, and have generally paid scant attention to individual behavior. By contrast, a focus on individual behavior is much more prevalent in Europe, and was also more common in the U.S. in the 1970s and 1980s. In recent years, there has been growing interest in the U.S. in using behavioral approaches. Pilot programs are being developed and evaluated, conferences are being held, and new approaches are being discussed.

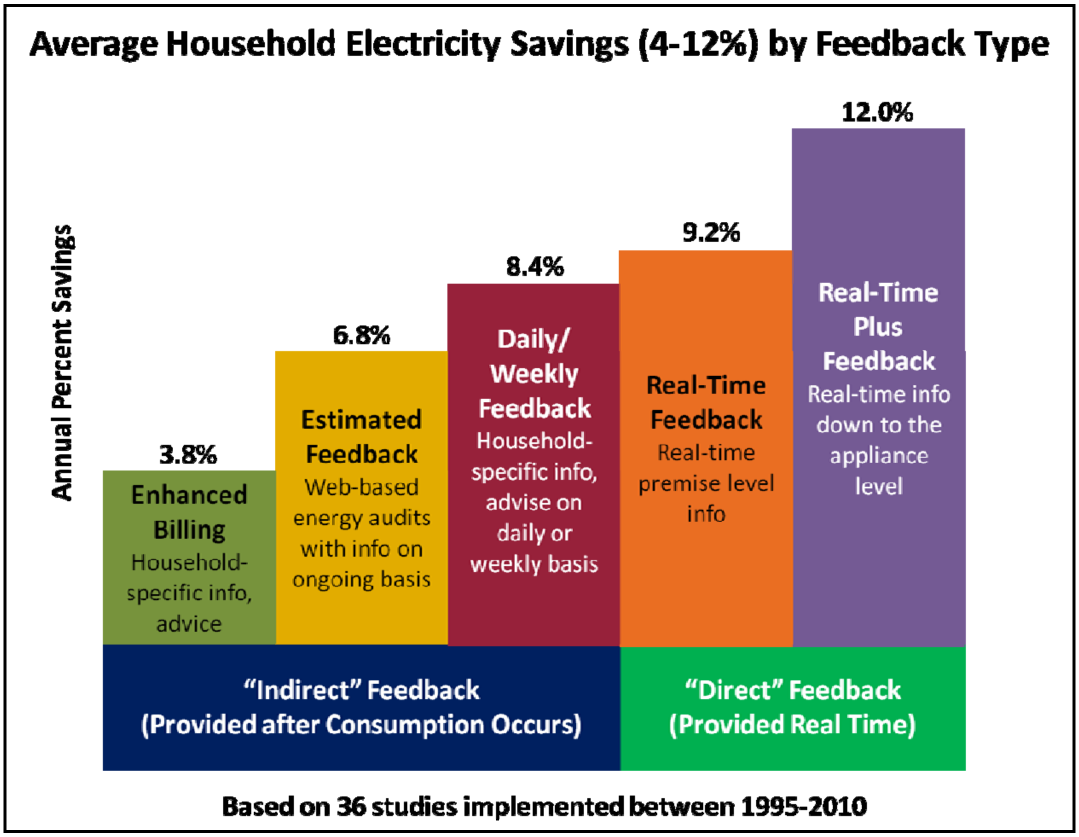
In particular, there is growing interest in using advanced metering and other customer feedback tools to provide customers with information to encourage shifting of loads to off-peak periods and/or to encourage lower levels of overall consumption. Such approaches have the potential for substantial and cost-effective energy savings, but it can be difficult to separate the hype from legitimate claims. To address this problem, the American Council for an Energy-Efficient Economy, with support from The Overbrook Foundation, Kresge Foundation and Sea Change Foundation, decided to conduct a significant meta-review of more than 60 feedback studies we could find. We examined the results of 57 such studies which had sufficient data on the energy savings from various feedback approaches. The studies covered primarily two continents (North America and Europe) and more than three decades of research. The data is sliced and diced in various ways in order to tease out the effects of different treatments, different time periods, and differences between regions. Overall, we find that significant savings can be achieved, and also find that there are some very promising approaches that need further study. We also find many useful lessons on ways to increase energy savings using lessons from behavioral science, since like all program approaches, for feedback to have the intended results, it must be done well.

We hope the results here provide a useful foundation for expanded use of feedback, and for continued experimentation. Such efforts will be important tools for achieving further increases in energy savings and cost-effectiveness.

Steven Nadel
Executive Director
American Council for an Energy-Efficient Economy

EXECUTIVE SUMMARY

A variety of new feedback initiatives are making energy resources visible to residential consumers throughout the United States (and many other developed countries). As summarized in the chart below, these initiatives are opening the door to potential energy savings that, on average, have reduced individual household electricity consumption 4 to 12% across our multi-continent sample.[3] In so doing, feedback is proving a critical first step in engaging and empowering consumers to thoughtfully manage their energy resources. On a national scale, our estimates indicate that feedback programs for the residential sector might generate electricity savings that range from as little as 0.4% to more than 6% of total residential electricity consumption. If broadly implemented throughout the United States using well-designed programs, residential sector feedback programs could provide the equivalent of 100 billion kilowatt-hours of electricity savings annually by 2030.



Advanced metering is likely to play an important role in meeting the data demands of feedback programs. While feedback can take many forms and need not include utilities or advanced metering initiatives (AMI), the planned proliferation of advanced meters will provide powerful new opportunities for the collection of detailed, household-level energy use data.[4] In combination with a variety of enabling-technologies (e.g., appliance measurement and automation sensors), AMI could provide households with an expanded array of mechanisms for reducing energy waste and maximizing energy bill savings. Of critical importance, however, is the way in which the feedback

[3] The range of savings reflects the average savings, by program type, for programs implemented between 1995 and 2010. A total of 36 programs is included. When the scope is limited to studies in the U.S., savings range from 2 to 11%. These U.S. studies took place between 1974 and 2010.

[4] In addition to potential residential sector energy savings, advanced metering infrastructure can also provide utilities with the means to improve monitoring of energy distribution and transmission-related energy losses, quickly identify power outages, and reduce the need for meter readers.

is provided and whether people understand the information, believe that they are capable of making a difference, and are motivated to take action. Achieving maximum feedback-related savings will require an approach that combines useful technologies with well-designed programs that successfully inform, engage, empower, and motivate people.

What do past studies tell us? Results from the meta-review.

Our meta-review provides the most comprehensive review of residential sector feedback studies to date and includes the systematic assessment of information gathered from 57 primary studies. The studies span two eras and nine countries, including research performed over the course of the past 36 years in the United States, Canada, Europe, Australia, and Japan. The meta-review explores the effects of a variety of variables associated with temporal and regional context as well as various program design characteristics with the goal of providing preliminary insights as to the ways in which and the degree to which different factors are likely to influence feedback-induced energy savings.

***The effects of feedback type*.** Regardless of the actions taken, some types of feedback appear to be more effective than others in generating more substantial energy savings. Past studies suggest that daily/weekly feedback and real-time plus feedback ("plus" means that useful details on energy use are provided and not just total consumption) tend to generate the highest savings per household. Median energy savings, across all countries and decades, for studies employing these two approaches were both above 10% (11% and 14%, respectively). However, these estimates are dominated by studies with small sample sizes and short duration; further studies with large sample sizes and longer duration are needed before conclusions can be drawn. Studies that used estimated and real-time feedback strategies generated savings on the order of 7%, while programs that relied on enhanced billing strategies achieved savings of 5.5% on average. As discussed below, when results are limited to relatively recent studies in the U.S., savings tend to be somewhat lower.

***Feedback-induced savings and household participation*.** At a more aggregate level (national, state, city, utility, community), the total amount of energy that can be saved from the implementation of different types of feedback depends on two factors: the average household-level energy savings associated with a particular type of feedback and the likely level of household participation. Importantly, participation rates tend to be significantly higher for programs that are designed using an opt-out (as opposed to opt-in) design. The amenability of Enhanced Billing, Real-Time Feedback, and Real-Time Plus feedback programs to opt-out designs greatly increases the likelihood of their success in achieving dramatically larger overall energy savings. As discussed in more detail in Section IV of this report, once participation rates are taken into consideration, the implementation of real-time plus feedback programs is likely to generate the most dramatic energy savings across a given community, state, or region (on the order of 6%). The second highest aggregate level energy savings are likely to result from aggregate, real-time feedback programs (approximately 4% savings), while enhanced billing programs could generate on the order of 2% energy savings at the aggregate level.

While these insights are important, it is also important to recognize the substantially lower investment costs associated with enhanced billing programs (when compared to either real-time or real-time plus programs in particular due to their reliance on costly advanced metering equipment and in-home displays). These results suggest that enhanced billing strategies are currently one of the most effective and affordable means of providing residential consumers with meaningful feedback about their energy consumption patterns. Nevertheless, as utilities continue to install advanced meters throughout the residential sector with the goal of meeting other utility objectives, real-time and real-time plus feedback mechanisms could well become an increasingly viable and cost-effective approach to providing households with useful feedback. These new technologies, and the feedback mechanisms that they empower, can be used to complement the feedback from enhanced billing.

Feedback gadgets alone are unlikely to maximize household energy savings. Instead, the most effective forms of feedback are likely to include both products (meters, displays, and other devices) and services (compilation of data, targeting and tailoring of recommendations, etc.) that provide consumers with timely and detailed information that is presented in multiple ways, tailored to the consumer, and contextualized to provide meaning and motivation. In addition, incorporating the best motivational techniques and behavioral approaches will be important to realize optimal savings. Such approaches include the use of: commitments, goal setting, social comparisons, normative messaging, and engaging participants in small, actionable steps.

Motivational elements and program effectiveness. Feedback-induced energy savings and overall rates of household participation are malleable and can be enhanced through the use of motivational elements such as the use of goal setting, commitments, competitions, and social norms. Research by Nolan et al. (2008) and Schultz et al. (2007) suggest that the use of social norms can result in household energy savings of 5.7–10% and that the use of both descriptive and injunctive norms is important in shaping household energy behaviors. Despite the evidence of enhanced savings, however, relatively few feedback projects have incorporated these noneconomic levers. In many ways, OPOWER has been a pioneer in the application of social norm research in conjunction with its innovative home energy reports (a form of enhanced billing). More research is needed to explore the potential power of these (and other) non-economic incentives and the degree to which they can enhance household energy savings.

Demand response and peak versus off-peak savings. The effectiveness of feedback initiatives in generating household energy savings is dramatically influenced by the focus of the program. While programs that are focused on peak load savings are generally successful in shifting energy use from peak periods to off-peak periods, they are much less successful in generating energy savings throughout the billing cycle. Results from this meta-review suggest that programs focused on reducing energy consumption during specific time periods save considerably less energy than programs focus on promoting energy conservation and efficiency at all times. More specifically, data from existing studies indicate that the overall energy savings from programs focused on peak load shifting have averaged around 3%, while programs focused on promoting conservation and efficiency have averaged around 10%. These studies generally include some combination of feedback, time of use rates and/or incentives and thus do not represent savings from a single type of intervention. While these results provide some preliminary insights, more research is needed to document the overall energy savings from programs focused on reducing peak demand and energy use during specific time periods, and on savings from different combinations of interventions.

Changes in habits, lifestyles and choices. Once people receive information about their energy consumption patterns, there are a wide variety of things they can do to reduce the amount of energy they consume. Energy savings are typically achieved as a result of three categories of action: 1) simple changes in routines and habits, 2) infrequent and low-cost energy stocktaking behaviors (i.e., replacing incandescent bulbs with CFLs, weather stripping, etc.), and 3) consumer investments in new energy-efficient appliances, devices, and materials. Evidence from past studies suggests that most of the energy savings achieved through feedback programs results from changes in behaviors (not investments) although people who invest tend to save the most energy. (Notably, observed patterns may be a function of past program designs.)

Additional evidence suggests that energy saving strategies are likely to vary by income level such that higher income households are more likely to purchase new energy-efficient appliances, windows, and devices while lower income households are more likely to engage in energy stocktaking behaviors or change their energy use habits and routines. Moreover, investments in new equipment and appliances are often undertaken in conjunction with a change of residence or a remodel or part of a stylistic (as opposed to functional) upgrade. Regardless of the action taken, feedback-induced behaviors appear to be motivated by a variety of factors including self-interest (energy bill savings) as well as civic concerns and altruistic motives. These findings suggest that narrowly defined energy efficiency programs aimed at the installation of new, more energy-efficient technologies alone (the practice of traditional utility programs) are likely to realize only a small fraction of potential behavior-related residential energy savings. Similarly, programs that limit their appeal to self-interest alone are unlikely to leverage the broad range of factors that motivate people to action.

Study duration and the persistence of energy savings. An important focus of our meta-review is to gain a better understanding of the correlation between time and savings. We consider this relationship in two ways: 1) by assessing the relationship between study duration and energy savings across studies, and 2) by assessing the persistence of energy savings as reported by a significant subset of the larger sample of primary studies. Our assessment of the relationship between study duration and feedback-related energy savings reveals that average energy savings tend to be higher for shorter studies (10.1% on average) than for longer studies (7.7% on average). Given that the larger studies tend to include a more representative sample of households, these findings may suggest that large-scale feedback programs are also likely to experience more modest savings. While these results are far from conclusive, future research is likely to prove valuable in answering this question.

Furthermore, our assessment of the relationship between duration effects and persistence also revealed interesting insights. Notably, evidence from the 27 studies that measured within-study persistence of feedback effects suggests that feedback-related energy savings are often persistent (although multiple studies also suggest that the persistence of energy savings may rely on the continued provision of feedback). Our assessment of the discrepancy between duration and persistence suggests that the lower rates of savings associated with shorter studies are not a reflection of the persistence of energy savings but instead reflect the inability of shorter studies to capture seasonal variations in energy end-uses. Given that the majority of the shorter studies were performed during summer months when electricity demand is at its highest, the higher levels of savings associated with these studies is likely to reflect the large savings that can result from reducing air conditioner use. These insights provide interesting research questions for future research and suggest improved research methodologies that can account for seasonal variations as well as measure the persistence of energy savings over time.

***Program eras and regional contexts*.** Data from the meta-review reveal distinct trends in feedback-related energy savings by era and region, suggesting that savings are influenced by temporal and regional contexts. Research on the effects of feedback strategies spans four decades and two important eras: the energy crisis era of the 1970s, 1980s, and the first half of the 1990s; and the Climate Change Era beginning in 1995 and spanning the first decade of the new century. Notably, feedback-induced energy savings are lower in the Climate Change Era than during the energy crisis era, regardless of the feedback strategy employed. This finding is important because it suggests that prior reviews of the feedback literature that have compared feedback-related savings across all four decades may have come to erroneous conclusions regarding the range of potential feedback-related energy savings today. The results also suggest that temporally specific shifts in culture, politics, and lifestyles (as well as other factors) are likely to impact the effectiveness of feedback in generating energy savings. Such shifts may play an important role in defining changes in the future as well.

Regionally, evidence from the meta-review suggests that during the Climate Change Era (1995-2010), feedback programs in Western Europe have been successful at generating much greater levels of energy savings than in the United States. As discussed in Section III of this report, during the Climate Change Era, feedback-induced savings in Europe have averaged 10.5% while the average household savings of U.S. feedback programs were found to be 3 percentage points lower (7.4%). The reason for these differences is unclear although differences in political leadership and culture are likely to play an important role. A more narrowly focused, comparative analysis is likely to reveal additional means of enhancing feedback-related savings in the United States.

What should we know about residential sector feedback technologies?

Feedback technology characteristics. As outlined in Section II, feedback technologies range from indirect feedback to direct feedback to whole home automation. Indirect feedback technologies provide whole house electricity information, specific household and appliance information and advice, and estimations of expected electricity consumption. Indirect feedback can be derived from utility data, including monthly meter readings, more frequent advanced metering data, and data that has been processed by a third party to provide personally and socially contextual feedback. Direct feedback is provided at the time of consumption (or shortly after consumption) and includes real-time feedback, appliance-specific real-time feedback, and home automation technologies. Direct feedback technologies include in-home energy displays, "smart" appliances and devices, and complete home automation networks.

Third-party providers are likely to be important players in feedback solutions whether working in conjunction with or independently of utilities. A variety of third-party providers have already developed different types of tools and technologies for providing households with feedback regarding their energy consumption patterns and new players are rapidly entering the market. Many of these third-party providers are already working with utilities to test and refine their products, while a variety of other providers have made their products available directly to consumers through the retail market or online. Historical evidence suggests that while some proportion of utilities may provide consumers with in-home energy displays, they are unlikely to work independently to provide consumers with contextual information, non-financial incentives, and motivational mechanisms, or tailored recommendations for saving energy. Instead, utilities have opted to partner with third-party providers and we anticipate that this trend will continue into the future.

The best feedback approaches are likely to be incremental in nature and will "evolve" as technologies become more sophisticated. Given the wide range of available feedback technologies and the ongoing research on new feedback devices, automation technologies and in-home energy management systems, it is currently impossible to determine what future feedback initiatives are likely to look like or which devices and approaches are likely to generate the most savings. Given these uncertainties, today's programs should maintain as much flexibility as possible and be designed with change in mind. At the same time, existing approaches should be used to the maximum extent possible. For instance, existing approaches that use statistical methods to analyze multiple data sources should be implemented now. These approaches can provide feedback using existing hardware such as computers, mobile phones, and televisions. In addition, investments should be made in new feedback mechanisms with the goal of testing and learning from existing approaches, building a knowledge base, and providing the means for the development of more advanced feedback and automation technologies as well as their increased affordability. A technology voucher system is likely to provide consumers with the most choice and flexibility in determining which approach is most effective in meeting their needs.

The future of home energy management is likely to involve a complex network of wireless, consumer-controlled, home automation systems, although some automation devices can begin to be installed now. Home energy management can be greatly facilitated through "set and forget" systems that allow consumers to program their use of specific appliances and devices including their water heater, furnace, and pool pump. Such systems maintain consumer control in determining appliance settings as well as in determining when appliances should cycle on or off. The benefit lies in both the ability of these devices to eliminate the requirement that consumers remember to manually set their preferences on a daily basis and in consumers' active involvement in designing tailored energy solutions.

Recommendations for achieving potential feedback-induced energy savings.

Consider the range of existing mechanisms for providing households with useful feedback. Advanced Metering Initiatives (AMI) represent just one of several means of providing households with useful feedback. For many people, the relatively recent expansion of utility interest in AMI and the palpable excitement over the promise of Smart Grid technologies has sparked a new or renewed interest in providing households with detailed energy use information. As a result many energy practitioners are increasingly likely to associate feedback with AMI technologies. However, feedback can be provided by a variety of different means and mechanisms, and it doesn't require advanced metering technologies. For example, several ongoing enhanced billing programs are providing residential consumers with useful feedback as well as energy-saving tips. These types of programs typically generate a lower range of energy savings but high levels of participation. These programs result in measureable and cost-effective energy savings. Other types of feedback technologies including many different types of whole house (aggregate level) energy monitoring devices can be installed regardless of the presence of an advanced utility meter and can provide households with real-time measures of aggregate level energy consumption. In addition, current research is underway to develop new feedback technologies that will be able to disambiguate appliance-specific energy signals and thereby provide real-time, appliance-specific feedback for major appliances without the use of advanced metering technologies. Recognizing the diverse array of feedback mechanisms and technologies is important for several reasons but especially because the roll out of AMI technologies will take years to complete and because it isn't yet clear whether utilities will provide consumers with the tools they need to access to their own energy consumption data. In the meantime many other viable opportunities exist to provide households with useful feedback.

- **Act now to provide all households with energy consumption feedback and provide measurable and cost-effective savings to households throughout the United States. The best short-term approach to feedback is to provide households with enhanced billing reports.** (See our detailed assessment and discussion in Section III of this report.)

- **To the extent possible, provide households with both direct and indirect forms of feedback.**

Make feedback convenient, engaging, and beneficial for consumers. The effectiveness of feedback initiatives and the success of the smart grid, advanced metering, and energy management and home automation technologies depends heavily on consumer acceptance and participation. Despite the existence of significant barriers, research suggests that the utilities may be starting to recognize that significant numbers of consumers may actually <u>want</u> to play a role in energy management and that this interest may be profitable for utilities to use as means of enhancing demand-side management programs. Nevertheless, most utilities are not equipped to deploy complex home automation systems or engage in the behavioral research required to design effective solutions. As such, partnerships and cooperative endeavors between utilities and third-party providers are likely to be needed in order to maximize consumer participation and consumer satisfaction.

- **Maximize consumer engagement and product innovation by encouraging partnerships and cooperative endeavors between utilities and third-party providers.**
- **Provide households with a variety of non-financial forms of motivation through the use of social norms, goal setting, commitment, competitions, and special events. Leverage existing social networks and organizational memberships to help motivate and build community. Focusing on the financial benefits may backfire**.
- **Use opt-out program designs whenever possible to maximize consumer participation.**

- **Encourage households to engage in new habits, stocktaking behaviors, and adopt appropriate technologies** – people need to know that technology alone will not solve the problem and that there are no-cost and low-cost things they can do to make a difference. Most energy savings come from changes in behaviors (not investments).
- **As utilities roll out advanced metering technologies, require that they also provide consumers with access to real-time data.** Households that have advanced meters should have access the real-time data that such meters can collect either through the use of in-home displays or Web-tools.

Link in-home displays to basic automation technologies*.* When utilities provide in-home displays, the displays should be combined with some basic, consumer-controlled automation technologies such as smart-thermostats, pool pumps, water heater controls, and power strips that improve the capacity for household energy management.

Further research is needed*.* This meta-analysis summarizes many studies and provides useful information on the range of savings that can be achieved with feedback. However, many of the findings are tentative because they are limited by small sample sizes and limited data. Further research on energy savings from feedback are needed, particularly studies with large sample sizes that examine savings over periods of a year or more, and that then examine savings persistence over multi-year periods. Such studies should particularly target daily/weekly feedback and real-time plus feedback, two approaches that the limited data available indicate are particularly promising. Also, it would be useful to conduct additional research on why recent savings are higher in Europe, and whether there are lessons from Europe that could be usefully transferred to the U.S.

About ACEEE

The American Council for an Energy-Efficient Economy (ACEEE) is a nonprofit research organization dedicated to advancing energy efficiency as a means of promoting economic prosperity, energy security, and environmental protection. For more information, see aceee.org. ACEEE fulfills its mission by:

- Conducting in-depth technical and policy assessments
- Advising businesses, policymakers, and program managers
- Working collaboratively with businesses, public interest groups, and other organizations
- Organizing technical conferences and workshops
- Publishing books, conference proceedings, and reports
- Educating consumers and businesses

Projects are carried out by staff and selected energy efficiency experts from universities, national laboratories, and the private sector. Collaboration is the key to ACEEE's ongoing success. We collaborate on projects and initiatives with dozens of organizations including international, federal, and state agencies as well as businesses, utilities, research institutions, and public interest groups.

Support for our work comes from a broad range of foundations, governmental organizations, research institutes, utilities, and corporations.

Acknowledgments

This report has emerged from a growing body of interest in the social and behavioral dimensions of energy consumption and energy efficiency. It is the product of ACEEE's own emerging interest in the topic and the organization's efforts to expand its focus beyond technological

considerations. This new realm of research has been housed in ACEEE's Economic and Social Analysis Program and has been responsible for numerous publications as well as playing a principal role in the development of the Behavior, Energy and Climate Change (BECC) Conference. Following the overwhelming level of participation and interest in the first two BECC conferences[5], ACEEE has decided to establish a full program on Behavior and the Human Dimensions of Energy Use. The Overbrook Foundation was similarly encouraged by the potential energy savings associated with residential feedback technologies and the energy saving behaviors that they appeared to induce. As a result, Dan Katz, a project officer with the Overbrook Foundation, took the initiative to fund this important piece of research with the goal of bringing together the findings from past feedback studies as well as gaining new insights through a meta-review of their findings. The ACEEE research team is profoundly grateful to the Overbrook Foundation and to Mr. Katz for their funding of this project and for their vote of support. Despite the many constraints and obstacles which delayed the issuance of this report, we are confident that the findings summarized in this study hold the potential for positively shaping future energy and climate change policy. As the project grew in scale, additional funding was needed and we gratefully acknowledge the contributions of the Kresge Foundation and Sea Change Foundation in helping to make this report possible.

While funding is certainly a critical aspect of any successful research effort, our work would be wholly incomplete without the benefit of the many pioneering efforts undertaken by the individuals who engaged in the primary research associated with the many feedback studies that underpin this report. Included among these are researchers such as Seaver and Patterson who began to explore the potential benefits of feedback-related programs as early as 1974, and the many institutions that supported their efforts. In addition, we would like to acknowledge the many entrepreneurs who have provided new feedback technologies and services that have enabled enhanced energy savings and new energy consumption patterns and practices. As such, we want to acknowledge, in particular, the authors and co-authors of the 62 primary research studies that form the heart of our analysis.

Finally, we greatly value the contributions and feedback our many peer reviewers and technology experts who provided invaluable insights, feedback and information, including: Nancy Brockway (Independent), Sarah Darby (Oxford University), Barbara Farhar (University of Colorado), John Petersen (Oberlin College), Adam Reed (University of Colorado), Jennifer Robinson (Electric Power Research Institute), Tom Sandquist (Pacific Northwest National Laboratory), Linda Schuck (California Institute for Energy and Environment), and Wes Schultz (California State University-San Marcos). We also acknowledge several other ACEEE staff who contributed to this report including Marty Kushler (Utility Program Director), Steven Nadel (Executive Director), and Renee Nida (Editor). All of these individuals and institutions have made this report possible and have provided the means for the establishment of the many insights provided herein. It is our profound hope that the results of this report will be used as a foundation for continued research on this topic and as a resource for policy makers, program managers, and other decision makers who are involved in the design, implementation and evaluation of feedback programs. With this effort, one thing is very clear—feedback technologies and programs can enable a smarter and more informed consumer as well as significant levels of energy savings. However, not all approaches to feedback are the same, and efforts to maximize potential savings will require an informed perspective that can discern the benefits and disadvantages of specific feedback technologies and program elements so as to successfully motivate people to action. Informed policies, adequate funding, smart design, and effective implementation will be needed to achieve potential feedback savings

[5] The Behavior, Energy and Climate Change Conference is co-convened on an annual basis by the California Institute for Energy and Environment (University of California), the Precourt Energy Efficiency Center (Stanford University), and the American Council for an Energy-Efficient Economy. (See www.BECCconference.org for more information.)

I. Introduction

In 2010, the typical American household will spend roughly $1,500 for the electricity and natural gas used in their home. However, recent estimates indicate that, given currently available technologies that are cost-effective, most homes in the United States consistently use 20 to 30% more energy than they might actually need. A significant proportion of the energy that is wasted could be saved without major investments (Laitner et al. 2009a). One way to achieve these savings is through the use of feedback technologies and programs that provide consumers with the information, motivation, and timely insights that can help them develop new energy consumption behaviors and reduce wasteful energy practices. Households benefit directly from lower energy costs while society benefits from reduced carbon dioxide emissions.

While feedback can take many forms, the recent proliferation of advanced metering initiatives (AMI), has opened up new opportunities for providing households with more timely and more meaningful information about their energy consumption practices. In combination with a variety of enabling-technologies (e.g., appliance measurement and automation sensors), AMI could provide an important means of supplying the feedback needed to catalyze very large energy bill savings. In addition, advanced metering infrastructure offers utilities the potential to improve monitoring of energy distribution and transmission-related energy losses, quickly identify power outages, and reduce the need for meter readers.

This study investigates the ways in which feedback and AMI can reduce energy consumption in the residential sector. The report is comprised of five principal sections: the introduction, a review of residential sector feedback technologies, a meta-review of 57 primary research studies, an assessment of potential nationwide feedback-induced energy savings, and conclusions. The introduction begins by describing the problem of energy resource invisibility followed by a discussion of the characteristics of residential energy consumption and the proliferation of advanced metering infrastructure. The section concludes with a description of the research methodologies used in this report.

A. The Invisibility of Energy Resources

Household energy resources are in many ways invisible to residential energy consumers. This makes energy management and conservation practices both difficult and unusual. When compared to the use of wood and coal, the more modern energy resources provide an increasingly *invisible* means of meeting demands for heating, cooling, lighting, refrigeration, food preparation and entertainment. Today, both natural gas and electricity supplies flow seamlessly and silently into our homes, fueling our furnaces, powering our air conditioners and other equipment, and meeting our demands for a wide variety of energy service demands without any notable trace of their presence. For most people, the only measure of their energy consumption is the bill that they receive up to 45 days after consumption. Unfortunately, the monthly bill—even for the best energy detective and the most energy-conscious consumer—is an inadequate tool for managing energy resources. Monthly bills may report the number of kilowatt-hours (kWh) of electricity consumed and the costs that are incurred, but they don't indicate which end-uses are demanding the most energy, how energy intensive or energy-efficient existing appliances might be, and how changes in our own choices and behaviors can either enhance or offset energy demands associated with changing weather patterns, new appliances, and other electronic equipment. Unfortunately, most people in the United States are among the energy blind; we cannot see the energy that we consume.

The dysfunctionality of our current energy system has been recognized for many years. More than a quarter century ago, Kempton and Montgomery (1982) illustrated the paradox of consumption without meaningful information in the following way:

> [Imagine a grocery] *store without prices on individual items, which presented only one total bill at the cash register. In such a store, the shopper would have to estimate item*

> *price by weight or packaging, by experimenting with different purchasing patterns, or by using consumer bulletins based on average purchases*.

The invisibility of modern energy resources also impedes the establishment of social norms concerning “appropriate” levels of energy consumption. Not only are most energy consumers blind to their own level of energy consumption, but they are also equally unaware of the energy consumed by others. Without an appropriate frame of reference, individuals and households have a hard time determining whether their patterns of energy consumption are excessive or moderate and whether some type of intervention is warranted.

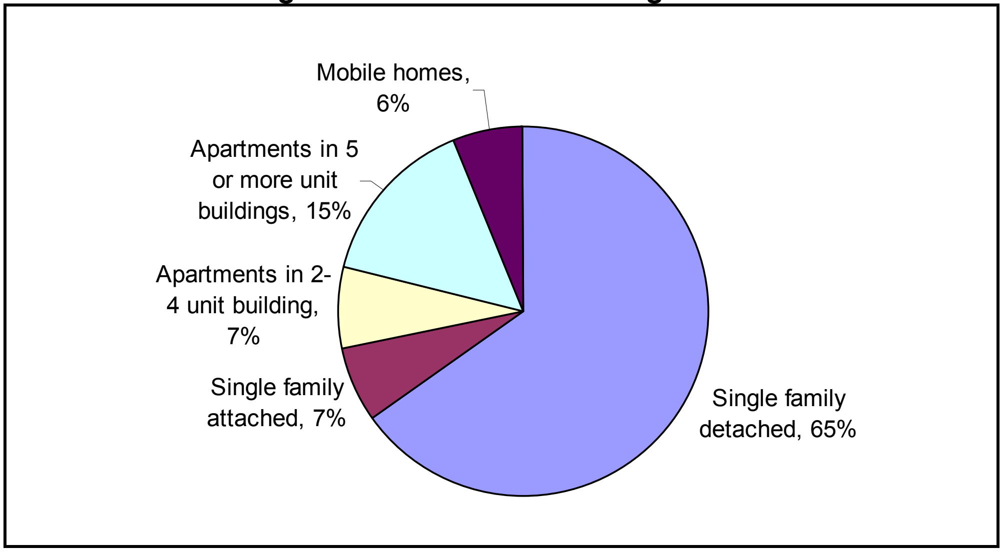
B. Characteristics of Residential Energy Consumption

Residential buildings now account for more than one-fifth of our nation’s total energy demand (approximately 22%) and residential energy use is on the rise. In the past decade alone, residential energy consumption increased by 23%, and projections through the year 2030 indicate that energy household energy expenditures are likely to increase another 25%. Much of the projected increase is expected to result from population growth and increased demand for energy services. At the same time, the growing demand for energy in the residential sector is expected to be partially offset by on-going improvements in energy efficiency.

Persistent demographic trends are expected to continue to contribute to increasing residential sector energy demands. One of the primary drivers of the continued growth will be continued growth in the U.S. population. Although there are early signs the trend may be reversing, a second and often overlooked driver is the tendency toward fewer and fewer occupants in each household. The combination of population growth coupled with the shrinking size of households will result in a more rapid expansion in the number of U.S. households. As illustrated in Figure 1, currently there are an estimated 115 million households in the nation. The largest proportion of U.S. housing stock (72%) consists of single-family homes, followed by apartment building units (22%), and mobile homes (6%) (EIA 2009b). By 2030 the number of U.S. households is projected to top 141 million (a 23% increase) at an annual growth rate of 1%. Similarly, U.S. population estimates suggest that the U.S. population will grow by 63 million people between 2010 and 2030, reaching 375 million by 2030 (EIA 2009a).

In addition to the energy strain that will be induced by population growth, energy service demands per capita have also been on the rise. According to the Energy Information Administration’s *Annual Energy Outlook 2010*, “efficiency improvements have been more than offset by increases in air conditioning use and the introduction of new appliances” (EIA 2009a). In particular, as the variety and popularity of home electronics grows—ranging from iPods, cell phones, and computer games to many kinds of home appliances—these gadgets are expected to contribute an increasingly large percentage to home energy use, growing from about 34% of residential electricity consumption today to about 39% by 2030.

Figure 1. Residential Housing Stock



Source: EIA (2009b)

The majority of energy used in the residential sector is devoted to space heating (42%), followed by water heating (17%), air-conditioning (7%), and refrigerators (3%). The remaining 30% of energy is used by other appliances and lighting (EIA 2009a).[6] Among home appliances, energy consumption for personal computers and related equipment is projected to increase by 0.7% annually, televisions and set-top boxes by 1.2%, and all other consumer electronics by 1.7% (EIA 2009a). Of particular note, these and other home electronics consume power not only when in use, but also when they are in standby and off mode. In aggregate, their power supplies alone can draw significant loads even when disconnected from the appliance.

Several other appliances are projected to see rapid growth in energy demand, including furnace fans and boiler circulation pumps (1% each) and cooking (0.7%). The average annual increase in energy consumption through 2030 for all residential end uses is 0.4% (EIA 2009a).

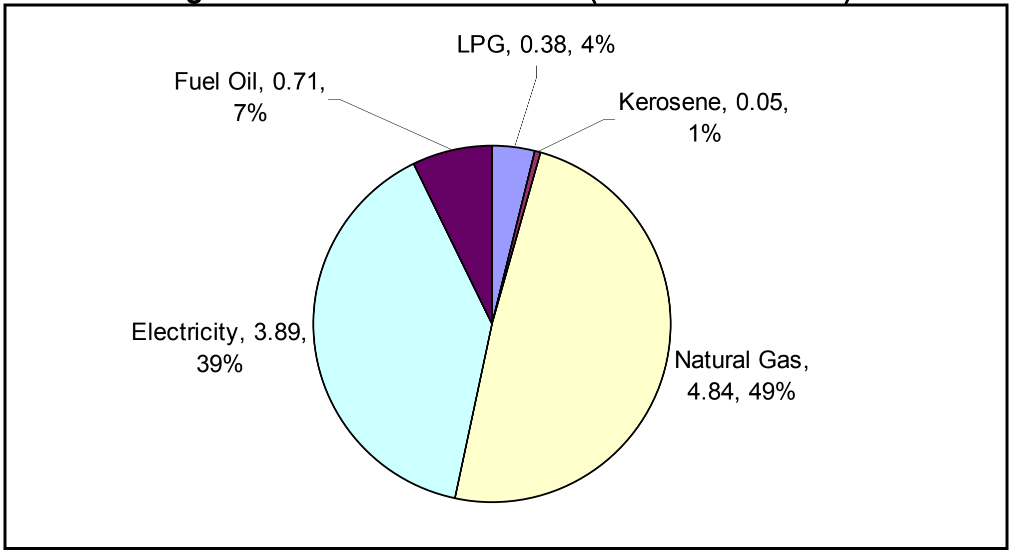
Increasing numbers of residential energy service demands are also expected to result from the growing number of people working from home. Over the last several decades the number of people working from home has increased both in number and as a percentage of the workforce. As more people spend a greater amount of time in the home, their energy demand grows. In 1980, 2.18 million, or 2.3% of the American workforce worked from home. By 2000, the number had grown to 4.18 million people or 3.3% of the workforce (Census 2004). The increasing market penetration of computers and the Internet have made working at home easier for many professionals. According to the 2007 U.S. Census, over 72 million households (61.7%) had access to the Internet and this percentage is likely to continue to rise (Census 2009).

Household Energy Resources

While there are three major fuels used in households in the United States (electricity, natural gas, and fuel oil), natural gas and electricity provide 86% of all energy in the residential sector (see Figure 2). Natural gas and fuel oil are used predominantly for space and water heating, while electricity is most often used for air conditioning and other consumer appliances. A small fraction of households use liquefied petroleum gas (LPG) and kerosene for space heating, cooling, and powering appliances.

[6] These proportions vary by region such that heating comprises a larger proportion of energy use in cooler climates while air conditioning comprises a larger proportion in warmer climates.

Figure 2. Residential Fuel Mix (in Quadrillion Btu)



Source: EIA (2009b)

Electricity

Nearly every household in the U.S. uses electricity. In 2001, nationwide electricity loads reached 1,140 billion kWh, or about 10,656 kWh per household (EIA 2009b). By 2010 will increase to about 1,388 billion kWh, or 12,039 kWh per household (EIA 2009a). Roughly half of total residential electricity is used to power consumer electronics and appliances. An estimated 16% goes air conditioning. The balance goes for space heating, water heating and lighting. Table 1 below summarizes the current usage patterns. At the same time total costs for residential electricity consumption will be on the order of $146 billion in 2010, or about $1,271 per household (EIA 2009a).

Table 1. Electricity Consumption by End Use in 2010

End Use	Total Consumption (Billion kWh/yr)	Consumption per Household (kWh/yr)	Total Cost (in billions)	Cost per Household
Space Heating	125.5	1,089	$13.2	$115
Air Conditioning	222.2	1,928	$23.5	$204
Water Heating	130.4	1,131	$13.8	$119
Lighting	210.3	1,824	$22.2	$193
Appliances	699.3	6,067	$73.8	$641
Total	1,387.7	12,039	$146.5	$1,271

Source: EIA (2009a)

Natural Gas

Natural gas is used in 63% of homes, which will consume 4.95 quadrillion Btu in 2010, or about 43 million Btu per average household in the United States. The purchase of natural gas resources will cost the nation's households nearly $54 billion, or $467 per household throughout 2010. Roughly 67% of all natural gas consumption in households is used for space heating. Another 27% is for water heating. The 6% balance is used for other appliances such as stoves, ovens, and clothes dryers (EIA 2009a). Table 2 below provides a breakdown of total natural gas consumption by end use within the residential sector for the year 2010 (note that financial values are in constant 2008 dollars.)

Table 2. Natural Gas Consumption by End Use in 2010

End Use	Total Consumption (Quadrillion Btu)	Consumption per Household (Million Btu)	Total Cost (in billions)	Cost per Household
Space Heating	3.31	28.7	$36.0	$312
Water Heating	1.35	11.7	$14.7	$127
Appliances	0.29	2.5	$3.2	$28
Total	4.95	42.9	$53.9	$467

Source: EIA (2009a)

Fuel Oil and LPG
While only small minority of homes rely strictly on either fuel oil or liquefied petroleum gases or LPG (these two fuels constitute only 10% of total residential energy consumption), because of their significant expense, efficiency gains for these fuels are also important. Table 3 details the 2010 consumption and expenditures total household consumption of these fuels as well.

Table 3. Fuel Oil and LPG Consumption by End Use in 2010

End Use	Total Consumption (Quadrillion Btu)	Consumption per Household (Million Btu)	Total Cost (in billions)	Cost per Household
Space Heating	0.76	6.6	$14.6	$127
Water Heating	0.18	1.5	$3.6	$32
Other Uses	0.18	1.6	$4.4	$38
Total	1.13	9.8	$22.6	$196

Source: EIA (2009a)

In summary, energy use in the residential sector is significant and growing but the characteristics of residential sector energy use also provide important energy savings opportunities. Currently, the residential sector is responsible for more than one-fifth (22%) of our nation's energy demand and for more than half (54%) of all energy consumed within buildings.

Moreover, demand is expected to continue to steadily increase as a result of population growth, the likely growth in the size of households, and the growing demand for energy services Notably, much of the expansion of energy service demands is likely to be linked to discretionary uses such as those associated with new electronics and appliances. Other less discretionary uses will include the increased use of air conditioning and energy used for home-based employment. While electricity and natural gas are the two primary energy resources used to meet energy service demands in the residential sector, all fuels easily lend themselves to advanced metering technologies and other feedback mechanisms that can encourage cost-effective reductions in residential sector energy consumption.

C. The Proliferation of Advanced Metering Initiatives

Unlike old-fashioned meters with their distinctive rotating disks, advanced utility meters are digital devices that communicate energy use information directly with the utility and (potentially) with the household residents and household appliances and devices. Advanced meters hold the potential of providing energy consumers with real-time energy consumption data and energy cost information, empowering consumers to effectively manage their household energy consumption. According to the Federal Energy Regulatory Commission (FERC 2008a) advanced metering is "a metering system that records customer consumption (and possibly other parameters) hourly or more frequently and provides for daily or more frequent transmittal of measurements over a communication network to a central collection point." Advanced meters with the capability to record at least hourly information can also provide the mechanism to price electricity and natural gas according to the time of usage.

These new devices offer an important means of overcoming the historical invisibility of household energy consumption (and production) and of dramatically improving the ability of households to manage their energy consumption practices. More specifically, recent innovations may provide new opportunities for rapid energy savings in the very near term by providing household-level feedback and by facilitating better energy management practices. Many of these AMI-related innovations rely on a range of increasingly ubiquitous information and communications technologies (ICT) (see, for example, Laitner and Ehrhardt-Martinez 2008). Importantly, the application and integration of ICT in the production, distribution, and consumption of energy resources is likely to provide dramatic improvements in both the overall energy efficiency of the electric grid as well as household-level energy management practices resulting in the elimination of many previously hidden sources of waste.

Additional energy saving opportunities may be achieved through the use of advanced meters in conjunction with dynamic pricing structures and "smart" energy devices (such as thermostats, large household appliances and electronic devices) that can be set to automatically respond to changing price signals. (See Faruqui and Harris 2009, Faruqui and Sergici 2009, and Faruqui and Wood 2008 for more information.) Moreover, the viability of a variety of future technologies such as electric vehicles and on-site renewable generation systems is likely to depend on the wide spread proliferation of advanced metering technologies and their ability to further optimize household energy use. In other words, ICT technologies are playing a critical role both inside and outside of the home. On the inside, ICT are likely to include new sensor technologies and smart appliances that can be called on to help automate smart household energy management practices. On the outside, numerous forms of ICT will play a defining role in the modernization of the electric grid. Advanced meters will provide the means for two-way communications between utilities and households.

The 2008 FERC study documents the recent proliferation of advanced meters within the United States.[7] Using data collected through a survey of nearly 2,100 entities throughout the electric power industry, the FERC study indicates that as of December 2008 advanced meters represented 4.7% of all residential electric meters in the U.S. For all three sectors, commercial, industrial, and residential, 6.7 million advanced meters were being used for advanced metering in 2008[8], representing an increase of nearly 5.8 million meters during the prior two year period. Most of these advanced meters (93%) were installed by cooperatives (2.4 million meters) and investor-owned utilities (3 million meters). Similarly cooperatives and municipal entities also reported the highest advanced metering penetration at 16.4% and 4.9%, respectively. Investor-owned utilities reported a penetration rate of 2.7%, while public utilities penetration was approximately 3.3% (FERC 2008a, 2009).

Regionally, residential sector penetration of advanced meters was highest within the Florida Reliability Region (10.8%) followed by the Electric Reliability Council of Texas (8.5%). Both the Southeast Reliability Corporation and the Southwest Power Pool Region reported residential penetration rates of 6.1%—with complete regional data provided in Table 4 below.[9]

[7] Note that FERC uses advanced meters and advanced metering infrastructure (advanced metering) interchangeability to include both one-way and two-way types of meters. We break out the two types of meters where possible.
[8] Note that FERC points out that not all installed advanced meters are being used as advanced meters.
[9] Nonresidential sector penetration of advanced meters was highest in the ERCOT region of Texas (12.4%) followed by the FRCC in Florida (7.8%) and the RFC (6.1%).

Table 4. Penetration Rates of Advanced Meters by Year, Region and Sector

Region	Overall Advanced Metering Penetration		Residential		Nonresidential Penetration	
	2006	2008	2006	2008	2006	2008
Florida Reliability Coordinating Council	0.1%	10.4%	0.1%	10.8%	0.5%	7.8%
Electric Reliability Council of Texas	0.7%	9.0%	0.7%	8.5%	0.7%	12.4%
SERC Reliability Corp.	1.2%	5.8%	1.3%	6.1%	1.0%	3.2%
Southwest Power Pool	3.0%	5.8%	3.3%	6.1%	1.8%	4.2%
Reliability First Corp.	0.4%	5.1%	0.3%	5.0%	0.8%	6.1%
Midwest Reliability Org.	0.6%	3.7%	0.5%	4.0%	1.1%	2.2%
Western Electricity Coordinating Council	0.5%	2.1%	0.3%	2.1%	1.5%	2.0%
Hawaii	0.0%	1.6%	0.0%	1.6%	0.1%	1.6%
Northeast Power Coordinating Council	0.1%	0.3%	0.3%	0.3%	0.8%	1.0%
Alaska Systems Coordinating Council	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Average	0.7%	4.7%	0.6%	4.7%	1.0%	4.2%

Source: FERC 2008a

As indicated in Table 5, fourteen states reported overall penetration rates above the national average of 4.7%. Notably, the number of advanced meters in Pennsylvania (1.4 million), Texas (868,000) and Florida (765,000) far exceeded those deployed in other states.

Table 5. Penetration of Advanced Meters by State 2008

State	Number of Advanced Meters	Advanced Metering Rank	Penetration Rate	Penetration Rank
Pennsylvania	1,443,285	1	23.9%	1
Texas	868,204	2	8.0%	7
Florida	765,406	3	8.0%	8
Georgia	342,772	4	7.6%	9
Missouri	204,498	5	6.6%	10
California	170,896	6	1.2%	33
Arkansas	168,466	7	11.3%	3
Oklahoma	161,795	8	8.6%	6
North Carolina	143,093	9	3.0%	19
Alabama	139,972	10	5.0%	12
Wisconsin	117,577	11	3.9%	16
South Carolina	114,619	12	4.8%	14
Illinois	112,410	13	2.0%	26
Idaho	105,933	14	13.8%	2
Kentucky	105,460	15	4.9%	13
Kansas	61,423	20	4.3%	15
South Dakota	41,191	24	8.7%	5
North Dakota	33,336	28	8.9%	4
Vermont	20,755	31	5.5%	11
TOTAL	6.7 million		4.7%	

Source: FERC (2008a)

According to FERC, planned deployments of advanced meters scheduled to take place in the near term (during the next 5 to 7 years) is nearly 52 million, representing a nearly eight-fold increase.[10] When combined with the 6.7 million advanced meters already deployed, the total penetration of advanced meters in the near term will approach 40%. Notably, however, while approximately 11% of advanced meters are being used in price responsive demand response programs, less than 1% is being used in conjunction with home area networks or with other technologies that have the potential to maximize the consumer benefits and residential energy savings.

To date, advanced metering technologies have achieved a relatively low level of market penetration, in the United States however, most utilities have committed to their proliferation in the near future primarily as a result of the potential energy savings and cost benefits that may be captured by the utilities. In particular, utility-based decisions about the ways in which these technologies are deployed and implemented are likely to shape the resulting energy savings levels in important ways, as well which players will benefit the most. Of critical importance is the distinction between utility benefits and consumer benefits and how the distribution of benefits is likely to determine overall levels of energy savings.

Several other countries have also implemented advanced metering solutions. In fact, Australia and Italy are most likely leading the way. In 2005, Itron dominated the North American metering manufacturing industry (measured by revenues) with 45% market share, followed by Landis+Gyr (21%), General Electric (19%), Elster (10%), and Others (5%) (FERC 2008a).[11] Today, exact market positions are unknown, but research suggests that Itron's early edge in one-way market position may be threatened by upcoming competition.

The remainder of this study reviews and documents existing research on the impact of feedback mechanisms and advanced metering initiatives. The goal is to determine the most effective strategies for maximizing energy savings within the residential sector and to generate a working estimate of the current and future impact on both energy consumption and energy expenditures—both for individual households and for the larger economy.

Following a brief discussion of the research methodologies used for this report, we begin with an overview of the characteristics of residential energy management technologies.

D. Research Methodologies

Several different research methodologies were employed to gather and assess the data that are presented in Sections II, III, and IV of this report. The methodologies for each section are discussed separately in the following paragraphs but generally include 1) an extensive literature review (including over 170 bibliographic citations); 2) interviews with utility representatives, private for-profit and non-profit organizations, and experts on feedback technologies and programs; 3) a qualitative review and quantitative assessment of 61 research studies, journal articles, program evaluation reports and other sources of primary data that assess the energy savings impact of different types of feedback (these studies describe and evaluate 57 different feedback initiatives which serve as the basis of the information presented in Section III of this report); and 4) a macro-economic assessment of the potential national-level energy savings from feedback initiatives.

Section II of the report explores in detail the many different types of residential sector feedback technologies that are currently available. The discussion and insights in this section draws from an extensive literature review from academic, news, industry, and company Web page sources, as well as several in-depth interviews with feedback product and service vendors. These efforts were

[10] FERC does not differentiate between deployments of one-way or two-way advanced meters.

[11] For a July 2009 Smart Grid industry update see The Smart Grid in 2010: Market Segments, Applications, and Industry Players (Leeds, 2009). For a January 2009 advanced metering industry update, see (Fehrenbacher, 2009a) http://earth2tech.com/2009/01/26/faq-smart-grid/. For vendor scorecards from SmartGridNews.com, see http://www.smartgridnews.com/artman/publish/Key_Players_Vendors/index.html. For a 2009 Home Area Network overview, see PG&E Presentation (PG&E, 2009) http://www.edisonfoundation.net/iee/issueBriefs/PG&E_HAN_January_2009.pdf.

focused on collecting information about feedback devices and home automation systems, including current levels of market penetration, associated behavioral considerations and approaches, services provided, product capabilities and specifications, product and program costs, cost-effectiveness, collaboration efforts, and energy savings. This information was assessed from the user's perspective with a focus on household behavior, energy savings, market mechanisms and characteristics, and technology characteristics.

Due to the role of non-utility vendors that help consumers manage energy use, we conducted several in-depth interviews with both utility advanced metering and non-utility in-home technology and service providers. The number of interviews was necessarily limited, therefore, we only included a few companies specialized in taking an approach to feedback that ideally included behavioral insights associated with providing effective residential sector feedback products and services. Since the advanced metering and home area technology and service industries are large and growing daily, the interviews were selected solely to provide a big picture view and to develop an overall framework of the consumer-facing side of the smart grid industry—not to select technology, industry, or company "winners".[12]

The collection and analysis of data for Section III of the report involved an extensive review of prior work including several meta-reviews on the topic as well as feedback-related journal articles, reports, program evaluation documents and other sources of information. In all, information from more than 150 publications was assessed. The core findings of the meta-review and analysis were based on a qualitative review and quantitative assessment of 61 primary research studies as reported in journal articles, program evaluation reports and other documents. These studies describe and evaluate 57 different feedback initiatives, span a range of 36 years (1974-2010), and represent work on several different continents and nine countries.[13]

The data collected for the meta-review were assessed using descriptive, bivariate and multivariate assessment strategies, providing the means for a more nuanced exploration of the data as well as a higher level of familiarity with the quirks and inconsistencies associated with a large subset of the studies. More sophisticated statistical techniques were not employed due to the limited number of studies, the considerable variability in the quality of the studies, and the intention of the researchers to avoid creating a false impression concerning the strength of the data and the findings that were drawn from them. As stated elsewhere in the report, because these findings are rooted in a relatively small sample of studies that vary greatly in their quality, they are best characterized as a comprehensive review of existing evidence but somewhat preliminary in nature. In the future, as the number and quality of studies on this topic continues to expand, additional assessments will be able to apply more rigorous assessments using more sophisticated statistical methods.

Appendix A provides a complete listing of all of the studies and feedback initiatives that were included in the meta-review. Most of the tables in Section III of the report show the average and/or median feedback related savings across specific groups or subgroups of the studies listed in Appendix A. Important groups and subgroups were identified by means of the literature review as well as exploratory analysis of the data. The relevant groups and subgroups used in bivariate and multivariate assessments include feedback type, study era, study duration, study size, and location of the study.

Both qualitative and quantitative assessments were used to assess information concerning the persistence of energy savings. Qualitative assessments of reported persistence were based on a collection of statements and characterizations of persistence as they were made in approximately 28

[12] We recognize that there are at least 400 different companies in different stages of maturity from start-ups to established market players that have similar products and services. We do not intend to endorse any company, to exclude any company, or to assess relative market positions. As pointed out by one reviewer, a complete industry assessment is likely needed since many others engaged in innovative activities would be valuable for developing the market. Although the authors conducted fairly extensive industry research, it is out of scope to analyze and report on every company in the industry. In fact, it is near impossible to keep track of the industry without following it daily.

[13] A more detailed characterization of the studies is provided in Section III.

of the 57 initiatives included in the meta-review. A summary of these statements can be found in Appendix B. Subsequently, the qualitative review was compared to a quantitative assessment of the relationship between study duration and energy savings. Our initial expectations were that persistent savings would be evident through both a qualitative reporting of such a relationship in individual studies as well as a measurable quantitative relationship such that longer studies experienced savings that were greater than or equal to shorter studies. Instead the comparison of quantitative and qualitative results revealed conflicting results. The paradox was resolved through further qualitative assessment of the studies that explored the distinct characteristics of both shorter and longer duration studies. The results are presented in Section III.B.4 of this report.

Finally qualitative and quantitative assessments were used to assess information concerning the effects of motivational elements (Section III.B.3) as well as the effect of feedback programs on the establishment of new habits, lifestyles and choices (Section III.E). The discussion of motivational elements primarily consists of a literature review which summarizes both quantitative and qualitative evidence concerning the effects of programs that use social norms, goals, commitments and other social mechanisms to encourage energy savings. The section on new habits, lifestyles and choices provides a detailed review of qualitative assessments as they appear in the primary studies as well as qualitative comparisons of disparate quantitative measures.

Section IV of the report uses a Monte Carlo scenario exercise to develop estimates of potential, national level energy savings that could be achieved through the widespread implementation of different types of feedback programs throughout the residential sector. As specified in Section IV of this report, the Monte Carlo estimation approach uses energy data from the AEO in combination with feedback-specific estimates of potential household-level energy savings and participation rates to develop aggregate savings estimates. Among the critical inputs to the model are: 1) an estimated range of household-level energy savings associated with three particular types of feedback, 2) an estimated range of household participation levels, and 3) estimated technology costs associated with the different types of feedback.[14] In all, we specify and explore the potential energy savings associated with four potential combinations of feedback type and level of participation. The scenarios selected (enhanced billing with high participation, real-time feedback with low participation, real-time feedback with high participation, and real-time plus feedback with high participation) reflect a range of potential scenarios that provide the means to assess the costs and benefits of different policy paths. For each of the four scenarios, the Monte Carlo method runs 10,000 estimates by randomly selecting a measure of energy savings and participation from within the specified range. The final estimate reflects the average measure of energy savings from the 10,000 estimates.

II. CHARACTERIZING AND DESCRIBING RESIDENTIAL SECTOR FEEDBACK TECHNOLOGIES

This section provides a basic summary and discussion of residential sector feedback technologies; their importance to utility advanced metering initiatives; and the advantages and disadvantages of specific feedback technologies. Of particular interest is the actual and potential role of these technologies in empowering consumers, facilitating new, smarter energy use behaviors, and reducing residential energy consumption. During this review, consumer behavior was defined broadly to include behavioral change associated with energy conservation, energy efficiency, and reductions in peak demand. In addition, based on this review, the following approaches comprise the best set of energy efficiency behavior practices as they are now implemented: real-time feedback, commitment, goal setting,[15] social comparisons, normative messaging, and engaging participants in small, actionable steps.[16]

To provide the big picture, we first describe the overarching smart grid. We next employ an analogy of an onion to frame the different types of feedback and automation technologies, starting with a

[14] These estimates are drawn from the information presented in Sections II and III of this report.
[15] With goal feedback framed as commitment to a goal (rather than progress) (Zhang, Fishbach, & Dhar 2007).
[16] For more information on small, actionable steps, see the third principle for embracing customers as co-creators of smart meter value (Honebein, Cammarano, & Donnelly 2009).

characterization of utility feedback approaches, specifically advanced metering systems. Next, we explore non-utility technology feedback and automation solutions, and then discuss home automation—focusing on do-it-yourself (DIY) and vendor product and service solutions. The section ends with technology-related conclusions. Although they are very important issues, it is outside the scope of this report to consider issues of data ownership, security, standards and interoperability, or privacy.

A. The Overarching System: The "Smart Grid"

Smart grids are currently being deployed in the U.S. and around the world. The "smart grid" is generally the system that delivers electricity to the specific end-use, including electricity generation, transmission lines, and distribution systems. In some situations, the smart grid can even include smart appliances, feedback displays and other devices operated inside the consumer's home. With actual deployments varying by utility, the U.S. Department of Energy (DOE) includes the following basic technical elements within their smart grid definition:

1. Integrated, open architecture, real-time communications for information and control;
2. Sensor, measurement, and interface technologies for monitoring, system diagnosis, decision-support, feedback, time-of-use (TOU) pricing, and demand-side management, etc.;
3. Advanced components, such as superconductive transmission lines, storage, power electronics, and diagnostics; and
4. Control and monitoring methods that make it possible to solve problems quickly and accurately (DOE 2009, Kay 2009).

Implementing the U.S. smart grid is complex, requiring intelligent and efficient communications over a shared, interoperable network that currently includes about 14,000 transmission substations, 4,500 large distribution substations, and 3,000 public and private owners (Fehrenbacher 2009a, DOE 2009). In fact, residential consumer participation in the smart grid (which would involve household energy management) likely depends heavily on the integration of a complex network of non-utility residential measurement, feedback, and automation product and service vendors.

The next section introduces the onion metaphor to define consumer-facing feedback and automation technologies.

B. Defining the Consumer-Side of the Smart Grid

Inside the residential consumer's home, feedback and automation technologies can be used to involve the consumer in managing energy use. Feedback will be explained in more detail in Section III, but for now, it is important to know that energy users can receive two primary types of feedback about their energy consumption: 1) <u>indirect feedback</u> provided after consumption, and 2) <u>direct feedback</u> provided in (nearly) real-time. To better understand the potential impacts of the feedback and automation technologies and services currently available to the residential consumer, we have constructed an analogy based on an onion. [17]

As shown in Figure 3, the outside layer of the onion includes utility-provided feedback and the core of the onion represents an entirely automated home that optimizes energy use according to consumer preferences and/or market signals. The onion is divided into three primary parts with the feedback becoming progressively more sophisticated moving from the outer layer to the inner core:

- <u>Indirect Feedback</u> (after consumption) comprises the three outer layers,
- <u>Direct Feedback</u> (nearly real-time) makes up the next three layers, and

[17] The onion metaphor grew out of the initial draft and the reviewer comments. Peter Porteous, CEO of Blue Line Innovations Inc., started the framing when he shared an onion analogy used by Blue Line Innovations. John Peterson's detailed comments also helped frame this section more clearly. Note that the onion metaphor maps fairly closely to the EPRI (Electric Power Research Institute) Feedback Types as explained in Section III (see Figure 11).

- The core represents whole-home automation.

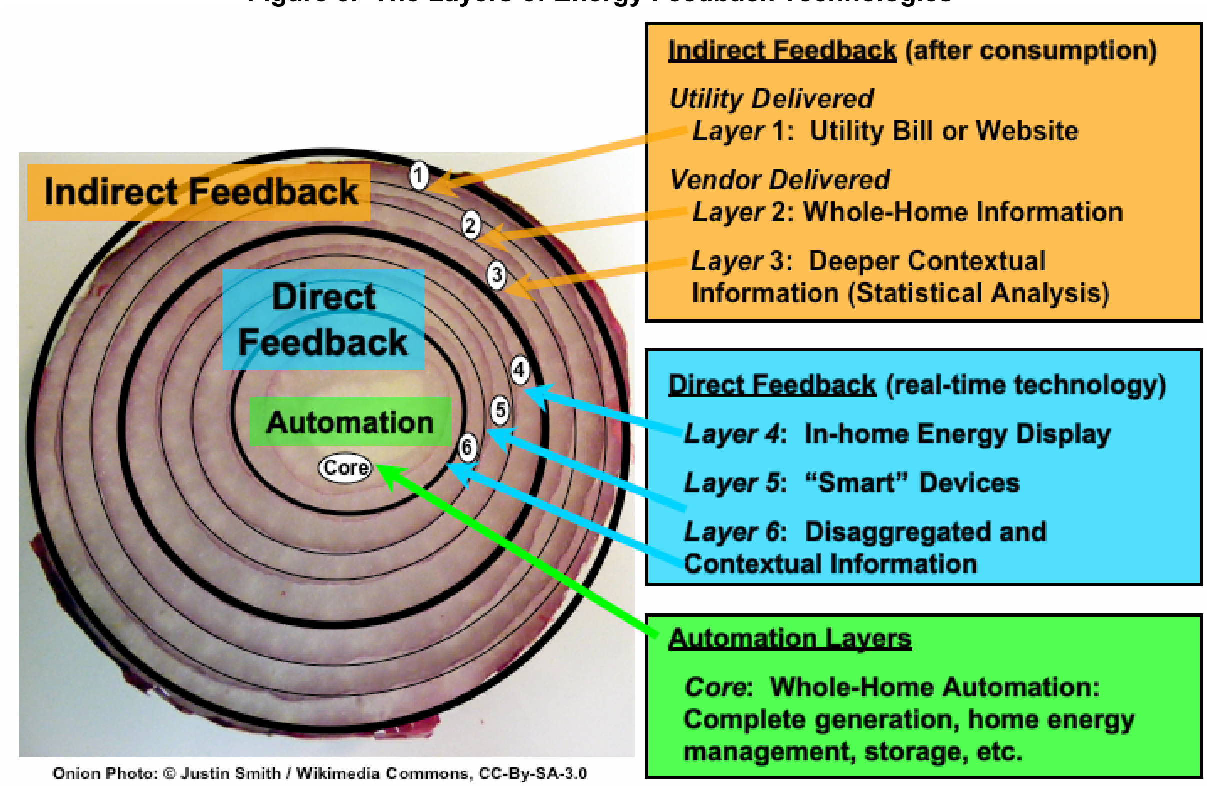
The three layers of Indirect Feedback, include feedback types such as: enhanced utility billing with specific household information and advice; estimated feedback that uses statistical techniques to estimate (and potentially disaggregate) total household energy usage based on a customer's household type, appliance information, and billing data, and daily/weekly feedback that uses real energy use measures gathered by a utility or third party and presented to the customer via the web, email, or mailed reports. The next three layers represent Direct Feedback mechanisms. They provide energy use information at the time of consumption (or shortly after consumption) and include: real-time feedback, appliance-specific real-time feedback, and simple automation. At the core of the onion, we describe whole systems that include the highest level of real-time feedback, home automation, and sometimes energy generation and storage systems.

It is important to note that both the Indirect Feedback and Direct Feedback layers of the onion:

1) Start with outer layers that include simple information;
2) Move into inner layers that provide basic information to allow people to learn by doing, and
3) Build to more specific feedback to help individuals develop a deeper contextual knowledge of their own energy use and waste (Porteous 2010).

This deeper contextual knowledge is gained through appliance-specific, historical, and social comparative feedback.

Figure 3. The Layers of Energy Feedback Technologies



Although we've separated the industry into different types of feedback to create a general framework, the vendors in this space often use one or more types of feedback and automation to provide their services, crossing through several layers of the onion at once. The next several subsections will further use the onion metaphor to describe specific technologies that are organized into onion layers by feedback and automation levels. It allows us to visualize the incremental nature of home energy management systems, and the different types of technologies that generally fit into each layer.

C. Indirect Feedback: Utility-Provided Feedback[18]

The outermost layer of the onion represents the current monthly utility bill, as well as existing and proposed advanced metering installations, that provide the consumer with limited Indirect Feedback. Although advanced metering is capable of providing energy feedback and management services to residential consumers, thus far advanced metering systems are being underutilized in almost all cases. Given this fact and the expected rate of growth of previously discussed advanced metering systems, we include advanced metering systems in Layer 1 at this time. We further describe advanced metering, including details about the technology, costs, and potential functions and benefits here.

Technology:[19] Dating back approximately to 1990, the early solid-state advanced metering, or Automatic Meter Reading (AMR), technologies: 1) record interval meter data (e.g., hourly, daily, or monthly) of whole-home electricity (or natural gas or water) use; and 2) transmit a one-way radio (or other network) signal that utilities can access using a drive-by or walk-by meter reading system. Most one-way (from the home) communicating devices have time-of-use (TOU) and other flexible pricing capability, as well as remote theft and tamper detection (Frost & Sullivan 2007). More recent solid-state advanced metering, or Advanced Metering Infrastructure, technologies can also record interval data (e.g., hourly or better). These newer advanced meters use two-way communication between the meter and the utility, meaning that utilities can remotely read the meters, as well as provide price and supply condition information to enable the consumer to react. Utilities sometimes share advanced metering data with technology and service vendors to provide the customer with more advanced indirect and direct feedback.[20]

Although it is technically feasible, only in very limited cases do advanced meters provide communication directly to the consumer via short-distance wireless, broadband, cell phone, short-range radio, and home power lines (Frost & Sullivan 2007). The technological limitations for one-way systems are that whole-home signals are sent every 30 seconds to two minutes, while two-way advanced meters can broadcast and receive signals as frequently as every seven seconds (Ruth 2009, Spaur 2009).

Costs: The total cost of a one-way meter starts at around $85 to $100 depending on the vendor and the features, such as time-of-use pricing capability (Spaur 2009, Levy 2005). The installation of two-way communicating technology is more expensive with costs also varying by vendor and meter functionality (Spaur 2009, Levy 2005). According to Itron, an OpenWay® two-way advanced metering costs start at approximately $120 (meter only); however, a total system, including the meter and utility communication, control, computers, software systems, as well as installation, costs approximately $150 per household (Spaur 2009). Further research suggests that even higher total costs per advanced metering system could be upwards of $250 per household.[21]

Functions and Benefits of Advanced Meters: The 2008 FERC survey of utilities received responses from 91% of the utilities that have installed electricity meters in the U.S. The survey asked utilities to select from a pre-determined list the ways that they use advanced metering beyond meter reading (FERC 2008a). For this analysis, the FERC survey data was sorted to focus on the answers that specifically apply to residential advanced metering systems. The analysis was conducted to

[18] For this section we interviewed Itron. Attempts were made to interview other metering manufacturers who did not respond or later cancelled the interview.

[19] Advanced metering definitions adapted from the Demand Response and Advanced Metering Coalition (DRAM 2009).

[20] These vendors make up the remaining layers of the onion and will be discussed throughout the next several subsections.

[21] Individual two-way equipment and installation costs vary on a utility-by-utility basis, making it necessary to examine individual advanced metering regulatory proceedings to determine exact costs.

determine the customer and societal benefits accruing from residential advanced metering deployments.

As shown in Figure 4, utilities with residential advanced meters indicated that they are using advanced metering to enhance customer service approximately 66% of the time. This application was followed closely by several system management reasons from outage detection (53%) and theft detection (52%) to remotely changing the meter (27%) and upgrading firmware (13%), etc. Since many of the utilities with residential advanced metering also have commercial advanced metering, it seems that enhanced customer service may not even apply to residential customers. For instance, benefits for residential customer uses were selected on a limited basis, such as demand response (19%) and pre-pay (5%), which also may or may not be exclusive to commercial customers. Using the advanced metering systems to connect to in-home appliances wasn't selected by any utility. This analysis indicates that even those utilities that are deploying advanced meters are not currently using them provide either indirect, or direct, feedback to households. In fact, FERC report makes it painfully obvious that even demand response is low on the list of priorities, and energy efficiency is completely absent from the list. Advanced metering initiatives are being driven by utility operational issues instead of concerns regarding in-home energy management.

Figure 4. FERC (2008) Survey Residential Advanced Metering Uses

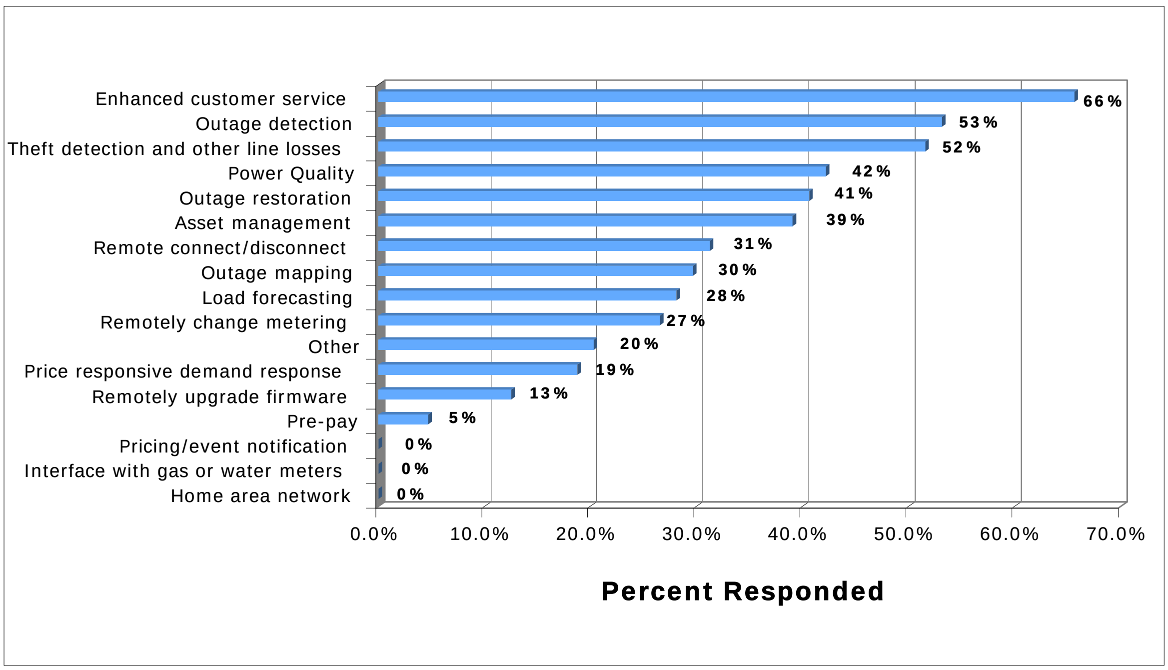


Table 6 breaks out the FERC-identified advanced metering functions (building on the functions identified in (Kathan 2008)) by how the benefits of the current installations generally accrue to utilities and residential consumers. In addition, we explore the potential benefits of widespread advanced metering deployment to society from advanced metering deployments. The "present day implementation" column is a "back of the envelope" representation of the prevalence among current smart meter deployments for each FERC-identified advanced metering function. For example, we estimate that widespread deployment represents over 50% and limited deployment represents less than 25% implementation.

As shown in Table 6, the functions that benefit utilities are more widespread in advanced metering deployments, such as: remote meter reading and connect/disconnect; outage notification, restoration, and voltage monitoring; tamper detection; and seven to 45 day on-meter memory. On the other hand, benefits that stand to strongly benefit the consumer tend to have limited deployment, such as: indirect and direct consumer feedback; demand response and pricing communications; pre-pay support; and connecting to in-home appliances and devices. In fact, most utilities with current advanced metering systems do not currently provide real-time (or even close to it) energy consumption feedback to the residential consumer—and they do not have plans to do so in the near future. The best non-pilot feedback level that we found with planned future deployment is next-day, 15-minute incremental feedback from California's advanced metering initiatives.

Table 6. Advanced Metering Functions, Implementation, and Benefits

<table>
<tr><th>Advanced Metering Functions (Kathan 2008)</th><th>Present Day Implementation</th><th>Utility Benefits</th><th>Consumer Benefits</th><th>Potential Societal Benefits (with Widespread Deployment)</th></tr>
<tr><td>Hourly, 30- min., 15-min. detailed interval meter reading of use with data capability, depending on individual deployment.</td><td>Some implementation of hourly meters; many meters still read monthly. Little to no data passed along to consumer.</td><td>System management and operational costs savings.</td><td colspan="2" rowspan="2">Little to no extra value unless information is shared. Some impact could follow from real-time (direct) and appliance-specific (contextual) feedback.</td></tr>
<tr><td>Providing feedback to consumers.</td><td>Some pilots and peak period programs provide customers feedback. Otherwise, little to no data passed along to consumer.</td><td>Could use the consumer as a demand-side resource (especially during peaks) if give effective feedback tools.</td></tr>
<tr><td>Pre-pay metering.</td><td>A few programs.</td><td>Operational cost savings.</td><td>Gives ownership/more control over usage, adds customer responsibilities that could be perceived as burdensome.</td><td>May be some benefit from residential energy conservation, but the response is likely to be curtailment when running low on the pre-paid dollars. This is especially true since pre-pay tends to be targeted to low-income customers.</td></tr>
<tr><td>Ability to connect advanced metering to in-home smart appliances (home automation).</td><td>Some pilot implementation with significant future growth expected.</td><td rowspan="2">Demand management and supply optimization. Target marketing opportunities. Measurement &Verification (M&V).</td><td rowspan="4">With enabling-technology, the customer could reduce waste, save money, manage their demand based on supply conditions.</td><td rowspan="3">Moderate to significant cost and possible environmental savings. Could allow many customers to participate in managing the energy system using enabling-technology and pricing signals.</td></tr>
<tr><td>Data warehousing systems (meter data management systems).</td><td>Widespread implementation, but very challenging.</td></tr>
<tr><td>Communicate for Demand Response, Pricing.</td><td>Limited implementation.</td><td>Demand management, supply optimization, some customer service benefit.</td></tr>
<tr><td>Outage notification & restoration (voltage monitoring).</td><td rowspan="4">Widespread implementation. Automatically included on most advanced metering technology.</td><td>Cost savings, some customer service benefit.</td><td>Significant cost savings from reduced outages.</td></tr>
<tr><td>Tamper detection capability.</td><td rowspan="3">Some operational cost savings.</td><td>Limited consumer benefit.</td><td>Limited societal benefit.</td></tr>
<tr><td>Remote meter reading and connect/disconnect.</td><td>Very limited consumer benefit.</td><td rowspan="2">Unknown. Some potential transportation-related CO_2 emissions reductions?</td></tr>
<tr><td>Remote meter firmware upgrade.</td><td>Some customer benefit, depending on firmware capabilities.</td></tr>
</table>

The simple analyses provided in Table 6 helps illustrate how utilities and regulators may be overlooking the customer- and society-side of advanced metering deployments. Although advanced metering systems are being quickly approved, only a few utility projects include direct or indirect feedback. Even fewer include social scientists in their efforts to design feedback initiatives.

Regulatory Oversight: Despite the promise of significant consumer and utility benefits of implementing well-designed feedback programs and practices, the process and structure of gaining regulatory approval is complex and cumbersome. For instance, the utility industry is regulated by multiple agencies such as, the Federal Energy Regulatory Committee (FERC), Congress, the Department of Energy (DOE), and State Public Utility Commissions (PUCs), etc. Each state utility commission approves and sets different regulations for advanced metering, demand response, and rate requirements for major investor-owned utilities. Each individual activity that the utility undertakes requires separate public utility commission approval (e.g., advanced metering, residential rates, energy efficiency programs, etc.), which causes uncertainty for the utility about whether or not programs will be approved. These uncertainties impact utility business processes, leading to slow utility innovation, and low rates of adoption of new technologies and programs. In addition, complicated advanced metering regulatory cases lead to long utility sales cycles, which increase risks for and potentially discourage vendor partnerships.

To pay for advanced metering systems, there are a variety of regulatory funding approaches, including rate-based (and rate rebates), direct cost recovery (Ontario), and Texas retail utilities have even paid for advanced metering from marketing budgets in a competitive market (Delage 2009). But, the two main ways that utility companies make money provide disincentives to take steps to reduce loads because it would reduce: 1) energy sales, and 2) the need for large-scale generation (capital) projects (where utilities are guaranteed a future minimum rate of return). In essence, the current regulatory environment and funding structures result in the establishment of inefficient energy prices.[22] Inefficient prices result when residential customers are charged the same rate for a whole month, quarter, or year. A flat price means customers that don't have to think about when or how they are using electricity. For example, the majority of U.S. residential consumers pay a flat, or tiered (surprisingly sometimes rates decrease as consumption increases), electric rate that does not reflect actual market conditions (FERC 2008a). A few U.S. utilities do offer time-of-use (TOU) pricing, such as peak/off-peak rates, and/or demand response programs designed to discourage consumption when supply is more expensive (FERC 2008a).

Specifically, to gain state public utility commission approval for an advanced metering deployment, the utility must demonstrate a positive cost-benefit business case. In 50 to 90% of the cases, the business case for advanced metering deployment is justified by reduced operating costs and improved system management (FERC 2008a). Generally, utilities use the advanced meters to reduce billing data collection costs, and in some cases for remote disconnect for past-due customers (Galvin Electricity Initiative 2007). In fact, some utilities have proven a positive business case for advanced metering without involving the customer at all (by means of demand response or energy efficiency programs). Hence, our research strongly suggests that advanced metering system are not using the available tools to reduce consumer energy waste.

Conclusions: Most of the feedback available to today's households is provided by utilities and it consists of simple, indirect feedback. This outer layer of the onion, representing the least-effective form of feedback to the consumer, and does not motivate consumers to reduce energy consumption or energy waste. On the other hand, it is not clear that the responsibility for consumer-facing feedback should be held by utilities. Utilities may not want to convince their customers to use less energy except in limited peak periods. Moreover, forward-thinking consumers may want to make their own choices by purchasing feedback enabling-technologies and services directly. By doing so,

[22] By inefficient prices we mean utilities rates that do not reflect the full social or environmental costs of producing and consuming electricity. Hence, consumers, in this case, are given incomplete or inappropriate information about the impact of their choices to use electricity or to conserve or invest in more energy efficient behaviors and technologies.

consumers would be able to choose from the numerous vendors that are aligned with the social science and behavioral aspects of energy consumption, as explored in the next few subsections.

Technological Considerations: Growth in the deployment of advanced meters has resulted in a significant increase in the potential for peak load reductions associated with demand response programs (FERC 2008a). Moreover, actors at the state, federal and utility levels have been working to actively promote advanced metering initiatives and to remove barriers to demand response programs (FERC 2008a). However, the installation of advanced metering systems remains as a significant challenge for utilities, and few have actively invested in establishing a consumer-facing side of the smart grid that could realize significant energy savings in the residential sector. Notably, however, current evidence indicates that smart meter deployments alone will not provide the type of feedback or automation that residential customers need, even though the advanced utility meters are technically capable.

On the other hand, advanced metering is not the only means of providing households with feedback on their energy consumption, and it remains unclear if advanced metering initiatives are the best method for doing so. For instance, there are real limitations to providing real-time feedback using advanced metering systems. Advanced metering systems currently require greater amounts of power to send a stronger and/or more frequent signal. In addition, the frequency of the signal update from advanced metering infrastructure is limited to seven second intervals to avoid network traffic jams (Delage 2009; Spaur 2009). Despite these limitations, we know that indirect feedback that is broken out by the appliance level can be effective. Industry research suggests that for an incremental cost, it would be feasible (from an engineering standpoint) to upgrade advanced metering hardware with low-power micro-measurement, analysis, and communication chips to enable appliance-specific data, as well as automation for large appliances, such as heating and air conditioning units, pool pumps, etc. For instance, consider a new prototype chip from Intel that will soon provide whole-house appliance specific feedback, as well as future remote control capabilities (Kanellos 2010).

Regulatory Considerations: To a large degree, the future of how much feedback advanced metering will provide is in the hands of regulators and utilities. When designing the advanced metering business and rate cases, three very different sets of needs should be considered: those of the customer, the utility, and society at large. As such, regulators should require that advanced metering initiatives provide cost-effective, smart feedback and open protocols to enable the consumer to adopt the products and services on their own. This could potentially include home automation facilitated by utility price signals. The important point is that the customer should stay as involved and in control of his or her energy use to whatever extent they prefer. In a sense, this leads to a recommendation for policy-makers to rely on performance standards rather than prescribing specific technologies. For example, the regulator may have a goal of 20% energy efficiency by 2020, but the means should remain open and flexible.

The next few subsections peel back the exterior layer of the onion and explore the benefits and disadvantages of different types of indirect and direct feedback, as well as whole home automation. The discussion also includes an assessment of how these different feedback approaches might better enable consumers to manage their energy consumption and reduce energy waste. We start by exploring indirect feedback mechanisms provided by third party vendors using utility data.

D. Vendor Provided Indirect Feedback of Utility Data

Layers 2 and 3 of the feedback onion include several different types of indirect feedback, including aggregate or whole-house feedback as well as appliance and end use disaggregate feedback (e.g., estimated appliance-specific, historical comparisons, social comparisons, etc.). These types of feedback are provided by means of web-based presentations and utilize a variety of data sources including electric utility data and other existing types of data (e.g., assessor parcel maps, home audits, census, etc.). Able to deliver processed feedback on the consumer's computer, smart phone, iPad, etc., there are numerous service providers that leverage existing data to provide personal and social contextual feedback. Table 7 briefly describes three such companies that provide behaviorally-focused indirect feedback to residential energy consumers (after consumption with no automation).

Table 7. Example Vendors providing Indirect Feedback of Utility Data

Company	Feedback Technology	Behavior Principles	Maturity
OPOWER	Depending on utility, send monthly or quarterly mailings, and/or provide Web site with newly forming social networks.	Feedback Type: Indirect including: Household information and advice, web-based energy audits, billing analysis, estimated appliance-specific, CO_2, kWh, & $. Behavior Principles: Social Comparisons, Goals, Personal Comparisons, and Action Steps.	Growth Stage
Efficiency 2.0	Social community Website with energy and water consumption feedback.	Feedback Type: Indirect including: Household information and advice, web-based energy audits, billing analysis, estimated appliance-specific, CO_2, CO_2, kWh, $, and other units. Behavior Principles: Social Comparisons, Goals, Competitions, Social Networks, Personal Comparisons, and Action Steps.	Start-Up
Google.org	Google.org PowerMeter on Website, including Google social networks.	Feedback Type: Indirect including: Household information, estimated household and monthly bill, estimated appliance-specific. Behavior Principles: Social Comparisons, Goals, and Personal Comparisons.	Established start-up for the Google PowerMeter

Technology: Indirect feedback is primarily derived from monthly utility data or in very limited cases more frequent advanced metering interval data. The effectiveness of waiting for the utility to process the data adds a potentially costly delay to indirect feedback approaches. On the other hand, several vendors use statistical software algorithms to analyze existing data and user input to provide deeper personalized and contextual knowledge. Most utility-side indirect feedback vendors communicate feedback to households over the Internet, although several have mobile phone, TV, and other enabling-technology applications. In fact, many indirect feedback vendors can add enabling-technology to the solution, such as energy displays and smart appliances (both described in the next two direct feedback subsections).

Market: In contrast to markets for other feedback-related technologies (discussed later in this report), the market for the technologies discussed in this section is relatively new. This market was started approximately four years ago and may be just beginning to gain traction. For instance, OPOWER (formerly known as Positive Energy) has announced at least 11 partnerships with utilities; Efficiency 2.0 has embarked upon a number of U.S. partnerships and pilots; and Google.org announced partnerships with nine diverse utilities in May 2009. In addition, Google.org has recently partnered with Itron (with 8,000 utility partners), G.E., and Tendril (Lu 2009). In the long-term, Google.org plans to get involved in the home area network industry to make energy information more accessible and useful to end-users.[23]

Efficiency 2.0 sells a white label software service and charges licensing fees based on energy savings. They also hope to work with regulators to get direct credit for energy savings based on their software's measurement and evaluation functions. On the other hand, Google.org has stated that

[23] Another big software player, Microsoft, recently introduced Hohm energy management software (Fehrenbacher 2009b), and also has partnerships with advanced metering companies, including Itron and Landis+Gyr (Leeds 2009).

making money is not the project driver. For instance, Google.org hasn't done any revenue modeling, isn't considering ads in the near-term, and won't charge utilities or users for the service (Olsen 2009).

Feedback and Behavior: Feedback and other behavioral principles (outlined in Table 7 above) are discussed in this section. Web-based software vendors fit into the next two indirect feedback onion layers, crossing across Layers 2 and 3 by providing:

1. Basic energy consumption and energy cost information, where a person learns by doing, and
2. Some deeper personal and/or social contextual knowledge through the framing of the data.

As an example of learning by doing, a person first learns the cost of running the air conditioner (through feedback), decides to set back the thermostat, and actually does it. The person will also likely have to reprogram the thermostat from time to time. Household-specific energy information is provided in the form of: monthly, historical, and specific device-level usage. The second type of feedback provides contextual information about the energy use patterns of other households so as to provide a contextual frame from which any given household can assess their energy consumption performance relative to other people in similar circumstances. Comparisons with neighbors, friends, and communities provide a social context and information about what actions others are taking. OPOWER's approach uses utility data which they then combine with other data sources, and transforming it into tailored feedback that is more readily accessible by residential consumers (Kavazovic 2009). The use of a greater number of data sources enables a deeper contextual understanding of the audience without requiring that households provide a large array of data themselves.

OPOWER's feedback programs are based on the provision of home energy reports which are provided to residential consumers through the mail (usually separate from the utility bill). To date, OPOWER has developed several versions of the reports which have been field tested in several locations. In their first utility partner, OPOWER worked with the Sacramento Municipal Utility District (SMUD), to test multiple report schemes including monthly vs. quarterly, graphical vs. text-weighted, and different envelope designs (Figure 5) (Ceniceros & Bos 2009). In order to engage consumers to incrementally learn about energy, OPOWER provides tailored recommendations to each household with suggestions regarding actions that they can take to save energy. Their tactical action steps for a renter who is unlikely to make any large, strategic investments on new appliances are oriented to energy saving behaviors that renters are likely to engage in. For instance, a renter might be presented with a recommendations like "cool your house with a fan" (Figure 2) (Kavazovic 2009). On the other hand, a homeowner might receive strategic information, including advice associated with the purchase of a new ENERGY STAR refrigerator or a suggestion to replace the home's air conditioning system and information on how to get rebates. In an attempt to invoke social motivations, OPOWER has also developed a carbon calculator for SMUD with the goal of providing non-financial motivation to certain customers to "do the right thing" with respect to climate instability. OPOWER has also developed a dynamic efficiency database that consumers can use to provide more specific household information and find those tips that are most relevant to them (Kavazovic 2009). The Web interface enables contextual learning, allowing users to dig deeper into their energy consumption patterns.

Figure 5. Example Feedback: Social Norms and Action Steps (Kavazovic 2009).

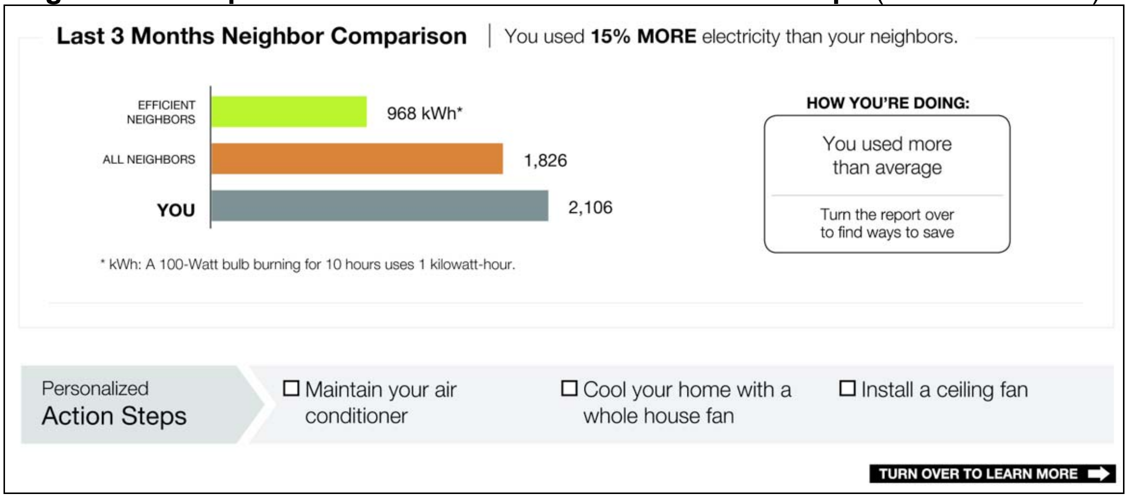
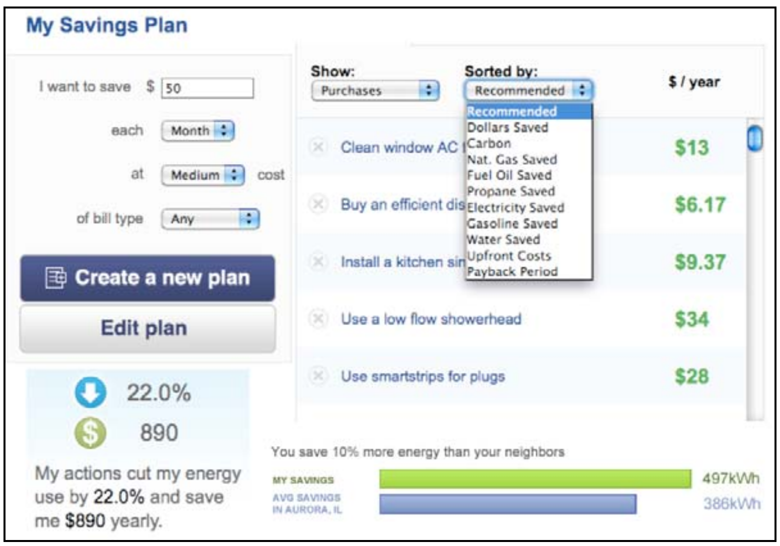


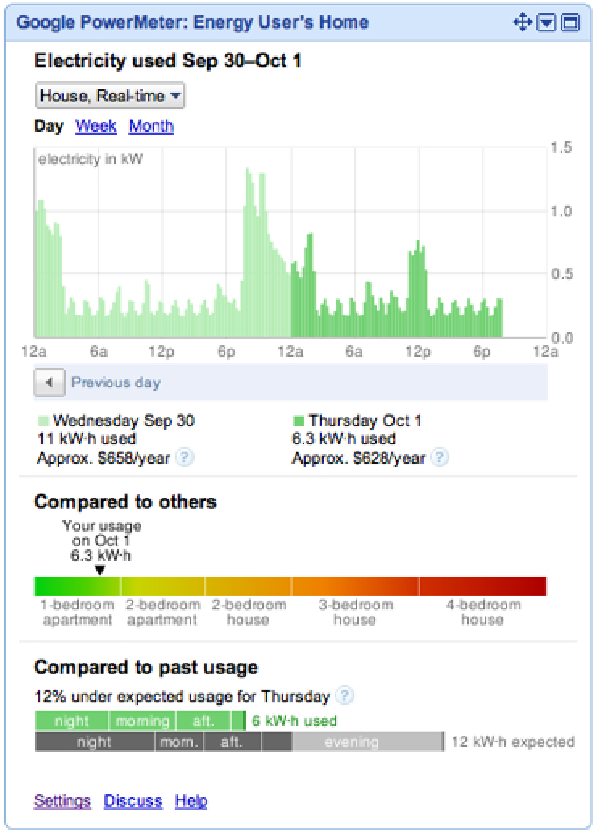
Figure 6. Efficiency 2.0 Savings Plan: Information, Goal-Setting, and Feedback



Another company, Efficiency 2.0, uses similar data acquisition, analysis, and behavioral, and feedback techniques as OPOWER. Their software (see Figure 6 above) is designed to create a customized Savings Plan based on user parameters and inputs, such as desired spending, savings goals, rates, and personal values.[24] Efficiency 2.0 tries to increase engagement in energy decisions and to influence passive consumers (Frank 2009). To personalize the feedback, algorithms are used to evaluate the costs and benefits of hundreds of possible actions that might be undertaken by consumers or households. Comparisons are made in terms of an estimated baseline energy use. The Website's anticipated energy bill savings from technology and behavior actions are then confirmed using interval (usually monthly) billing data (Frank 2009).

[24] Results vary based on the amount of user input and participation.

Figure 7. Google.org PowerMeter Example



A third company, Google.org, is also leveraging existing data sources to provide residential sector energy feedback. The primary goals of the Google.org PowerMeter (Figure 7) are to make information accessible and useful, and to leverage commitments from users to create smarter energy choices. Google.org considers the impact of the feedback to be the "most important metric of success." Google.org contends that personal energy use data belongs to the consumer and that it should be available in a standard, non-proprietary manner. In the short-term, Google.org plans to harvest data from utilities, but the organization has also partnered with a company that produces an in-home energy measurement and display device, The Energy Detective (TED 5000). TED 5000 uses current clamp hardware to measure, monitor, and report electricity consumption. Although they don't directly disaggregate the signal, Google.org is training the software to recognize energy signal patterns and correlate them with appliance-specific usage like the dryer or refrigerator (Olsen 2009).

Conclusion: Companies that provide indirect feedback offer evidence that post-consumption feedback can be provided with existing technologies and using existing data. Notably, these approaches do not require any *additional advanced metering hardware*. The approach primarily focuses on presenting feedback on household patterns of energy consumption, making it meaningful through the use of aggregate patterns of energy consumption, and providing tailored recommendations regarding actions that households can take to save energy and reduce energy waste. These types of feedback can enable residential consumer to choose which energy-saving actions to take as well as the scope of behaviors they engage in. Although most of these technologies have only recently been introduced to the market, these approaches are likely to include increasingly complicated analytics as more detailed, frequent, and disaggregated data becomes available. By moving in this direction, these technologies are likely to deliver even better contextual information to the consumer.

Technological Considerations: Google.org has recently opened the software platform to selected developers, which could spawn other in-home energy display and feedback device innovations (e.g., smart phone applications). Google.org's product development philosophy is to release early and leverage user feedback and innovation to constantly add new features, following a successful product/idea development approach commonly known as crowdsourcing, or Collective Intelligence (Howe 2008, Shirky 2008). This way, Google.org may be able to harness the power of the crowd to quickly develop solutions (Olsen 2009).

In addition, there has been a recent introduction of a number of free websites that "scrape" a person's electricity and natural gas consumption information directly from the utility's website. The person in a sense logs into his or her utility Website via the free indirect feedback website. Then, depending on the Website participation nearby, a participant can also received comparisons with people in the neighborhood, the state, and the U.S. Some sites also have shopping platforms, where one can purchase sustainable products like, energy efficient light bulbs, low-flow showerheads, or dryer cleaning kits. Often times, a person will receive points to use towards products or services for saving water or energy. A consumer can use these platforms today for free to receive feedback about existing monthly data at the very least. [25]

The future of feedback may also be very different for children and young adults. For instance, Efficiency 2.0 has built a virtual world, social networking software platform, Climate Culture, with the objective of raising energy awareness in a younger audience. They are part of a recent trend in massive multi-player online games (MMOGs). In fact, interest in online energy efficiency gaming seems to have increased significantly since 2008 or 2009. For instance, Stanford University professor, Byron Reeves, is building a MMOG game based on smart meter data and energy consumption (Wagner 2009). The game is based on behavioral research, as well as the emotional investments of players in their characters and in the goals of the game (Wagner 2009). Additional research on this topic uncovered several other types of social networking and gaming sites, indicating some level of interest in on-line social involvement in energy consumption and climate change.

Market Considerations: The involvement of independent companies and organizations in the development of energy feedback mechanisms is likely to be the consequence of two potential factors: 1) utilities are currently unable or unwilling to provide competitive consumer-facing feedback and/or, 2) third party interests have recognized the value of reducing residential energy waste more quickly than utilities and regulators. Regardless of the reason, the companies who are entering the field bring with them unique approaches to solving feedback problems. Experienced with fast product development and growth, Google.org uses an open software approach that should encourage developers and users to contribute to the complexity of the PowerMeter. If contributed to by the masses, it could potentially level the playing field for innovators and vendors to drive down costs in the market. Depending on user contribution levels and vendor partnerships (and because the product seems to be free to utilities and customers), the Google.org PowerMeter may have the potential to quickly grow a home energy management industry, while accumulating large amounts of data regarding home energy use.

Although these approaches to residential feedback are still at an early stage, this approach to indirect feedback appears promising. In combination with the enabling-technologies described in the next section, real-time, appliance-specific information becomes possible

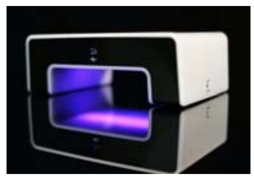
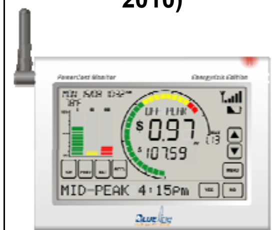
E. Direct Feedback Using In-Home Energy Displays

Moving further inside the onion to Layer 4 (as seen in Figure 3), real-time, direct feedback provides a wide range of contextual knowledge to users and enables users to learn by doing as well as through the provision of more tailored and socially-relevant feedback. For instance, in-home energy management displays provide the potential for "learning by doing" when the user carries the device through the home while switching on and off devices. The user receives immediate, appliance-

[25] See, for example, http://wegowise.com/, http://www.earthaid.net/, http://www.wattzy.com/

specific feedback that allows him/her to learn about energy in an incremental fashion. A few of the in-home energy displays that focus on behavior principles are shown in Table 8. The next section discusses some of their specific characteristics.

Table 8. In-Home Energy Display Device Examples

	The Energy Detective TED 5000 	**Wattson** 	**PowerCost Monitor (WiFi edition due mid-2010)** 	**Efergy Elite** 
Technology Description	Display, Supportive Software, Mobile Applications	Display, Supportive Software with Holmes and 20TEN Communities	Display, Supportive Software, Mobile Applications	Display
Feedback Mechanisms	Displays real-time kW, \$/hr, CO_2; daily kWh and \$; billing cycle in kWh, \$, peak use, min/max V, and projected cost and demand. Viewable in seconds, minutes, hours, days, months. Alarm: red flashing light, beep.	Displays near real-time usage in W, kW, and estimates bill. 3 to 20 s readings. Glows by usage: blue=low, purple=average, red=high.	Displays near real-time (30 s) kW and \$/hr, peak usage in last 24-hrs, counting kWh (reset), appliance measurement feature.	Displays near real-time in kW and \$/hr (6, 12, or 18 s readings), hourly, daily, weekly, monthly, and average information. Alarms for high usage.
Consumer Behavior Principles	<u>Feedback Types:</u> Direct including: Household feedback and advice, web-based energy audits, billing analysis, estimated appliance, CO_2, \$. <u>Behavior Principles:</u> Social Comparisons, Goals, Personal Comparisons, and Action Steps.		<u>Feedback Types:</u> Direct: Household feed-back, billing analysis, est. appliance, CO_2, \$. <u>Behavior Principles:</u> Goals and Personal Comparisons.	<u>Feedback Types:</u> Direct: Household information, billing analysis, Elec., \$. <u>Behavior Principles:</u> Goals and Personal Comparisons.
Cost	\$239.95 (& up for addl. circuit sensors and/or solar/wind connections)	£99.95 (UK only)	\$250	£39.95

Technology: Almost all in-home energy displays provide whole house, near real-time electricity consumption information. There are numerous other energy displays on the market that contain some combination of the standard features shown in Table 8 with most of them being very similar to the Efergy. In most cases, the data are sent from the home's main circuit panel, where they are measured using two to three current clamps that wrap around the home's electricity mains. In some cases, such as The Energy Detective (TED 5000), the energy display can monitor up to four 220 Volt or eight 110 Volt circuits or separate consumer appliances and devices. It is sensitive to as little as one Watt of electricity consumption. This means, the device can provide circuit-level data, so it is conceivable that one would know how much electricity one is using in the kitchen, family room, bedrooms, bathroom, or anywhere else, thereby providing more specific feedback to enable households to make smart, money-saving changes in their energy usage. On the other hand, with its simple installation requirements, the PowerCost Monitor optically "reads" 90% of existing utility meters by clamping around the meter ("reading" the spinning dial or receiving an optical pulse). While easier to install, the accuracy of the device is also a bit lower relative to other, similar feedback devices.

All but a few energy displays transmit near real-time, whole-home (or in limited cases circuit-level) data to the display using wireless technologies. Communication ranges to the display vary from 30 meters up to 70 meters, depending on the home's signal obstructions. A few devices communicate over the home's electricity lines, using what is called powerline communication. Most of the units include batteries, but the newer energy displays are deploying rechargeable units. Data storage capabilities vary greatly and are dependent on the number of on-board components. For example, the Wattson can hold 28 days worth of data, while the TED 5000 can store up to 10 years worth of data. Several other monitors fall somewhere in between, including the PowerCost Monitor and Efergy with one and two years' worth of data storage capacity, respectively. Other features also vary greatly among the representative displays shown in Table 8. For example, the Efergy and Wattson provide simple, easy to read displays, while the TED 5000 includes web, mobile, and stand-alone display technologies that can coordinate with a complete home generation and automation network (discussed later). Notably, these technologies are changing rapidly. For example, while the PowerCost monitor was previously a simple $100 in-home energy display, a more advanced WiFi edition will be coming out in mid-2010 for a similar price.

Market: The current end user market for in-home energy displays continues to consist primarily of early adopter types, however there is evidence that interest is expanding quickly. Certainly, the product offerings are becoming more and more consumer-focused with several companies currently offering technologies that involve a second, third, or higher-level product release. In addition, marketing evidence indicates a growing number of partnerships among energy display companies. For example, The Energy Detective has partnered with Google.org's PowerMeter to provide indirect and direct feedback into one product. In addition, while the PowerCost Monitor initially gained their market position through utility promotions (such as rebates and giveaways), the manufacturer (Blue Line Innovations Inc.) is currently focusing on direct-to-market sales and has developed partnerships with Black and Decker, Elster meters, SmartHome.com, newegg.com, Fry's electronics, etc. (Porteous 2010). Each of these partnerships provides the residential energy user with increased accessibility to both direct and indirect forms of energy feedback.

Feedback and Behavior: As shown in Table 8, while feedback types are relatively standard, the application of consumer behavior principles varies widely by energy display. For instance, some devices display information in ambient ways through colors and alarms and some provide indirect feedback through websites or on a digital T.V. (Darby 2008). At a minimum, all feedback devices provide household-level information, some billing analysis, and estimated usage for some period of time. Most of the stand-alone displays show household energy use information (such as electricity usage and cost per hour) in near real-time (2 to 30 seconds). Other displays provide information on energy-related carbon dioxide emissions, voltage, peak-use, and other measures. Each of these measures provides additional signals to reduce waste. Notably, however, most energy displays do not provide direct operational services, such as demand response and dynamic pricing signals. Nevertheless, most of the energy displays are programmable for various fixed-rate structures, including: increasing block rates, time of use, and other rate components, such as taxes, System Benefits Charges.

In some cases, displays and supplemental web software packages provide additional personal and social contextual information, including household baseline energy use information, energy use trends, projections, alarms, and goal tracking. A few energy displays, such as the Wattson, also include on-line communities that can provide social comparisons to potentially help consumers gauge their own consumption patterns. In addition, this feature allows community members to consult each other for advice about effective means of reducing energy waste. Some devices are opening up their developer communities with the aim of increasing innovation and product flexibility. For instance, the WiFi edition of the PowerCost Monitor will have an open platform for certified partners to build Web and mobile phone applications. The goal is to enable access for the consumer to their data and to improve consumer choice about how to use the energy display (Porteous 2010).

Conclusion: As with all of the other types of feedback analyzed thus far, the effectiveness of the energy displays discussed in this section will be highly dependent on the design of the technology and associated applications. In other words, consumer engagement will likely vary by the number of behavior principles incorporated into the design. Future technology assessments based on user experiences will be needed to determine actual product effectiveness, however, several conclusions can be drawn.

Technological and Market Considerations: The wide range of in-home energy display products provides a variety of direct feedback types, ranging from real-time, whole-home feedback to real-time appliance-specific information. Although generally more expensive, the latest energy display models can also deliver many different types of tailored feedback as well as meaningful social contexts. Some devices are even forming utility and other third party partnerships to increase product accessibility and to enable the provision of contextual information through networks and competitions.

Behavioral Considerations: There is an open question about the product life span of some of the enabling-technologies, such as energy displays and smart thermostats that currently provide the missing data link to consumers. Currently, for instance, in-home energy displays require installation as opposed to allowing for consumer installation. The installation has proven sufficiently difficult that a significant proportion of people who have purchased the energy displays have not installed them. This is less true of the PowerCost Monitor, which doesn't require circuit panel installation by an electrician, potentially increasing its accessibility to the average consumer. Further evidence suggests that even when consumers do install the more complex displays, some fraction of the displays will become inoperable as a result of consumer failure to replace dead batteries.

The next, penultimate layer of the onion focuses on other enabling-technologies that can be layered on top of software interfaces and/or in-home energy displays to provide highly-specific, real-time feedback and automation.

F. Direct Feedback and Automation with "Smart" Devices

Layers 5 and 6 of the onion consist of energy efficient and "smart" (automated) appliances that can provide direct, real-time plus feedback, and include appliance-specific information as well as automation. Another critical feature of these smart devices is their capacity to receive pricing signals and utility load control in some cases. This section describes the broad range of feedback, behavior, and automation devices and appliances available for direct consumer purchase (see Table 9). Most of these devices can be classified as do-it-yourself (DIY), but still early-adopter, energy management tools, and include sensors (measurement, diagnostics, automation), in-home energy displays, programmable communicating (two-way) thermostats (i.e., smart thermostats), smart plugs, lights, and appliances, and utility load control devices.

Table 9. Automation, Settings, User Behavior, and Cost for "Smart" Devices

Appliance Attributes	Resultant User behavior	Regular Device and Appliance Examples	"Smart" Examples	2010 Cost Range
Low automation Many settings	User required for part of operation. Settings easily altered during operation.	Grill, Stove, Oven, Simple Thermostat, Iron, Vacuum.	Dimmer Light	$10 to $70
Low automation Few settings	User required for operation. Simple automation (turns off when not in use).	PC, TV, Light, Oven hood	Smart Outlets and Lights	$15 to $150
			Smart Power Strips	$25 to $200
High automation Many settings	User not required during operation. Difficult to change settings, causes interruption of operation.	Washing Machine, Dryer, Dishwasher	Smart (two-way) Thermostats	$175 to $250
			Energy Displays	$100 to $250
			Smart Appliances	Near-term Market*
High automation Few settings	User not required during operation. Settings easily altered during operation and rarely need changed.	Coffee Pot, Heater, Air Conditioner, Freezer, Refrigerator, Pool Pump, Water Heater	Utility Load Control Devices	$15 to $150
			Sensors/Networking Chips	$7 to $150

*This is accomplished today using smart outlets and network chips.
Source: Builds upon Wood and Newborough (2007b).

Technology and Cost: The data presented in Table 9 reflect a general behavior framework as developed by Wood and Newborough (2007b). This framework can be used to categorize different appliances by the degree to which their attributes are automated and the complexity of settings (Wood & Newborough 2007b). We expanded this basic framework to categorize examples of "smart" devices and appliances by automation, behavior, and cost features. Among the simplest data collection and automation technique is a sensing and/or communicating networking chip, such as those found in smart outlets and smart appliances, as well as lighting and automatic utility load control devices. These chips have the capacity to communicate in both a one-way and a two-way fashion. Chip cost and component complexity typically determine whether communications move in both directions.

The costs of consumer-purchased enabling technologies vary widely and are related to the complexity of the automation features. For instance, when purchased in large volumes, numerous types of networking chips can be purchased for under $10 each. The price range for smart outlets and smart power strips (devices that allow for control of individual electrical devices and appliances) can range from $25 to $200. Similarly, these devices also include a diverse array of features. For instance, a smart power strip generally has one or more "always-on" plug(s) for the T.V. control box, and five or so plugs that (manually or automatically) turn off the other entertainment devices when not in use. A more expensive smart power strip will also have a "control" appliance that automatically turns off all of the other plugged-in devices when the control appliance is turned off.

With even higher degrees of automation and more settings, the price of smart thermostats currently ranges between $175 and $250. These devices can include features such as wireless, two-way communication with the utility, LCD displays, and utility load control functions. In comparison, a high-end programmable thermostat without communication features is around $150 (Delage 2009). In the next couple of years, smart appliances such as washing machines, dryers, dishwashers, and water heaters. will also enter the market. Smart appliances typically include delayed start features and are able to receive signals regarding energy supply conditions, such as price and/or carbon emissions, and can use this information to decide when to operate. Utilities have already implemented one-way load control sensors where, with the customer's permission, the utility "cycles-off" a customer's air conditioner, freezer, or other appliance for a short time during peak period conditions.

Market: The market is almost exclusively consumer-direct purchase and do-it-yourself install, although, there is a small market segment that purchases the devices and hires an electrician (or friend) to install individual home automation components or a more complete home automation system. As has been the case for approximately 30 years, do-it-yourself components and systems are mostly purchased and installed by early-technology adopters who have a well-defined interest in energy management, carbon emissions, home automation, and/or entertainment and security systems.

Behavior and Automation: This topic is discussed in detail in the next subsection on home automation networks, as well as in the conclusions.

Conclusions: Although, it is still an early-adopter market, do-it-yourself and third-party installer home automation device sales are expected to grow considerably, especially given its ties to the other home automation market segments (ABIresearch 2009). For instance, a utility-sponsored demand response program, such as a PowerCost Monitor giveaway or rebate, as well as a consumer-direct third-party system can prove to be an important means by which residential consumer are introduced to home energy management. This introduction may also result in the purchase of additional devices and the expansion of the consumer's home network. On the other hand, this type of utility giveaway can result in lower program cost-effectiveness since some people are still unlikely to participate.

An important limitation of advanced metering strategies is that they currently require consumers to invest in additional tools, such as energy displays and/or software in order to achieve near real-time feedback. Similarly, a typical vendor-installed mainstream home automation system involves the initial purchase as well as costs associated with add-on devices, operational system changes, and professional installation; However, some companies are working toward do-it-yourself plug-n-play, home automation systems. This is important because most consumers are not willing to personally navigate through the installation and learning necessary for today's home automation systems. In fact, research on programmable thermostats suggests that many programmable thermostats are run in manual mode less than a year after installation, greatly reducing the energy efficiency potential of the thermostat.

While a motivated do-it-yourselfer can piece together a home energy management system with smart device components; this type of system is likely to have limited appeal to all but the early technology adopters that are already interested in energy-saving devices. Yet, despite the current complexities surrounding the cost and installation of home automation systems, the consumer-direct market already includes numerous and various automation software solutions, such as manufacturer-specific software for individual control of lighting, heating and air conditioning, and other electronic devices. An example of a seemingly easy-to-use and affordable ($39) home automation solution for Mac OS X operating systems is the Thinking Home. It supports at least 100 devices, as well as voice commands, scripts in several computer languages, and schedules to continue automation when the computer is turned off. It provides an example of what may be a good solution for the do-it-yourselfer that enjoys tinkering in the home. There is even a newly forming community of users to help out when a problem arises. ("Thinking Home v2.1 is here!," 2009)

The next subsection describes an approach that is best described as a complete home energy management system that leverages all of the previously described layers of the onion.

G. The Core: Direct Feedback and Automation Using Home Networks

This subsection describes the inner core of the onion (again, see Figure 3). It is really a combination of the six outer layers, including indirect and direct feedback, as well as energy-efficient technologies and automation enabling-technologies. The complete home energy management system includes a complete network of residential wireless and wired sensor networks, display and feedback devices, and automation that may or may not communicate with the utility. The home automation, or home area, network provides complete energy management, including information and control, for the residential home through a wide selection of (mostly) interoperable products and services. This means that different products and service components are integrated together and act as one system. The following subsection details both utility-centric and consumer-direct approaches and especially targets companies focused on behavioral strategies. Note that except for homeowners skilled in electronics, home automation networks require installation from a third-party vendor.

To include real-world company experience about utility-centric and direct-to-consumer market approaches, in-depth interviews were conducted with five home automation providers (summarized in Table 10). These companies were selected because they focus on whole home systems and they incorporate consumer behavior principles. Again, interviews were not chosen to select marketplace winners nor to categorize the entire home automation industry. Table 10 details a range of typical feedback, behavior, and automation vendors.

Table 10. Consumer-Focused Home Automation Network Sample Companies

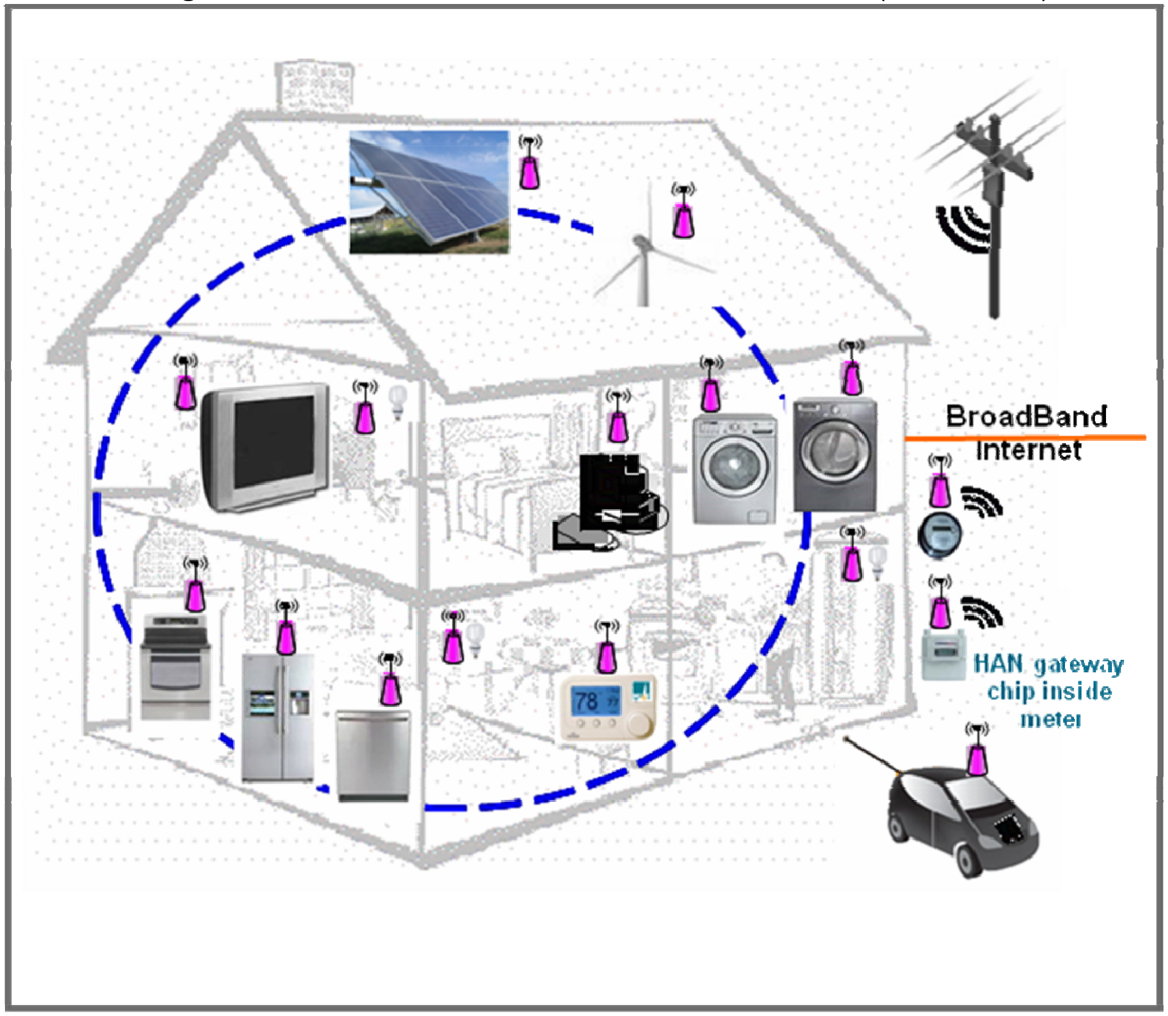
	Feedback/ Automation Technology	Behavior Principles	Automation
Control4	In-home energy and smart thermostat touch panels, TV, DVD, mobile, Web partners.	Feedback Type: Direct (<2s): Whole-home, device specific hardware, enhanced billing, estimated usage and budget, daily/weekly feedback, historical, and real-time plus. Behavior Principles: Norms, Goals, Pricing, and Actionable Steps.	Full energy, entertainment, comfort, and security automation, including all analytics and control. 5,500 automated devices for lighting, audio, video, security, and energy, such as water heaters, pool pumps, HVAC. Bridge devices to utility for direct load control and demand response.
Energate	Smart thermostat touch panel. Web partners.	Feedback Type: Direct (7s): Whole house, device specific hardware (load switch, smart plug, thermostat). Behavior Principles: Goals.	Partial home automation. Load control for HVAC, water heaters, pool pumps, lighting, with broadband gateway. Demand response, dynamic pricing via smart thermostats.
EnergyHub	In-home energy and smart thermostat touch panels, Web, mobile.	Feedback Type: Direct (<2s): Whole-home, device specific hardware, enhanced billing, estimated usage and budget, daily/weekly feedback, historical, and real-time plus. Behavior Principles: Norms, Competitions, Networks, Comparisons, Pricing, and Actionable Steps.	Full energy automation, including all analytics and control. House sleep mode, smart thermostats, window A/C, pool pumps, hot water heaters, unused devices. Partnering for utility demand response and real-time price signals.
Tendril	In-home energy touch panel, smart thermostat, mobile, Web.	Feedback Type: Direct (<7 to 10s): Whole-home, device specific hardware (2s), enhanced billing, estimated usage and budget, daily/weekly feedback, historical, real-time, and real-time plus. Behavior Principles: Norms, Goals, Competitions, Networks, Comparisons, Pricing, and Actionable Steps.	Full energy automation, including all analytics and control. Partnering with load control devices for water heaters, pool pumps, HVAC, etc. Bride devices to utility for direct load control, demand response, and real-time price signals.
Widefield Technology	In-home energy touch panel and Web.	Feedback Type: Direct (<7 to 10s energy display): Whole-home, device specific hardware (2s), enhanced billing, daily/weekly feedback, historical, real-time, and real-time plus. Behavior Principles: Goals, Networks, Pricing, and Actionable Steps.	Full home automation, including all analytics and control. Via E-hub: integrate home's remote controls with drag and drop icons on a touch monitor. Also includes environmental monitoring, load management, and demand management programs

Technology: The home automation network ranges from piece-meal parts of the network to a full-fledged interoperable network of water, gas, and electricity devices that can communicate with the utility. The complete home network can result in a system that optimizes household performance based on supply conditions and time-of-use (TOU) market prices, as well as consumer price, comfort, and environmental preferences. .

Notably, a complete home automation network will include the following components (Figure 8):

- In-home smart devices and appliances: Networking and/or communicating chips embedded in and attached to appliances and devices that allow for wireless and/or wired automation;
- Advanced network systems and software: Wireless mesh networks and/or disambiguation algorithms that provide measurement and feedback of appliance specific data; and
- Potential for two-way communication with the utility: Interface tools that analyze and display data from smart meters and utilities to in-home energy displays, smart thermostats, Web, T.V., mobile phone, etc.

Figure 8. Elements of a Home Automation Network (PG&E 2009)



For example, a complete home automation network provides monitoring and automation of appliances, lighting, space conditioning (heating, air conditioning, and ventilation systems), and/or specific electrical plug-load (anything that plugs in) and natural gas (e.g., water heater, pool pump) devices (Figure 8). It also includes some form of a consumer interface for direct, real-time feedback. The simplest home automation network begins with a smart thermostat that controls heating and air conditioning equipment and that communicates with a central computer and/or the utility's metering system. Incremental components, such as smart appliances, distributed renewable generation, and plug-in vehicles, can be added to expand the home energy network over time.

In today's market, there are three types of home energy networks available to consumers. These are comprised of some combination of the previously described layers of the onion. The three types are:

- A consumer direct purchase system;
- An utility-provided in-home energy management system [interviews with the following: Energate (Michael Delage) (Delage 2009), EnergyHub (David Wechsler) (Wechsler 2009), Tendril (Michael Ruth) (Ruth 2009), and Widefield Technology (Richard Mueller) (Mueller 2009)]; and
- A consumer-direct in-home energy management system installed by a home automation service and technology vendors, such as Control4 [interview with Paul Nagel (Nagel 2009)].

Interestingly, several of the vendors contacted for this review were stepping outside the boundaries of normal Intellectual Property restrictions and into an open-development approach. As one example, Control4 uses an "open licensing mode which allows vendors to bring their software and devices more directly and with little hassle onto the Control4 platform. This more collaborative arrangement is likely to lead to new product developments as vendors develop novel technologies and software applications that complement the Control4 platform capabilities. For instance, in January 2009 LG announced that it would embed Control4 home automation capability into their television sets. This will enable the T.V.'s energy-efficient features, such as dimming its backlights or turning it off instead of using stand-by power. Where customers are planning to purchase a new T.V. or other appliance, these embedded approaches are more energy and cost-effective than buying a separate piece of hardware. Consumers can add functionality with small incremental fees to unlock functionality and enable features when they want them (Nagel 2009). Industry research found evidence of numerous newly-forming partnerships and collaborations.

Market: Home automation technologies, including pieces from all of the onion layers, have been on the market for more than thirty years; however, it was a relatively niche market dominated by higher-end custom home automation system installations, and then followed by do-it-yourself piecemeal systems purchased directly by technology early-adopters (Galvin Electricity Initiative 2007, ABIresearch 2009). Today, the home automation industry is made up of numerous large, established companies, and countless small start-ups and recent industry entrants and is in continuous flux, continuing to grow and change on an almost daily basis. In fact, prior research has identified more than 400 active players in the residential technology and service provider segment. New players are literally entering the marketplace on a daily basis. New market players also include information technology (IT) network companies, telecommunication corporations, software system integrators, intelligence device manufacturers, and private infrastructure developers (Galvin Electricity Initiative 2007). In addition, many broadband suppliers are also planning to enter these new home automation markets and are conducting pilots that deliver managed home automation services as part of a bundled offering (Nagel 2009). Many of the major players in the residential energy management space are also engaged in expanding their product lines, and improving their offerings in communications and sensors aimed at the comfort, security, and entertainment markets (Galvin Electricity Initiative 2007). The complicated interdependent collection of technology and service vendors are often working through a web of flexible partnerships and joint ventures to implement new business models; many aimed at capitalizing on future utility demand response opportunities (Galvin Electricity Initiative 2007). In addition, many companies are also expanding into non-residential market segments (e.g., hotel, residential via contractors, consumer electronics, light commercial, and elderly care, utilities, etc.). These new opportunities should improve the experience of vendors and also lead to lower costs as the scale of the technologies increase.

Currently, the main customer demographic of vendors includes single-family homes with large energy use patterns that enable cost-effective automation (Delage 2009), although multi-dwelling installations are also beginning to occur with some frequency. Companies are beginning to see the value of both approaching the customer through the utility and/or going directly to the consumer. Most of the companies we examined have traditionally approached the market through the utility and provide devices that communicate with the utility's advanced metering and/or backhaul systems. . At the same time, most vendors are fairly platform-agnostic, communicating with both standards-based and open systems. While many home automation network vendors, like Tendril, are primarily focused on a utility-centric approach, others are considering or developing direct-to-consumer solutions. A third option, as practiced by Control4, involves a combination of the two approaches.

While exact installation numbers per company are unknown, Control4 has approximately 80,000 customers using their home automation systems, and have shipped over one million ZigBee devices mostly to approved home automation network installers throughout the country. They offer an astounding number of devices (5,500) that operate on a common and affordable platform including devices to control TV operation, security, irrigation, door locks, and other devices. They also support a large selection of interoperable products and platforms (including legacy systems such as Ethernet, serial, infrared, etc.) to enable a custom home automation system (CEPro 2008, 2009). Despite current economic conditions, forecasts indicate that there has been rapid growth in both the penetration of advanced utility metering initiatives as well as consumer interest in energy issues. In fact, home energy management users have been forecasted to reach 28 million worldwide by 2015, including 14.4 million in-home energy display devices shipped by 2015, 11.1 million users of web-based energy dashboards, and 2.6 million mobile phone applications (PikeResearch 2009). Moreover, the increasing number of devices available from vendors and retail outlets is further driving the do-it-yourself and mainstream segments' market growth (Gallen 2009). Since some luxury systems cost $40,000 and up, the most mature home automation segment is the only segment that could be negatively impacted by the recession (Lucero 2009).

Costs: Costs are considered here for three home automation market segments, including: do-it-yourself technologies, standards-based third-party installed systems, and luxury systems. For example, do-it-yourself technology, software, and network costs range from $200 to $5,000 and include smart devices discussed previously. Standards-based third-party technology, software, and network systems cost between $1,000 to $25,000, with a few additional monthly fee business models. Finally, luxury systems typically cost over $25,000 (ABIresearch 2009, CEPro 2009). Not surprisingly, do-it-yourself systems are the least expensive. System costs also vary as a function of deployment characteristics. Market research finds that product prices are expected to decrease fairly rapidly in the next few years, which will also drive technology adoption. Research indicates that many potential customers do want to remotely monitor their homes, as well as manage their spending and use. If it is relatively convenient some of them are willing to pay between $1,000 and $5,000 for systems (Lucero 2009, CEPro 2009, Galvin Electricity Initiative 2007).

For the installer direct system considered in this section, standards-based wireless technologies, such as ZigBee and Z-Wave, have pushed down higher-end system costs to the $10,000 to $15,000 range and prices are expected to continue to fall (ABIresearch 2009). Simpler systems can be purchased for much less money. For example, Control4 provides a simple home network for under $800 plus installation, including remote control for all TVs with lighting and heating and A/C control and the ability to scale-up with additional devices (Nagel 2009). Tendril is aiming to drive individual device costs down to $50 each for in-home energy displays and smart thermostat technologies since their utility customers may be aiming for rate-based support of simple home automation devices such as smart thermostats or energy displays between $75 and $125 per home (Ruth 2009). At volume, a device such as the EnergyHub, which is a combined touch screen energy display and two-way thermostat, should hit the same price point as a standard two-way thermostat (Wechsler 2009).

Automation and Behavior: Home automation systems vary considerably in their cost, level of control, ease of use and installation, and the degree to which they incorporate important behavioral principals (as shown in Table 10). Home automation service and technology options range from cost-effective to moderate to high-end, including in-home theater systems, audio/video, gaming and media servers, amplifiers, thermostats/space heating and air conditioning, lighting, window and shade control, intercoms, security, etc. (CEPro 2009). Home automation companies often provide flexible and integrated home control systems, including simple-to-use, touch-screen interfaces that enable control of various devices (see Figure 6). Installation difficulty ranges from a complete-line of customer-installable devices that are programmable and controllable from a central consumer interface[26] to completely professional installation required for every system component (most companies).

A sophisticated home automation network provides greater consumer control over home energy use, including the opportunity to respond to comfort-related concerns, energy savings targets, spending budgets, or some combination of motivating factors. As such, consumers can use a home system to address energy-related expenses, environmental concerns, or to conform to normative trends in energy consumption. Consumer preferences can be incorporated into a home energy management system to automatically control devices. For instance, several vendors described a layered approach to developing a “rulebook” of algorithms to automate the home based on the consumer’s preferred comfort levels (e.g., target temperature in the weekly schedule). The customer can also integrate information concerning acceptable and prohibitive energy prices, and/or household energy budgets and the system automatically adjusts heating, cooling, and other conditions in response. In most cases, the customer maintains the choice to override the system at any time or to simply “set and forget” and let the home network optimize household energy use. These systems also typically provide action-based tactical messages, such as: set back the thermostat four degrees, as well as objective-based messages that indicate the need for immediate individual energy conservation, because “X” is happening in the electric grid. The individual then chooses how they want that event to affect their lives. For instance, they can ignore the event and pay higher peak rates where applicable, or they might choose to cycle the freezer or pool off for a couple of hours. The customer, in a sense, chooses if they want to be engaged in the information, and if so, they will hopefully continue to gain awareness and can eventually participate in a much more proactive way. This is another reason that framing the message and paying attention to the messenger are important considerations.

Figure 9. Control4 Touch Screen Whole-House Control

[26] Tendril’s first release in April 2010 is the “Vision”, see http://www.tendrilinc.com/products/vision/.

Conclusions: Many vendors are incorporating behavioral principals into their products and services to attempt to reduce energy waste (see Table 10).

Technological and Behavioral Considerations: Since home automation networks can be complex systems, some consumers can be confused about how to purchase, install, use, and set automation functions. On the other hand, a home automation network can start out with a system as simple as an in-home energy display that may or may not communicate with the utility, and be incrementally built over time into a complete home energy management system. In fact, future home automation systems could manage the entire home and include controls to adjust for comfort, convenience, entertainment, safety, and security. It will include the tools to coordinate both the energy supply and demand in the home. For instance, the system could be used to remotely manage energy efficiency, generation, storage, and maintenance issues through micro-metering, communicating, and control microchips (Figure 8).

The widespread adoption of energy management technologies means that residential consumers could also create value for utilities and society. It would enable aggregation of mountains of useable data to manage systems and drive behavior change. It could also drive the commercialization of microgrids and microgeneration technologies (Galvin Electricity Initiative 2007). For instance, still in early-adopter stages, it is possible that applications accessed on the customer's computer, mobile phone, home tablet, TVs, and other kinds of electronic devices will be part of the home energy management system. If the iPhone/iPad and Android platform application market places are any indication, mobile widgets could soon be ubiquitous. In addition, low-power, quiet, and modular technologies, such as battery cells, photovoltaic cells and fuel cells will be developed to store and manage the power generated through distributed systems (Galvin Electricity Initiative 2007). As people take a more active role in their energy generation and management, they are also likely to make more informed and cost-effective usage decisions. In this way they also will contribute to the management and innovation of the system. Moreover, if the home automation network is used to its potential, people will be able to manage the home's energy use without much through or effort.

Regulatory Considerations: There are some regulations that are successfully driving energy efficiency system installations. A look at third-party companies found that sales and utility partnerships are aligned with energy efficiency resource (or portfolio) standards. For instance, in states with the most ambitious energy efficiency standards (e.g., CA, WA, MN, MA, NY, IL, etc.), vendors have encountered an abundant number of utility clients (Kavazovic 2009). In fact, some utilities are beginning to recognize the potential of the consumer-facing side of the smart grid and have adopted several different open and proprietary standard platforms for the home network, as well as Web, mobile phone, and a few in-home energy displays.

Many solutions rely on collaborations and partnerships with some combination of utilities, one-way or two-way advanced metering manufacturers, network and software solutions, and consumer feedback vendors. In fact, by building collaborative approaches to feedback that deliver products and services in cooperation with the utility (or by having access to utility-quality data) programs can potentially provide many benefits, including the following:

- Interacting with the utility back-end and legacy systems, as well as other community-side existing social networks, to take advantage of existing data to manage customer relationships, increase participation, and optimize energy system conditions;
- Supporting government and utility energy efficiency, demand response, time-of-use rates, and other programs that are directly tied to and supported by the consumer; and
- Collecting, managing, analyzing, visualizing, and verifying large amounts of energy usage data.

Innovative utility programs may be coming in the near future. In addition to large numbers of pilot projects, some utilities foresee offering a "coupon" or a "rebate" to their customers to redeem at local retailers for a "utility-approved" energy management enabling-technology product. The customer may have several choices, such as low-end kits costing between $60 and $150 (Ruth 2009), and medium-end kits including an Audio/Video receiver (similar to digital TV converter box), an LCD television, and so on (Nagel 2009). The utility customer would get the choice of the right mix of utility- and/or regulator-approved products from vendors on which to spend the voucher. This would enable an incremental approach, where over time additional home automation-supported devices including plug and play devices, are added to make the home automation network more sophisticated.

H. Conclusions

Web software, smart thermostats, in-home energy displays, and other home automation devices can enable users to better manage energy consumption. If the residential consumer can visualize the available information, they will see how much consumption drives cost (or carbon) potentially resulting in less consumption (Smith 2009). To achieve this, the customer also needs to stay engaged and motivated over time.

In fact, ***the success of the smart grid, advanced metering, energy management systems, and home automation technologies all depend heavily on consumer acceptance and participation***. Despite the barriers identified herein, research suggests that the utility perspectives may be evolving to recognize that enough consumers may want to play a role in energy management; and more critically, that it is profitable to use them as a cost-effective demand-side resource. However, most utilities are not equipped to deploy complex home automation systems or behavioral solutions. Fortunately, numerous vendors have stepped up to meet customer demand for, as well as utility needs pertaining to, feedback and automation.

Technology Considerations and Recommendations: It is not necessary to have a smart grid in place to enable a significant and positive behavior change. Right now, statistical methods that analyze existing utility and other available data can be used to provide useful and educational consumer feedback. Then, as the supportive utility-side systems are implemented, more complete and integrated feedback systems can be developed that can establish new norms to drive additional behavior change. Another existing technology approach that can enable both demand response and a more compelling energy efficiency behavior is to tap into existing cellular networks. Mobile phones are becoming more and more ubiquitous. For instance, according to the CTIA-Wireless Association, there are over 250 million U.S. subscribers to cellular-phone service (CITA 2008).[27] Actual penetration rates are difficult to determine since some people have multiple phones, but at least 21% of Americans no longer have a landline (CITA 2008) and conservative estimates in 2007 were that 40% of Americans have a mobile phone with even higher penetrations around the world (Galvin Electricity Initiative 2007). If even 20% of homeowners managed their energy load using their mobile phone, it could result in a major reduction in electricity waste.

While this section looked at some of the best examples of behaviorally-focused technology solutions, examples of poorly deployed programs also exist.

Achieving the most effective home automation systems in the future will require a process of incremental deployment that includes a ramp-up from simple peak shaving technologies (thermostats and energy displays) and small behavior changes (e.g., turning out lights, setting back A/Cs, etc.), as most programs are presently designed, to more complete, full-scale home energy management and home automation systems in the near- and the long-term. Mass produced communications (wireless and wired), mesh networking sensors and control, micro-measurement devices, as well as standardization of Internet Protocols could make precise, real-time, on-demand, services-driven energy management available at a low-cost relative to other building investments in the next few years.

Even an incremental approach would now begin to close the information and the efficiency gap by providing:

[27] U.S. population was 306.5 million in June 2009. http://www.census.gov/main/www/popclock.html.

1. Indirect feedback, that uses existing one-way advanced metering systems and other existing data, but especially when coupled with enhanced billing; and/or
2. Direct feedback using in-home energy displays and other enabling-technologies.

For instance, an in-home energy display could be left in the home for several days, months, or years, with remote hardware, firmware, and software reprogramming capabilities to collect data to help segment customers and target messages; or an energy display can be temporarily loaned to a homeowner who wants to get a general sense of home electricity usage. As the customer becomes more educated and engaged, they may be inclined to provide their own enabling-technologies. At the same time, research suggests that people need feedback on a long-term basis for savings to persist.[28]

Market Considerations and Recommendations: There are several challenges to growth in the home automation market that are related to market mechanisms, including: (i) developing distribution channels; (ii) educating consumers about the benefits and availability of home automation technology and services; and (iii) relatively high system costs and installation difficulties. The sheer number of vendors in the market, for example, provides a difficult barrier for consumers to wade through in determining which company will provide the best products and/or services. Furthermore, advanced metering manufacturers have traditionally served the utility industry directly, focused on the utility rather than the household needs and product designs. Like their utility partners, they are not generally involved in providing consumer-oriented feedback and other services. Unless the utilities begin to demand feedback features from advanced metering manufacturers, such as frequent measurement to provide appliance-level detail, consumer-facing features are unlikely to be included in near-term advanced metering deployments.

Behavioral Considerations and Recommendations: The smart grid creates an opportunity for customers to voluntarily change consumption behaviors, participate in energy efficiency and demand response programs, and manage their energy demand based on the energy system's current supply conditions. Many current energy efficiency, demand response, and advanced metering deployments and programs provide a haphazard consideration of the consumer's needs, despite the likely potential for large-scale energy waste reduction. Careful design of feedback and automation approaches is needed for many reasons, not the least of which is that we're living in a more and more complex social world, with numerous Internet communication and social tools taking our attention, such as e-mail, Twitter, Facebook, LinkedIn, etc. Simple design that doesn't overwhelm the consumer with too much information but does require consumer participation is key. However, change management *campaigns that effectively combine technology AND behavior techniques* could make a significant impact. To do this well, social scientists must play an integral role in program planning, design, marketing, and evaluation. Advice and input from professionals in the fields of psychology, sociology, marketing, change management, and behavioral economics will be critical to motivate, enable, and continuously engage consumers in the management of residential energy systems.

Asking a consumer to reduce energy waste based on the utility bill is like asking a dieter to lose weight without using a scale. Perhaps it can be done, but the task is a lot more difficult. Today's technologies appear to be ill designed to drive big efficiency changes. Depending on other supporting characteristics—like the behavioral aspects of the feedback, demand response and energy efficiency policies, financing mechanisms, and incentives—providing direct feedback can reduce household energy consumption by 5 to 25%. In fact, informed consumers use less and pay less because they understand what they are paying for and when (Galvin Electricity Initiative 2007).

Regulatory Considerations and Recommendations: In this rapidly evolving industry with complex state-driven regulation, utilities and customers face many uncertainties associated with managing household energy use. Regulators will need to examine the uncertainty with an eye toward improving a more optimal or smart pattern of cost-effective electricity consumption. At the same time, utilities will need to adapt their business models and manage organizational change to ensure profitable cash

[28] The issue of persistence is addressed more completely in Section III that follows.

flows, and customers will need to learn how to proactively manage their home energy use. For instance, the utilities and the state utility commissions need to study, design, set, and continuously refine plans for feedback, enabling-technology, and change management. Based on the available evidence, we recommend a Federal best practice manual that builds on the current knowledge concerning smart practices in behavior, energy efficiency, demand response, advanced metering, and smart grid programs and installations. It should provide the much needed guiding principles for program implementation, by sharing information on the best methods for engaging the consumer in managing energy. The manual could be developed on-line in a moderated wiki-style to take advantage of current cumulative field experience; provide a common information storehouse to enable faster learning and uptake of ideas, as well as a place to rate products and services so others can benefit from the lessons. The "smart grid" best practices could also organize an extensive database of research, including work from utilities and industry, peer-reviewed and academic publications, and government and non-profit documents.

Current advanced metering business and rate cases are weighted toward utility system management and operational benefits with the benefits of consumer participation generally being overlooked. For instance, not all advanced metering rate cases require residential feedback, demand response, or other pricing programs that increase advanced metering system benefits for consumers. In the U.S., most states need to implement new regulations to provide utilities with direct and fixed cost recovery mechanisms, performance incentives, and virtual power plant regulations to encourage organizational and business model changes (EEI 2009).[29] In particular, performance incentives allow utilities to take a share of savings achieved by energy efficiency (EEI 2009). Here, for example, advanced metering rates of return could be tied to the resultant advanced metering energy efficiency savings. In addition, utilities (and regulators) will need to engage residential customers through the implementation of better pricing and rate programs and energy feedback and management mechanisms. Rounding out the business case should require including projected savings from demand response and energy efficiency to include more than utility operational savings (Faruqui & Wood 2008).

<u>Final Conclusion:</u> Advanced meters alone will not achieve energy efficient behavior change, but with a healthy mix of behavioral science, policy, and enabling-technologies, these technology and networking systems could achieve dramatic energy savings. If utilities begin to recognize the customer as a large resource for demand and cost management, a new utility services paradigm that leaves room for a whole host of new energy management products and services is possible. Now seems to be the time to act to take advantage of the growing public interest in energy and the growing number of products and services available on the market. Notably, however, the electric utility industry as a whole may be moving toward more of a demand-side rather than a purely supply-side business perspective in which customer preference will become increasingly important (Galvin Electricity Initiative 2007). Supporting this transition should result in a substantial reduction in energy waste (Glavin Electricity Initiative 2007), which means that the consumer-facing side of the smart grid should be an important consideration in advanced metering deployments.

Information provided by utility bills needs to be supplemented using all of the layers of the onion to provide better visibility of energy information, and encourage smart-energy practices. This objective can be achieved by incrementally installing some basic feedback technologies (such as in-home energy displays) in the home now in anticipation of the planned, large-scale rollout of advanced meters. Such an approach would allow for incremental education of utilities and customers and establishing smart energy management practices. It would also enable incremental improvements to technology development, policy strategies, and program approaches. Subsequent phases might involve increasing levels of home automation.

[29] Direct cost recovery programs include rate cases, system benefits charges to fund energy efficiency programs, and tariff riders/surcharges. Fixed cost recovery mechanisms include decoupling programs that separate profits from energy sales and lost revenue adjustment mechanisms (Kentucky and Ohio only) (EEI 2009).

III. The Impact of Feedback on Energy Consumption: The Meta-Review

Advanced meters are one method of providing households and businesses with information about their energy consumption, but they are not the only means of doing so. While the previous section of this report focused on the technologies of advanced metering and in-home displays, this section will focus on the historical evidence documenting the importance of smart feedback programs on energy use behaviors. Section IV that follows will evaluate the potential impact of feedback on U.S. residential electricity savings over the period 2010 through 2030.

A. How Feedback Works

An effective understanding of the relationship between feedback and energy consumption behavior should begin with a thoughtful classification of: (i) different types of energy-related behaviors, (ii) a categorization of different types of feedback mechanisms, and (iii) a consideration of feedback-related variables as well as past studies on the topic. This section begins by illustrating the range of energy-related behaviors and providing important distinctions between different types of behaviors. It goes on to describe six established types of feedback and concludes with a meta-review of 57 feedback studies that highlight the many important variables that shape the relationship between feedback and energy savings.

Types of Behavior

If the goal is to reduce residential energy consumption, a number of related tasks are essential. First among these is a well-researched understanding of existing energy end uses, including the types of behaviors associated with these different end uses. A second but related task involves identifying those behaviors that are most malleable and the types of interventions that are likely to have the largest impact. Since Section I of this report includes a description of residential energy end uses, they won't be repeated here. What is important is the recognition of the large end-use demands associated with space heating, water heating, space cooling, appliances, lighting, and the growing energy demand associated with new electronic devices and appliances.

Another way of understanding existing energy end use patterns is to identify the different types of behaviors that cause them. Figure 9 provides a typology of energy behaviors as a function of the frequency of the action taken and the economic cost associated with the undertaking of the action. When broken down in this way, three categories of behavior emerge. The first type of behavior might be thought of as *Energy Stocktaking Behaviors* and *Lifestyle Choices*. These include energy saving behaviors that are performed infrequently and can be performed at a relatively low cost (or at no cost) such as installing compact fluorescent lamps (CFLs) and weatherstripping, or choosing to live in a smaller house or apartment. The second type of behavior involves energy saving behaviors that must be performed or repeated frequently. These are generally referred to as *Habitual Behaviors* but they also involve some lifestyle choices. Examples include laundry routines and whether we tend to wash our clothes in cold water, use a mechanical drier, or air dry our clothes and linens. This category of behaviors also includes habits associated with appliance use and lighting and the frequency with which we turn off computers and other devices when not in use. The final type of actions involves infrequent but higher-cost behaviors. These actions are generally referred to as *Consumer Behaviors*, *Technology Choices* or *Purchasing Decisions* and involve the adoption of more energy-efficient products and appliances (Laitner et al. 2009a).

Figure 10. Energy Behaviors* as a Function of Frequency and Cost

	Frequency of Action	
	Infrequent	***Frequent***
Low-cost / no cost	ENERGY STOCKTAKING BEHAVIOR Install CFLs Pull fridge away from wall Inflate tires adequately Install Weather Stripping	HABITUAL BEHAVIORS AND LIFESTYLES Slower Highway Driving Slower Acceleration Air Dry Laundry Turn Off Computer and Other Devices
Higher cost / Investment	CONSUMER BEHAVIOR New EE Windows New EE Appliances Additional Insulation New EE Car New EE AC or Furnace	

* These include habits, lifestyles, technology purchases/investment decisions, technology use and maintenance.

Providing consumers with feedback on their energy consumption patterns has been shown to have an impact on a variety of different behaviors associated with each of the three categories. The fact that people have multiple means of reducing their energy consumption means that some people/households may be more likely to pursue energy savings through investment decisions in more energy-efficient technologies while others prefer to take stock of energy consumption patterns to make thoughtful adjustments in everyday practices. Research that reveals the many ways in which socio-demographic and psycho-demographic variables mediate the relationship between feedback and energy conservation or energy efficiency behaviors can provide critical insights for program and policy designs. They can also improve the accuracy of energy demand projections—especially under a variety of different policy, behavioral, and program assumptions.

Types of Interventions

Feedback strategies constitute one among several different types of efforts that may be pursued to change energy-related behaviors. In the behavior change intervention taxonomy proposed by Geller et al. (1990), interventions are categorized as either as involving antecedent or consequence strategies. Antecedent strategies are typically described as those that involve efforts to influence one or more determinants of a behavior prior to the performance of the behavior. Most often, these include mass media *information campaigns* aimed at increasing the public's knowledge about the impact of individual or household level choices or about the energy-savings options from which choices are made. Other antecedent strategies include efforts to elicit a *commitment* to change, to set behavior change *goals*, or to *model* or demonstrate the desired behavior (Abrahamse et al. 2005).

On the other hand, consequence strategies attempt to change behavior by influencing the determinants of a behavior after the behavior in question has been performed. *Feedback* falls into this category. According to Abrahamse et al. (2005) "giving households feedback about their energy savings may encourage them to (further) reduce energy use, because their level of self-sufficiency (i.e., perceived possibilities to conserve energy) has increased." Other consequence strategies include providing *rewards*. Among both antecedent and consequence strategies, feedback initiatives have been shown to be highly effective at creating behavior change and are receiving increased attention as a result of continuing proliferation of new information and communications technologies (including advanced meters) that facilitate the effective application of feedback mechanisms. More specifically, the application of information and communication technologies (ICT) as a means of monitoring energy consumption and energy savings provides the opportunity to give energy consumers more targeted and more timely feedback in a highly cost-effective manner.

1. How Feedback Shapes Behavior

The use of feedback initiatives and other consequence strategies is based on the notion that both positive and negative consequences have the power to shape individual behavior. Attaching positive consequences to energy-wise behaviors makes those behaviors more attractive to consumers, while attaching negative consequences can make unsound behaviors much less desirable (Abrahamse et al. 2005).

Moreover, certain characteristics of feedback initiatives have also been shown to be correlated with program effectiveness as measured by higher participation rates and energy savings. Of particular interest are (i) the frequency of the feedback, (ii) whether the feedback is direct or indirect, and (iii) whether or not the feedback provides a contextual framework by which the individual can evaluate his/her performance.

In terms of the frequency, feedback can range from continuous to infrequent. Past studies suggest that more frequent feedback tends to be more effective (Darby 2006, Fischer 2007, Abrahamse et al. 2005). For example, studies from as far back as the late 1970s have shown that in-home monitors have successfully reduced energy consumption by as much as 12% compared to a control group without the in-home device (McClelland and Cook 1979-80, van Houwelingen and van Raaij 1989). In a review of 17 feedback studies, Farhar (1989) found that feedback-induced electricity savings ranged from 5 to 20%. More recent studies indicate that even greater savings are possible (EPRI 2009) but that feedback-related energy savings from direct feedback generally falls within the range of 5 to 15% (Darby 2006).

The relationship between the frequency of feedback and subsequent energy savings also seems to depend on the energy end-use being targeted. According to research by Darby (2006), indirect feedback (feedback that has been processed in some way before reaching the energy user, normally through a billing mechanism) is usually more suitable than direct feedback for demonstrating the effect of changes in space heating, household composition and the impact of investments in efficiency measures or high-consuming appliances. Savings from indirect feedback have ranged from 0-10%, but they vary according to context and the quality of the information given to households. On the other hand, instantaneous feedback is more suitable for providing information regarding the energy impact of smaller end uses. "An instantaneous, easily accessible display may give the consumer adequate information on different end-uses, by showing the surge in consumption when the kettle is switched on, or the relative significance of a radio, vacuum-cleaner or toaster.". Potential savings from motivated participants can be in the range of 10-20% (Darby 2006).

Finally the contextual framework also seems to matter. Energy consumption information is generally thought to be more meaningful when situated in either an historical or comparative context, providing consumers with information about how their current levels of consumption compare to either their past consumption or how they compare to other households. According to Abrahamse et al. (2005) the comparison between households provides a feeling of both competition and social pressure. However, results from actual studies indicate mixed results for programs that compare households with other households and suggest that specific elements of program design are likely to play an important role in determining actual energy savings. Of critical importance is the way in which the comparison group is determined and whether or not households believe the comparison to be appropriate. A study by Egan (1999) indicates that households do not necessarily save energy when compared to other households particularly if people question the validity of the group to which they are assigned.

2. Feedback Types

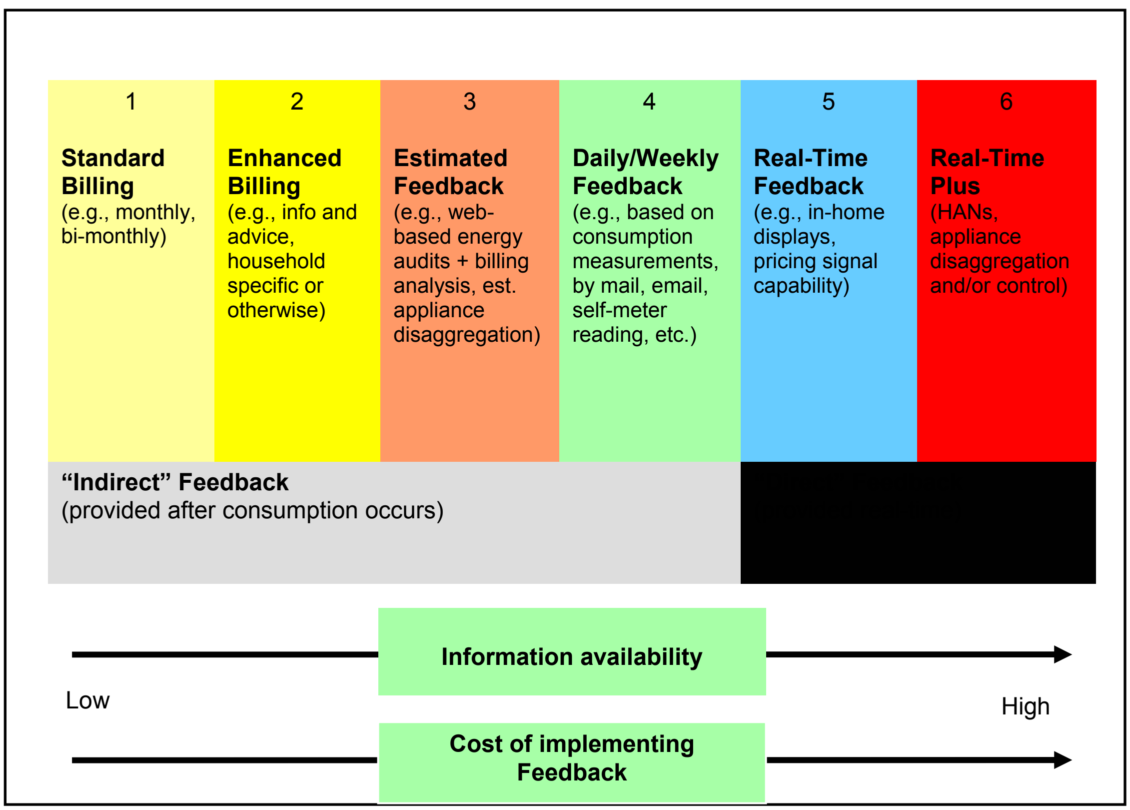
As noted above, one of the most useful means of categorizing different types of feedback is to differentiate by whether the feedback is direct or indirect.

In an earlier study Darby (2000) identifies five different types of feedback including direct, indirect, inadvertent, utility controlled, and energy audits. According to Darby, direct feedback is available on demand and includes direct displays (or in home monitors) as well as interactive feedback through personal computers. Indirect feedback involves the processing of utility data which is sent out to consumers by the utilities or a third party. Consumers are thought to learn from indirect feedback by reading and reflecting. Darby's classifications scheme identifies inadvertent feedback as involving a less systematic form of learning associated with the adoption of new energy using equipment and or social learning contexts. This type of learning is thought to occur through association. A fourth type of feedback (utility controlled learning) is not geared toward learning on the part of the consumer but on the part of the utility. Finally, Darby's fifth category focuses on energy audits which are identified as a type of feedback that provides baseline information as opposed to a source of continuous information.

A more recent study (EPRI 2009) builds on Darby's distinction between direct and indirect forms of feedback but develops a somewhat different classification scheme. The EPRI characterization framework is presented in Figure 11 on the following page.

While both characterizations recognize the important difference between direct and indirect feedback, the EPRI approach further refines this distinction based on the availability of information provided by a particular type of feedback as well as the cost to implement. As illustrated in Figure 11, EPRI's scheme distinguishes between four different types of indirect feedback and two different types of direct feedback. Indirect feedback includes standard billing, enhanced billing, estimated feedback and daily/weekly feedback, while direct feedback includes real-time feedback as well as real-time plus feedback. Not surprisingly standard billing tends to be the least costly to implement but also provides the least amount of information to consumers. At the other end of the scale are real-time plus systems that work with home area networks, providing frequent energy use data that is disaggregated by appliance.

Figure 11. Types of Feedback



Following the listing highlighted in Figure 11, a brief summary of the EPRI categories is provided below:

- Standard Billing—An energy bill that displays the monthly kilowatt-hour (kWh) of consumption and the unit rate ($/kWh), the corresponding total cost and other billing charges, as well as the total amount due. This form of feedback generally lacks comparative statistics or any detailed information about the temporal aspects of consumption
- Enhanced Billing—Provides more detailed information about energy consumption patterns, and often includes comparative statistics—either comparing the most current monthly electricity usage and expenditures together with historical consumption and/or a comparison to other households.
- Estimated Feedback—This approach uses statistical techniques to disaggregate the total energy usage based on a customer's household type, appliance information, and billing data. The resulting feedback provides a detailed account of electricity use by major appliances and devices. These most commonly take the form of web-based "home energy audit" tools, offered by a utility to its customers.
- Daily/Weekly Feedback—These reports use averaged data and often include consumer self-read studies (in which individuals read their meter and record the energy usage themselves) as well as studies in which individuals are provided with daily or weekly consumption reports from the utility or research entity.
- Real-Time Feedback—In home energy display devices that provide real-time or near real-time energy consumption and energy cost data at the aggregate household level.
- Real-Time Plus—In home energy display devices that provide real-time or near real-time energy consumption and energy cost data disaggregated by appliance.

3. The Range of Studies and Important Variables

This study reviews 57 primary feedback studies that were performed in the more developed countries of the world, including the United States, Canada, Japan, Australia and four countries of Western Europe (the Netherlands, Finland, Denmark, and the United Kingdom). Over half (58%) of the studies reviewed were performed in the United States, 22% in Europe, and 15% in Canada. Of the remaining 5%, two studies were performed in Japan and one in Australia. The studies also vary significantly in terms of feedback type. Roughly half of the studies involve the use of *indirect* feedback, including 11 studies that involve the use of enhanced billing, three studies that use estimated feedback, and 15 studies that consider daily/weekly feedback. The remainder of the studies explores the effect of *direct* feedback. Of these, 23 studies explore the effect of providing real-time feedback on household level energy consumption, while six studies explore the effect of providing appliance disaggregated, real-time feedback. The consideration of regional variation and feedback type can help reveal the potential importance of context, content and medium. In addition, we also consider when the study was performed to understand the potential impact of historical context, and the size of the study to ascertain whether or not important differences exist in the conclusions that might be drawn from larger, more generalizable research as opposed to smaller-scale studies.

The era in which a study occurs matters because it reflects the potential influence of its historical context. The primary studies reviewed for this report span a 35-year time frame: 1974-2009. While there has been a resurgence of interest in potential feedback-related energy savings in recent years, studies on this topic originally began to blossom during the 1970's in response to the OPEC oil embargo and the related energy crises. Subsequently, however, interest waned during the 1980s and more recent studies have only begun to gain new momentum as a result of growing concerns over global climate change as well as the emergence of new technological possibilities associated with high-tech information and communications technologies. New ICT applications offer an innovative means of increasing the scalability of feedback mechanisms, have expanded the potential means for residential energy management, and have reduced the costs associated with providing frequent and reliable energy feedback to residential consumers. Given these new circumstances and important historical events, two distinct time periods or eras of feedback-related research have emerged: the Energy Crisis Era (prior to 1995) and the Climate Change Era (1995 and later). In this report, we explore potential distinctions between these Eras and the way that they have shaped prior feedback studies and feedback-related energy savings. Approximately one-third of the studies reviewed for this report were performed during the Energy Crisis Era, while approximately two-thirds were performed during the Climate Change Era.

Finally, in addition to regional and temporal differences, we also consider the degree to which feedback-related research findings vary according to the number of households included in the study. While past reviews of the feedback literature have looked for patterns and lessons without a consideration of sample size, we are interested in exploring whether the findings of larger, more generalizable studies are similar to those of smaller-scale studies and, if not, how might the findings of larger and smaller studies differ. Study size is measured in two ways: 1) by the total number of study participants, and 2) by the total number of study participants receiving feedback. Small studies are considered to be those with less than 100 participants, while large studies are those with 100 or more participants. A review of studies by overall study size reveals that 18 of the studies (32%) have a sample size of less than 100 while the remaining 39 studies (68%) have sample sizes of 100 or more. When measured as the number of participants receiving feedback, the split between large and small studies is roughly 50%.

In addition to the variables discussed above, there are several other important factors that shape the impact of feedback on energy savings that deserve more attention and research. These include issues surrounding (1) peak savings versus conservation/efficiency effects, (2) the importance of program design elements, (3) the ways in which energy savings vary across population segments, and (4) the persistence of feedback-related energy savings. Unfortunately only a small subset of the feedback studies that have been executed (thus far) which address these factors. This, of course, limits our ability to provide a thorough assessment of these issues. We do, however, briefly discuss these important issues in this section of the report and discuss the need for more research on these topics in Section IV.B. "Unresolved Questions".

B. Review of Primary Research

This review builds on earlier reviews of feedback-related energy savings (Darby 2006, Fischer 2007, EPRI 2009). It does so in several ways. First, this review includes the largest sample of studies reviewed to date. Second, this review provides a more in-depth assessment of the programmatic features, design elements, and contextual factors that are likely to help explain the variation in feedback-related energy savings. We begin with Darby's (2006) suggestion that feedback mechanisms can induce residential energy savings of 0-15%. (In fact, the studies reviewed for this report suggest a range of average energy savings as high as 21%.) Her review found that the type of feedback is likely to play an important role in determining the subsequent levels of household energy savings. According to her study, indirect forms of feedback tend to be associated with lower levels of energy savings (0-10%) than direct forms of feedback (5-15%). We seek to look more deeply at the effects of feedback type on energy savings by evaluating the energy savings associated with the more specific feedback types identified by EPRI (2009). In addition, this review also considers the ways in which historical and geographical contexts are likely to impact feedback-related energy savings.

A surprising amount of existing research on feedback was performed in the 1970s and 1980s during what might be referred to as the Energy Crisis Era. This study seeks to include these studies but to distinguish their findings from those of the more recent period. We also seek to explore potential geographical differences in feedback-related energy savings and in particular assess whether cultural and political differences in Europe and the United States are reflected in achieved savings. In this section we also explore the importance of motivational elements such as the use of goal setting, competitions, commitments and social norms and their impact on household energy savings. Finally, we explore the relationship between sample size, study duration and the persistence of energy savings to better understand whether the feedback-related energy savings induced by smaller and shorter programs are likely to be replicable in larger and longer studies. We also explore the relationship between study duration and the persistence of energy savings to assess the likelihood of long-term energy savings from feedback.

In order to achieve the objectives outlined above, this section focuses more heavily on a discussion of the literature while the subsequent section, "The Intersection of Contextual and Program Variables", is more focused on an assessment of the data. Section B is broken into four parts:

- Study Era and Energy Savings
- Feedback Type and Energy Savings
- Motivational Elements and Energy Savings
- Sample Size, Study Duration and the Persistence of Energy Savings

An overview of all 57 studies is provided in Appendix A which identifies the data sources, the vintage of the study, the feedback type, average energy savings, and other study characteristics.

1. Study Era and Energy Savings

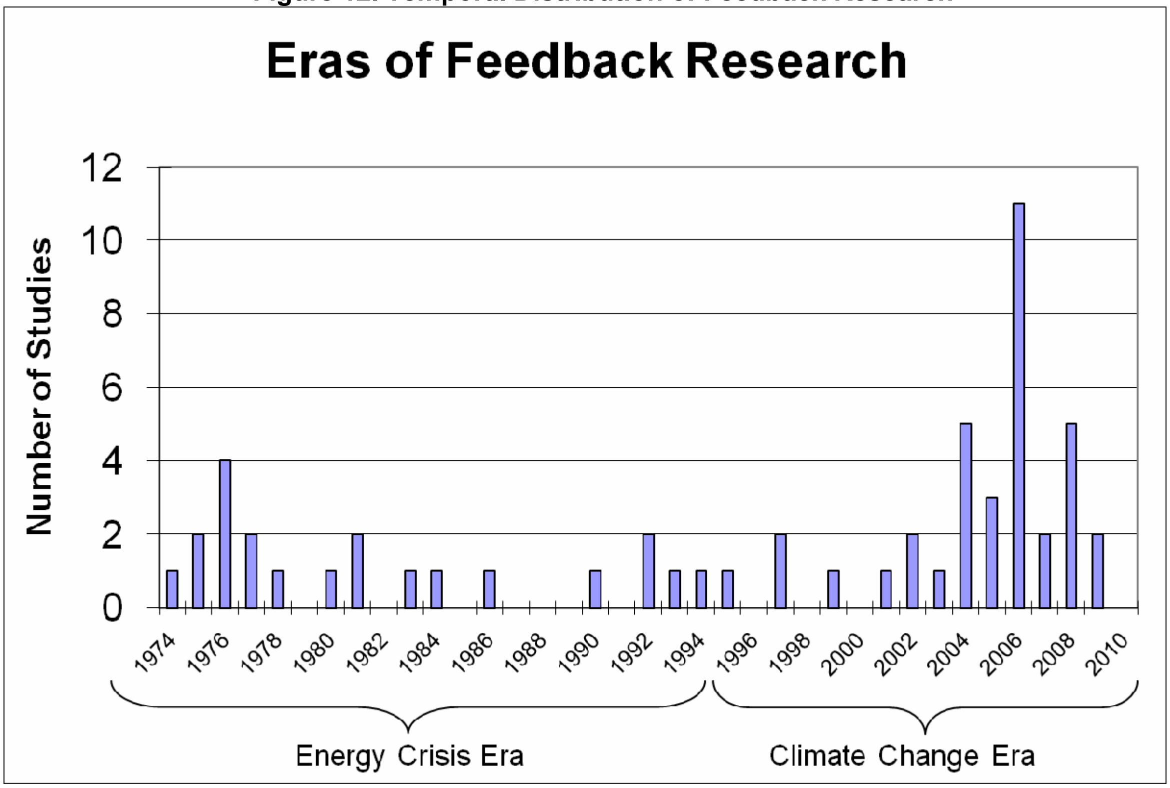
A review of the literature clearly shows that the research on feedback-induced energy savings has emerged during two distinct time periods and in response to two distinct policy concerns. The first set of studies began to emerge in the mid 1970s following the 1973 oil embargo and the ensuing energy crisis in the United States. These include Seaver and Patterson's 1976 study which considered the effect of enhanced billing on fuel oil consumption. Other early studies include Hayes and Cone's research on reducing residential electrical energy use published in the Fall of 1977 which explored the use of daily/weekly feedback in an 80-unit housing complex at West Virginia University, as well as Seligman et al.'s (1978) research on household energy use in New Jersey and McClelland and Cook's (1979) research on the potential energy saving impact of Fitch Energy Monitors. In all, 21 studies were performed during the twenty-one years between 1974 and 1994. This period is characterized by a sharp increase in research during the period immediately following the energy crisis and a subsequent decline in research beginning in the mid1980s and continuing for the following 10 years. Most studies during this period are focused on the impact of daily/weekly feedback (47%) while the remainder provide early research on real-time, household level feedback (24%) or enhance billing (24%). To facilitate discussion, we call this period the "Energy Crisis Era".

The second period of feedback research began in response to the growing concern over global climate change. These "Climate Change Era" studies reflect the huge growth in the development and application of new information and communications technologies (ICT) as they seek to explore the use of ICT on feedback and reductions in energy consumption. For example, 60% of this period's studies are focused on direct forms of feedback using in-home feedback devices, including both aggregate-level, real-time feedback and appliance-specific real-time feedback while other studies are exploring the application of internet-based technologies. Different types of in-home feedback monitors are among the technologies assessed (Allen and Janda 2006, Carroll 2009, Carroll et al. 2009, Case et al. 2008, Horst 2006, MacLellan 2008, Martinez and Geltz 2005, Mountain 2006 and 2008, Parker et al. 2006 and 2008, Pruitt 2005, Scott 2008, Sulyma et al. 2008) with widely varying results. The Energy Detective and the Blue Line Power Cost Monitor are among the in-home displays that have been the subject of several studies and show favorable results. Studies involving the use of The Energy Detective (Allan and Janda 2006, Parker et al. 2006 and 2008) indicate average savings ranging from not significant to around 7%. Studies using the Blue Line Power Cost Monitor (MacLellan 2008, Mountain 2006 and 2008, Scott 2008, Sulyma et al. 2008) indicate savings ranging from not significant to 18, with a median between 3 and 6.5%.

A variety of other studies explore the use of web-based feedback technologies. For example, Abrahamse et al. (2007) explores the use of an internet-based feedback tool that has helped European households to successfully generate an average savings of 5.1%. In the Netherlands, a web-based application was also found to produce average household savings of 8.5% (Benders et al. 2006), while a Japanese study found average savings of 18% (Ueno et al. 2006a and 2006b). In addition, a variety of other programs are using the Web to provide supplemental information as well as tips for saving energy so as to augment feedback-related energy savings.

Interestingly, the vast majority of Climate Change Era studies have occurred during the past 8 to 10 years. In fact, nearly 80% of these studies have been published since 2004. Another notable characteristic of studies performed during this Era is that a greater share is occurring outside of the United States. In particular, a wide variety of feedback studies are being researched in the Netherlands (Benders et al. 2006, Staats et al. 2000, Staats et al. 2004, Wilhite and Ling 1995, and Wilhite et al. 1999) and Canada (Hydro One Networks 2008, IBM 2007, Mountain 2006 and 2008, Robinson 2007, and Sulyma et al. 2008), and there seems to be growing interest in the contribution of feedback in Japan (Ueno 2006a and 2006b).

Figure 12. Temporal Distribution of Feedback Research



2. Feedback Type and Energy Savings

What can existing studies tell us about the relationship between the type of feedback and the energy savings that result? This section will briefly discuss the various studies that fall into five relevant feedback categories, including three of the four indirect types of feedback (enhanced billing, estimated feedback, and daily/weekly feedback) and both of the direct types of feedback (aggregate real-time feedback and appliance-specific or disaggregated, real-time feedback.

Enhanced Billing

Eleven enhanced billing studies, published between 1976 and 2009, were reviewed for this report. Five of these studies were performed in the United States (Alcott 2009, Ayers et al. 2009, Ehrhardt-Martinez 2009, Kasulis et al. 1981, and Seaver and Patterson 1976) and five were performed in Europe (Nielsen 1993, Staats et al. 2004, Wilhite and Ling 1995, and Wilhite et al. 1999). The remaining study was performed in Canada (IBM 2007). Reported energy savings range from 2 to 2.5% in various assessments of a recent enhanced billing program with SMUD that uses social norms to reshape energy consumption behavior (ADM 2009, Ayers et al. 2009, Ehrhardt-Martinez 2009, and Summit Blue 2009) to 8% in a Norwegian study that also provides consumers with historical and social comparisons in 1999 (Wilhite et al. 1999). Both of these studies are based on the idea that residential energy consumers can benefit from being provided a point of comparison from which they can assess the reasonability of their own levels of energy consumption. Comparative information can be provided in the form of historical data or social comparisons. Historical data show consumers how their current energy bill compares to past billing periods during the current year as well as prior years. Social comparisons allow consumers to assess their level of energy consumption relative to that of other people in homes and household like theirs. While the studies use a variety of complex data sources to calculate social comparisons, these approaches are relatively low cost, and when designed correctly, they have a proven track record of energy savings.

A more complex, multi-component study in Denmark by Nielsen (1993) achieved savings as high as 10% in single-family households (only 1% in apartments). The Denmark study provided feedback via enhanced billing but also offered households the opportunity to receive a consultation with a utility representative to assess potential means of achieving energy savings and provide financing opportunities. Another study by Seaver and Patterson (1976) explored the effect of enhanced billing and special customer commendations on fuel oil savings during the energy crisis. The authors found that the use of commendations played an important role in eliciting feedback-related savings. Finally a study by Staats et al. (2004) combined feedback through enhanced billing with the use of commitment strategies, group interventions, and social interaction to assess both short-term and long-term impacts. After a seven-month intervention period, the study had achieved 5% energy savings. However 2 years later, savings had *increased* to 8% despite the lack of any subsequent intervention, indicating that a well-designed program can result in persistent energy savings.

Estimated Feedback

Three recent studies, published between 2006 and 2007, investigate the use of web-based tools to provide consumers with estimated feedback. Two of the three studies took place in Europe and reported energy savings of 5.1 to 8.5% (Abrahamse et al. 2007 and Benders et al. 2006). The remaining U.S. study (Elliott et al. 2006) had a slightly different focus. Its purpose was to test if online (and through the mail) feedback could be used to increase peak period savings above and beyond the peak rate structure. The study found that participants did save more energy; however, the energy savings were not found to be statistically significant. Notably, the savings that were achieved were not limited to peak events, but instead tended to be distributed somewhat evenly across time.

Daily/Weekly Feedback

Fifteen of the research studies reviewed for this report focus on the provision of daily or weekly feedback. Approximately 66% of these studies were published during the Energy Crisis Era (1974-1994), while 33% were published during the current Climate Change Era (1995-present). Most (66%) of the research on this type of feedback has been performed in the United States (Battalio et al. 1979, Bittle et al. 1979, Bittle et al. 1979-80, Hayes and Cone 1977, Nolan et al. 2008, Schultz et al. 2007, Seligman et al. 1978, Becker 1978, and Winett et al. 1982). Three studies were performed in Europe (Brandon and Lewis 1999, Haakana et al. 1997, and Staats and Van Leeuwen 2000). The last two studies were performed in Canada (Robinson 2007) and Australia (Kantola et al. 1984). Energy savings varied greatly from 4% in an early study of the effect of daily cost feedback on residential electricity consumption to 21% in a complex Finish study (Haakana et al. 1997) of 105 district-heated single-family houses. The Haakana study provided targeted feedback to households involved in the program, including comparisons of their consumption to other households and information regarding their own consumption in preceding years. In addition, households were given focused information and energy savings tips regarding different brands of heating and ventilation systems and adjustment devices available to households, advice about different ways of doing housework and producing household services.

Savings of 10% or more are reported by roughly two-thirds of the studies using this type of feedback. Among those studies with higher levels of energy savings, most combined multiple approaches. For example, Hayes and Cone (1977) and Battalio et al. (1979) achieved energy savings of 18 and 11-12% (respectively) by combining a pricing rebate scheme with feedback. Brandon and Lewis (1999) achieved 12% savings through a program that included the use of comparative and historical norms. Notably, in a California study of nearly 1,000 households, Nolan (2008) achieved savings of 10% through the use of descriptive norms. According to the study, “normative social influence produced the greatest change in behavior compared to information highlighting other reasons to conserve, even though respondents rated the normative information as least motivating. Results show that normative messages can be a powerful lever of persuasion but that their influence is underdetected." A 1978 study by Seligman et al. combined feedback with goal setting. The study involved two study groups. The first was given a relatively easy savings goal (2%) while the second was given a much more difficult savings goal (20%). According to the research, the group with the difficult savings goal was the only group that differed significantly from the control group, saving 13% on average. Finally, a 1982 study by Winett et al. combined goal setting, commitment, modeling, information and feedback. The results suggest that feedback and modeling both played an important role in generating energy savings. Participants achieved electricity savings of 15% on average.

The Canadian study (Robinson 2007) is the only study that reports a lack of energy savings, however, this study is somewhat unique in that it tested for energy savings among households that already had time-of-use pricing incentives in place. The study was focused on assessing only the incremental effects of weekly feedback on household electricity consumption.

Notably, pilots and programs that have used daily/weekly feedback mechanisms have typically relied on relatively low-tech means of implementation. Of the studies reviewed, most relied on the use of feedback cards, doorhangers, and other hand written methods to inform participants of their energy consumption patterns and savings. As such, the predominant historical application of this approach has been relatively labor-intensive and difficult to scale up. However, more modern, higher-tech applications are possible and could provide the opportunity for significant energy savings on a large scale without the use of in home devices. For example, the use of existing, web-based technologies could be used to communicate daily or weekly energy use information to households in a timely fashion, facilitating immediate and large scale programs as well as consequent energy savings. Prior studies suggest that this type of feedback may be especially effective at catalyzing household energy management associated with heating and cooling, water heating, and other large energy end uses.

Aggregate, Real-Time Feedback

A total of 23 feedback studies were involved the application of real-time aggregate feedback; these studies represented nearly 40% of all feedback studies reviewed. This section provides an overview of the studies in this category and highlights some of the more interesting findings. Given that the development and application of any real-time feedback initiative is facilitated by the application of advanced information and communications technologies, it isn't surprising that 77% of aggregate, real-time feedback studies were published during the current Climate Change Era. Approximately 70% of the studies (16 studies) were implemented in the United States, while 26% were implemented in Canada and a single study was carried out in the Netherlands.

Energy savings associated with real-time aggregate feedback vary widely, but typically fall somewhere between 0.5 and 18%. Only five studies of household-level feedback (as opposed to one study that looked at feedback in college dormitories) documented savings of 10% or greater. Two of these studies were performed in the late 1970s by McClelland and Cook (1979) and Seligman et al. (1978). McClelland and Cook's research focused on all-electric homes that were built to be highly energy efficient. The study used Fitch Energy Monitors to provide in-home, real-time feedback and controlled for house size and household size. Given that study was performed in highly energy efficient homes, the authors safely conclude that the savings achieved through the feedback were achieved through behavioral change and that behavior (defined here to include conservation as well as changes in habits and lifestyles) can result in significant energy savings. Within these constraints, the authors also note that the greatest differences in energy use that were generated by the feedback devices over the course of 11 months, were achieved during months with moderate weather and low overall consumption. Their observations suggest that the behavioral change that resulted in the documented energy savings primarily resulted from energy uses other than heating and cooling.

In Seligman et al. 1978, researchers use an outdoor device that notifies participants when outdoor air temperatures fall below a temperature threshold, prompting customers to turn off their air conditioning. This simple feedback achieved energy savings of 15.7%. A third study (Van Houwellingen 1989) achieved 12% savings in the Netherlands through the use of an in-home device called "The Indicator" and the implementation of a combined approach that included the use of savings goals and general energy use information. Only 50 of the 325 study participants received the in-home displays and achieved the highest level of energy savings when compared to participants who received other types of interventions.

Only two household-level studies from the Climate Change Era have achieved energy savings in excess of 10%. Mountain (2008) documents the electricity savings of a Canadian program using the Blue Line Power Cost Monitor. The study compared the energy savings of 58 households which had the monitor installed and 10 households that comprised the control group. Households with meters consumed 18% less electricity. In addition, the study found that people with favorable attitudes were likely to conserve more energy, while senior citizens were likely to conserve less. Similarly, Pruitt (2005) examines the use of the SRP M-power Monitor in a study of 2600 Arizona households, resulting in average energy savings of 13% (13.8% in summer and 11.1% in winter). The Arizona savings resulted from a program that combined in-home monitoring devices with a pay-as-you-go program.

Two additional studies explored the effect of real-time aggregate feedback in college dormitories (Petersen et al. 2007) and as a diagnostic tool (Parker et al. 2006). Both studies report abnormally high levels of energy savings. Petersen et al. use feedback in conjunction with competitions to engage college students in saving electricity. The study provides students in two dorms with near-real-time data while the remainder of the dorms (16) receive weekly feedback. Real-Time feedback is provided by a customized wireless data monitoring system with a web-based interface that allows students to monitor their electricity consumption in near real-time on their computers. The monitors measure electricity use by floor and for the entire dorm. Weekly feedback is provided for the remainder of students through the same website. In addition to the feedback on electricity use, students are motivated to conserve through their participation in an inter-dorm competition with prizes for the dorm that saves the most electricity. Electricity use is measured for a 3 week baseline period, a 2 week intervention period and a 2 week post-intervention period. A comparison of electricity consumption before and after the intervention revealed an average savings of 32% across all 18 dorms. [30] Dorms receiving real-time feedback reduced their electricity consumption by 55% while those receiving weekly feedback reduced their consumption by 31%. The winning dorm reduced their electricity use by 56%.

Parker et al. investigate the energy savings that can be achieved through the application of real-time energy monitors as diagnostic tools. The study involves two case studies each of which uses a different in-home device: either the Energy Viewer or The Energy Detective. The goal of the research is to use the in-home devices to diagnose the relative energy intensity of various energy end uses and to address them using power strips and occupancy-based controls. Resulting energy savings in individual homes ranged from an increase in energy use to energy savings as high as 56%.

The lowest overall savings were found by two programs that were focused on reducing peak demand. In the mid 1980s, Sexton et al. (1987) studied 481 households in California who were participating in a time-of-use pricing structure. Sixty-eight of the households received Continuous Display Electricity Use Monitors and their energy consumption was tracked for a period of 12 months. The study found that feedback did not result in total energy savings but did contribute to shifting use from peak to off-peak periods. In fact, this study's focus on peak load shifting resulted in an overall *increase* (5.5%) in household electricity consumption. In a more recent study, Case et al. (2008) test the impact of the Ambient Energy Orb on energy use in a study of 1500 Maryland households. The study involves the use of both critical peak pricing and peak time rebates. In addition, one of the study groups was also using an AC switch. Peak savings ranged from 17 to 33% across the study groups, however total energy savings were only 0.5%. Notably, the primary goal of this program was to reduce electricity

[30] The energy monitoring system did not measure energy use associated with heating and reported savings are for non-heating end uses.

use during peak periods and program information emphasized the economic benefits to consumers of shifting energy use to non-peak periods rather than focus on overall energy conservation. The fact that the average monthly energy savings of households in this study are much smaller than for households involved in studies in which time-of-use is not emphasized provides additional evidence that while feedback devices are indeed a useful tool that can be used to empower households to better manage their energy consumption, the purpose to which they are applied matters greatly. Feedback applied to peak load shifting tends to result in dramatically less overall energy savings.

Disaggregated, Real-Time Feedback

Only five of the studies reviewed for this report focus on the provision of disaggregated, real-time feedback. Given the relative level of technologically sophisticated interventions, it is not surprising that all but one of these studies were carried out during the current Climate Change Era, with one Canadian study (Dobson and Griffin) published in 1992. The majority of studies on this type of feedback were performed outside of the United States, including two studies in Japan, two in Europe (U.K. and Denmark) and one in Canada. The sole U.S. study reported here was performed in Michigan (Horst 2006) with the purpose of achieving peak load reductions through the use of the Whirlpool Energy Monitor. The study was based on a sample of just four homes, each of which was given a clothes washer, a clothes dryer, and a dishwasher that would start only after electric rates dropped to evening off-peak rates. Overall energy savings were not reported.

The remaining studies reported overall energy savings of 9 to 18%. In their study of 100 all-electric houses in Canada, Dobson and Griffin (1992) investigated the energy saving impact of the Residential Electricity Cost Speedometer (a computer-based feedback mechanism). Feedback devices were installed in 25 households for a two month period between January and April. Feedback-related savings were nearly 13%. In two Japanese studies, Ueno et al. (2006a and 2006b) investigated the use of the Online Energy Consumption Information System. In the first study, (performed in 2003) nine houses received real-time appliance-level feedback for roughly 2 months. Participants reduced their electricity consumption by 9%. In a subsequent study of 10 households, use of the same online feedback mechanism (Ueno 2006b) resulted in an average decline in electricity consumption of 18%.

Finally, a study of real-time, appliance-level feedback in the U.K. tested for the effects of both feedback and energy information. The study involved the participation of 44 households. A total of 19 households received feedback (9 of these households received information about energy consumption in conjunction with the feedback), twelve households only received information, and the remaining households received neither information nor feedback. Feedback was provided through the use of an “Energy Consumption Indicator.” When compared with the control group, households who received the Energy Consumption Indicator reduced their energy consumption by 15% on average although savings ranged from 11 to as much as 39%. Households receiving feedback and information reduced their consumption by 8.9% on average, while households that received information only reduced their energy consumption by 3% on average

A Comparison of Feedback Induced Energy Savings by Type of Feedback

As shown in Table 11, this meta-review reveals distinct differences in the average and median energy savings associated with different types of feedback. Indirect forms of feedback are highlighted by a yellow background, while direct forms of feedback are highlighted with the blue/green background. As shown, median household savings vary from 5.5% for programs that employ enhanced billing strategies to 14% for those that provide real-time feedback disaggregated by energy end use. Notably, while aggregate, real-time feedback has recently gained much popularity due to its compatibility with smart meters, evidence from the field suggests that this type of feedback tends to generate modest levels of household energy savings (6.9%). On the other hand, median savings from daily/weekly feedback are nearly 11%.

While these differences between feedback types are important, it is equally important to note the significant variation that exists within each of the feedback categories. This “within category” variation suggests while the type of feedback is important, other less prominent variables are equally important in shaping feedback-related energy savings. As such more attention must be given to improve our understanding of this within category variation. Among the variables that are likely to contribute to an explanation are: motivational elements and other program design characteristics, study size, study duration, and regional context and culture. Each of these factors is explored below. The goal is to provide a preliminary assessment of the ways in which program context and content mitigate and mediate the energy-saving impact of distinct types of feedback.

Table 11: Average and Median Household Energy Savings by Feedback Type

	Number of Studies		Range of Savings	Average Savings	Median Savings
Type of Feedback	**#**	**%**	**%**	**%**	**%**
Enhanced Billing	11	19%	1.2 - 10.0%	5.2%	5.5%
Estimated Feedback	3	5%	5.1 - 8.5%	6.8%	6.8%
Daily/Weekly	15	26%	3.7 - 21.0%	11.0%	10.8%
Real Time Aggregate*	23	39%	-5.5 - 32.0%	8.6%	6.9%
Real Time Plus	5	11%	9.0 - 18.0%	13.7%	14.0%

3. Motivational Elements and Energy Savings

An important and growing body of research (Darby 2006, Ehrhardt-Martinez and Laitner 2009, Lutzenhiser 2009) suggests that noneconomic factors can provide an important source of motivation for energy savings in the residential sector. Despite this growing recognition, relatively few feedback projects currently incorporate noneconomic levers such as goal setting, competitions, modeling, and social norms. Feedback studies are equally unlikely to apply noneconomic levers to augment energy savings. For example, of the studies reviewed for this report, only 18 mention the use of noneconomic factors in their study design. Of those that do, 4 include the use of goal setting, 2 include the use of competitions, and 14 attempt to apply social norm research.

Goal Setting

Only four of the feedback studies reviewed for this report indicate the use of goal setting as a component of their feedback study. Among these, the earliest attempt to use goals was a 1978 study by Seligman et al. who investigated the impact of daily/weekly feedback on household energy consumption in New Jersey. In addition, the study design also explored the impact of setting goals and how the use of goals might expand feedback-related energy savings. As such the study hypothesized “that feedback would lead to more energy conservation if individuals were asked to adopt a difficult conservation goal rather than an easy one.” Of the 100 households involved in the study, 40 households were given a difficult conservation goal (20% energy savings) while 40 were given an easy conservation goal (2% energy savings) and 20 households served in the control group. According to the authors, “during the treatment, the only group with significantly lower energy consumption than the control group was the difficult-goal-with-feedback group.” This group used 13% less energy than the control group. In addition, the two groups that received feedback saved significantly more energy than the two groups that didn’t receive feedback.

In a 1982 study of daily/weekly feedback by Winett et al. [Winter months], 82 Virginia households participated in a study of household energy conservation. Participants in the four treatment groups were given a 15% reduction goal and asked to sign a form indicating their commitment to work toward this goal. They were also given specific instructions on turning back their thermostat. Although the study does not test for the effects of goal setting, the approach was successful in generating overall energy savings of 17%.

Similar to the above findings, Van Houwellingen’s 1989 study of the effects of aggregate, real-time feedback in the Netherlands also revealed benefits of goal setting. Among the study’s hypotheses, the authors set out to assess whether goal-setting in conjunction with feedback on goal attainment would assist consumers in monitoring and reducing their home energy use. The study involved the participation of 325 households. Each of the three treatment groups was given an energy savings goal of 10%. Although energy savings across these groups varied, each group experienced significant energy savings compared to the control group and compared to historical levels of energy consumption. Households with in-home displays exceeded their energy savings goal and were able to reduce their energy consumption by 12.3%. Households that received monthly feedback fell short of the goal but did reduce their energy consumption by 7.7%. Households that self-monitored their energy consumption reduced their energy use by 5.1%.

Finally a recent study by Abrahamse et al. (2007) considers the effect of individual and group goal setting on household energy consumption in the Netherlands. The Abrahamse et al. study of 189 households combined tailored information with a 5% savings goal and tailored individual feedback for a group of 71 households, and provided a second group of households (66) with the same treatment plus a group goal. Fifty-two households were designated as the control group. Households in the first group met their energy savings goal of 5% while households in the second group reduced their consumption by 5.3%. The authors concluded that the group goals were not incrementally effective.

Competitions and Commitment

While competitions and commitment are recognized means of motivating and sustaining behavioral change, only two of the present studies employ these strategies as part of their overall program design. Petersen's study of feedback-induced energy savings in college dormitories is the only study that explicitly incorporates a competitive element. As stated elsewhere, Petersen uses aggregate, real-time feedback as a means of inducing energy savings in 18 dormitories at Oberlin University. Petersen characterizes the study design as involving "a two week long campus-wide "Dormitory energy competition"" in which conservation incentives were provided to students to reduce their energy consumption. During the intervention period, students competed to reduce their resource use. The intervention resulted in average electricity savings of 32%. A post-intervention survey found that students were highly motivated, holding planning sessions to brainstorm ways they could lower resource use as well as email-based discussions on the topic. Despite apparent high levels of motivation, Petersen et al. report that actual attendance at the post-intervention ice cream party that served as the advertised reward for winning dorms was poorly attended. The authors conclude that "factors other than the incentive of a reward were responsible for the changes in behavior." Notably, these findings suggest that the challenge itself and the social interaction involved in meeting the challenge may be more important forms of motivation than the reward offered for the "winners" of the challenge.

In a separate study, Staats et al. (2004) explore the use of eco-team interventions as a means of providing feedback and generating commitment and durable energy savings in the Netherlands. The authors cite a study by De Young (1993) which argues that commitment techniques produce behavioral changes that are relatively long lasting when compared to techniques that rely on voluntary cooperation. The potentially long-lasting effects of commitment are further supported by at least two primary studies by De Leon and Fuqua (1995) and Pallack et al. (1980). The first study considers the effect of commitment and feedback on recycling activities and finds that households receiving feedback increased the weight of recyclable paper by 25.4%, households that made a commitment (and also received feedback) increased the weight of recyclable paper by 40%. Moreover, in a study of commitment on energy conservation, Pallack et al. found that a commitment approach resulted in effects lasting 1 year. In their study of eco-team interventions, Staats et al. (2004) explore the potential for significant and lasting behavior change associated with an approach that combines information, feedback and social interaction. The study involved 150 households in a 3-year longitudinal study. Energy conservation was among the targeted behaviors. Notably, the intervention resulted in a reduction in electricity consumption of 5% immediately following the test period, but even larger savings (8%) two years later without any subsequent intervention.

Social Norms

Numerous studies suggest that the effects of normative social influence have powerful effects on individual behavior (for a review see Cialdini and Goldstein 2004). According to Nolan et al. (2008), "descriptive norms can lead people to say things they know to be untrue (Asch 1956), to use illicit drugs (Maxwell 2002), or to fail to respond to an imminent threat (Latane and Darley 1970). Approximately one-quarter of the feedback studies reviewed for this report attempt to capture the powerful influences of social norms to help residential energy consumers reduce their energy consumption. Many of these interventions are associated with the work of OPOWER (formerly known as Positive Energy) and their collaboration with various utilities throughout the United States. The six studies that do the best job of documenting these effects (Alcott 2009, Ayers et al. 2009, Ehrhardt-Martinez and Laitner 2009, Nolan et al. 2008, Schultz et al. 2007, and Wilhite et al. 1999) are discussed in this section.

Several recent reviews of the enhanced billing interventions provided by OPOWER reveal that their innovative combination of monthly feedback and normative data can achieve low-cost energy savings of 1.2 to 2.5% (Alcott 2009, Ayers et al. 2009, Ehrhardt-Martinez 2009). OPOWER's approach provides households with monthly Home Energy Reports that include both targeted and contextualizes information, including 1) household level data on current and comparative historical energy consumption, 2) semi-tailored energy saving tips, and 3) information concerning the energy consumption patterns of other households similar to their own. This third component provides households with a social or normative context in which to compare and assess their own energy use patterns. By understanding the normative context, households can evaluate whether their consumption is abnormally high or low and spontaneously adjust their energy use behaviors as necessary. In order to reduce the likelihood that low-level electricity consumers will increase their consumption, OPOWER's reports also use injunctive norms and include energy use comparisons with "energy-efficient neighbors". While descriptive norms reflect the behaviors that people actually engage in, injunctive norms reflect what most people believe is the "right thing to do". Low-levels of energy consumption can be reinforced through the use of smiley faces or other indicators that suggest approval of household energy behavior.

OPOWER's first intervention was initiated early in 2008 in conjunction with the Sacramento Municipal Utility District. The SMUD intervention was very large, involving 85,000 California households. Subsequent interventions in Minnesota and Washington also involve large samples. In all three cases, households in the intervention group received normative information in addition to feedback and energy saving tips, making it impossible to separate out the unique contribution of the normative information. However, a comparison of the intervention and control groups reveals statistically significant energy savings of 1.1 to 2.5% among households receiving OPOWER's Home Energy Reports.

In another recent study by Nolan et al. (2008) the authors explore the use of social norms in conjunction with daily/weekly feedback. The study provided feedback to 271 California households using one of four predetermined messages with the goal of motivating participants to reduce household energy consumption. The alternative messages included three non-normative appeals (either to protect the environment, benefit society, or save money) or the normative appeal which indicated that the majority of the recipients neighbors conserved energy. Later analysis compared the effects of the four appeals to a control condition that included an information-only appeal. Actual energy use was measured through meter readings and revealed that the normative message motivated people to conserve more energy than did the control message or any of the three other messages that contained more traditional types of appeals. Overall, the normative messaging was shown to achieve energy savings of 10%.

In a similar study by Schultz et al. (2007), 290 California households were given weekly feedback on their energy consumption. This study also employed the use of injunctive norms with the goal of minimizing the proportion of initially low-consuming households who would respond to the descriptive norms by increasing their energy consumption. As part of the study design, all households in the treatment group were given handwritten door hangers with information on how much energy they used, as well as a descriptive normative message regarding average electricity use, and energy saving tips. The second group also received a smiley face or sad face to communicate approval or disapproval (the injunctive norm). Households assigned to the first treatment group experienced an overall decline in electricity consumption of 5.7%. However, in the absence of the injunctive norm households that were initially consuming below the average experienced a 7.9% *increase* in consumption. Notably, however, when the injunctive norm was added to the door hanger, low energy consumers maintained their low levels of consumption.

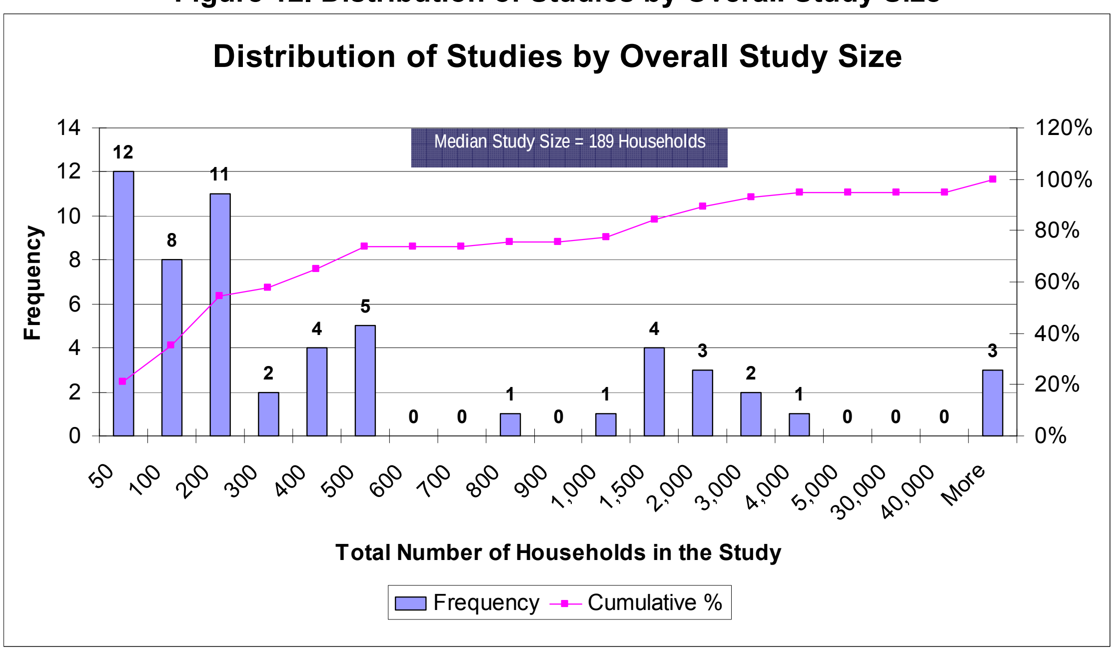
Finally, a study of enhanced billing in the Netherlands (Wilhite et al. 1999) also investigated the use of social norms as a means of reducing household energy consumption. Although norm-related savings were not reported, a post-intervention survey did find that customers expressed marked interest in normative feedback and that it was successful in generating increased awareness of energy consumption and acted as an incentive to reduce energy use.

4. Sample Size, Study Duration, and the Persistence of Energy Savings

As with any research, research findings regarding the effectiveness of energy use feedback are likely to be impacted by the size and duration of the study. In this section we provide some descriptive statistics that illustrate the range and variation in sample size and study duration for the 57 studies included in this meta-review. We also provide a preliminary assessment of the relationship between these characteristics and the resulting feedback-related energy savings.

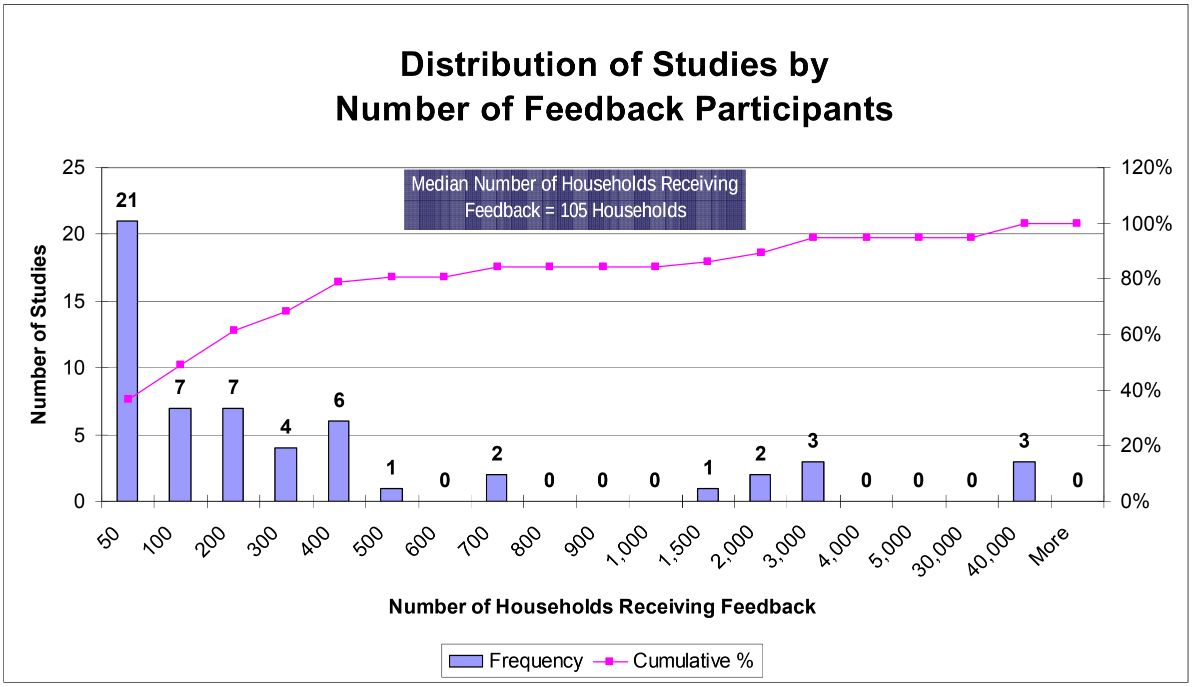
Sample Size. Study size can be measured in at least two ways: the total number of study participants (including control group participants), and the number of study participants receiving feedback. Because many of the studies included in this review were designed to test the effects of multiple experimental variables, our assessment considers both measures of overall study size (the total number of households participating in the study) as well as the number of feedback participants. As shown in Figure 12, overall study size varies dramatically. Among the 57 studies, a few provide in-depth assessments of the effects of feedback using just a few case studies while other studies involve the participation of more than 80,000 households. Most of the studies have between 60 and 600 participants with a median study size of 189 households. Figure 12 illustrates the frequency distribution of studies by overall size.

Figure 12. Distribution of Studies by Overall Study Size



Given the specific focus of this meta-review on the effects of energy use feedback, we also measure study size in terms of the number of households in the study that received feedback. Even when defined in this manner, the range of variation is tremendous. As shown in Figure 13, the number of feedback participants ranged from just a few (in the case study research) to nearly 40,000. Nevertheless, the vast majority of studies (85%) provided feedback to fewer than 700 households. The median number of households receiving feedback was 105.

Figure 13. Distribution of Studies by Number of Feedback Participants

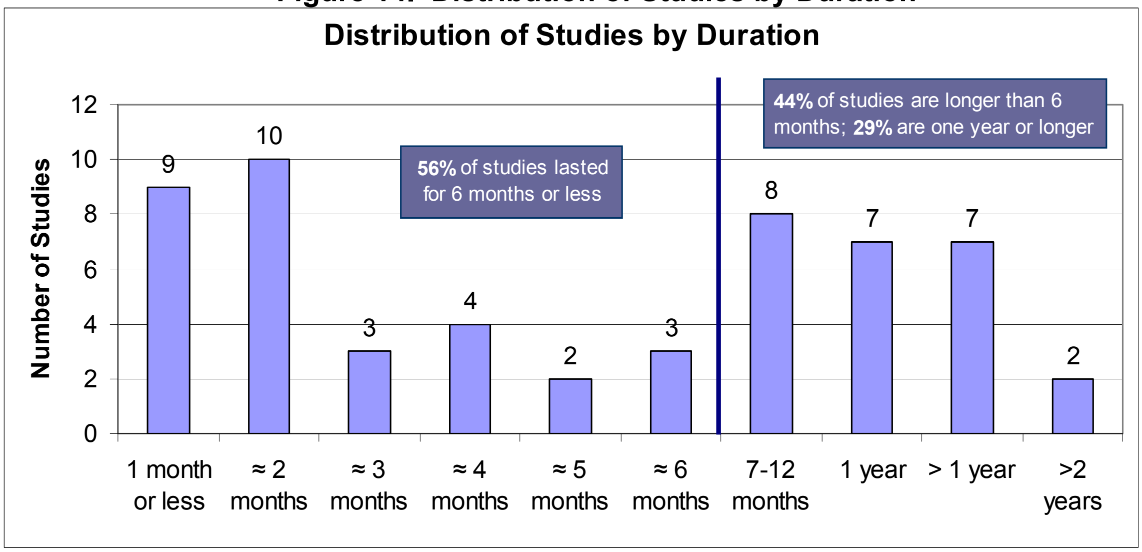


Not surprisingly, study size has important implications for feedback-related energy savings. In order to perform a preliminary appraisal, we assess the relationship between study size as measured by the number of feedback participants and feedback-related energy savings. As shown in Table 12 (below) studies with larger feedback sample sizes (100+) generally show lower levels of feedback-related energy savings than studies with smaller feedback sample sizes (<100). Since the findings of larger studies tend to be more generalizable to the larger population these findings are particularly relevant to efforts aimed at estimating the potential scope of feedback-related energy savings. According to our review, average energy savings across large-sample studies is roughly 6.6% compared to average savings of 11.6% across small-sample studies.

Study Duration and Persistence. Study duration ranged from a single day (in one study) to as long as two or three years. Most studies lasted between 2 and 12 months with a median study duration of 5 months. Figure 14 shows the distribution of studies by duration. Overall, 56% of studies lasted for 6 months or less. Notably, a review of the relationship between study duration and feedback-related energy savings revealed that average energy savings were higher for shorter studies (10.1%) than for longer studies (7.7%) as shown in Table 12. It is unclear whether this discrepancy in energy savings is a function of a decline in savings over time since most studies simply report overall energy savings. Notably, however, the discrepancy remains even after controlling for feedback type, the era of the study, and the study size (as measured by feedback participants) in bivariate assessments.

While the cross-tabs discussed above indicate an inverse relationship between study duration and energy savings, evidence from the 27 studies that attempt to measure the within study persistence of feedback effects (see Appendix B) suggests that feedback-related energy savings are often persistent. As suggested by Darby (2006) and reinforced by several studies reviewed here, however, persistence of energy savings may rely on the continued provision of feedback. For example, in a recent study of an enhanced billing program, Alcott (2009) found that there was some decay in the months between reports for those households receiving quarterly reports. However, this decay in energy savings was not found for households receiving more frequent (monthly) reports. Similarly, in a 12-month study of the effects of real-time feedback in the Netherlands, van Houwellingen et al. (1989) found that in-home displays were highly successful in reducing energy consumption (by 12.3%), however when the energy monitors were removed from households following the 12 month intervention period, energy savings did not persist.

Figure 14. Distribution of Studies by Duration



Note: two studies did not report study duration and are not included in this chart.

These findings suggest that while savings may be lower in longer studies, the lower rates of savings are more likely to be associated with the ability of these studies to capture seasonal variations in energy end uses rather than a reflection of a decline in the persistence of savings over time. This is reinforced by the fact that most of the shorter studies are intentionally carried out during warm summer months when electricity demand associated with air conditioning use is at its highest and more dramatic savings are more easily achieved by simply turning off the air conditioning. Notably, some of the longest studies that measure persistence (Mountain 2006 and 2008, Nielsen 1993, Staats et al. 2004, Staats et al. 2000, Wilhite and Ling 1995, Wilhite et al. 1999) show that energy savings do persist over time. (Studies with measures of persistence are shown in Appendix B. [31])

In order to resolve this question, future feedback studies should provide feedback over a period of at least 24 months and report on the related savings over several time periods while controlling for seasonal variations in end use demands.

C. The Intersection of Contextual and Program Variables

This section builds on the preliminary insights gleaned from earlier discussions of bivariate relationships between energy savings and feedback type, program characteristics, regional context, study size and study duration by exploring some of these variables in combination. More specifically, cross-tabs are used to assess whether these relationships persist once the effects of other variables are controlled. For example, although our preliminary bivariate assessments indicate that energy savings from studies performed during the Climate Change Era are lower than savings from studies

[31] The issue of persistence is also discussed in the conclusions of this report.

performed during the Energy Crisis Era, we suspect that newer studies may also tend to be larger and therefore use cross-tabs to consider the effect of study era independently of study size. Similarly, although our preliminary bivariate assessment indicates that real-time plus and daily/weekly feedback generate the larges amounts of household energy savings, this section seeks to ascertain if those findings persist once we control for study era, study size and study duration. Finally, the persistence of geographical variations in feedback-related energy savings is explored in light of the effects of study era and study size. The discussion begins with a description of the variation in energy savings across salient variables. Then we take a closer examination of these variables using cross-tabs.

Our analysis using cross tabs is guided by the following questions:

- To what degree is the effect of study era on energy savings influenced by study size and duration? Is the effect of study size on energy savings influenced by the duration of the study? Or is the effect of study duration influenced by the size of the study?
- To what degree is the effect of feedback type on energy savings influenced by study era, study size, or study duration?
- To what degree is the effect of feedback type on energy savings influenced by the geographical context of the study?
- To what degree is the effect of regional context influenced by the era, size and duration of the study?

To summarize some of our earlier findings, average feedback-related energy savings vary greatly across the studies from -5.5% to 32% with an adjusted, study-wide average of 9.1%.[32] As shown in Table 10 on the following page, average feedback-related savings are greater than 10% for two types of feedback: real-time plus (13.7%) and daily/weekly feedback (11.0%). Real time feedback which provides households with aggregated energy consumption information is shown to yield average savings of 8.6%, while estimated feedback and enhanced billing are associated with average savings of 6.8% and 5.2%, respectively.

The effects of feedback are also likely to be shaped by regional context. The studies reviewed for this report were carried out in a variety of different countries including, the U.S., Canada, the Netherlands, Norway, the United Kingdom, Finland, Denmark, Australia, and Japan. We suspect that social, cultural, political, and structural differences associated with these regions are likely to influence feedback-related energy savings. However, as shown in Table 10, there appears to be only limited variation by region. Energy savings in Europe and the U.S. (across all time periods and types of feedback) average 10% in Europe and 8.8% in the U.S., while savings in Canada and other regions (namely Japan and Australia) average between 7.3 and 8.2%. However, as noted later in this report, regional differences in feedback-related energy savings become more pronounced when the assessment is limited to more recent studies implemented during the Climate Change Era.

[32] The median energy savings across all studies was 8.6%.

Table 12. Summary of Primary Data Studies

	Number of Studies		Range of Savings	Average Savings	Median Savings
	#	%			
Type of Feedback					
Enhanced Billing	11	19%	1.2 - 10.0%	5.2%	5.5%
Estimated Feedback	3	5%	5.1 - 8.5%	6.8%	6.8%
Daily/Weekly	15	26%	3.7 - 21.0%	11.0%	10.8%
Real Time Aggregate*	23	40%	-5.5 - 32.0%	8.6%	6.9%
Real Time Plus	5	9%	9.0 - 18.0%	13.7%	14.0%
Region					
United States*	33	58%	-5.5 - 32.0%	8.8%	8.5%
Canada*	9	16%	0.0 - 18.1%	7.3%	6.5%
Europe	13	23%	5.0 - 21.0%	10.0%	8.5%
Other	3	5%	3.7 - 12.0%	8.2%	9.0%
Study Era					
Old—Energy Crisis Era	21	37%	-5.5 - 21.0%	10.3%	11.0%
New—Climate Change Era	36	63%	0.5 - 32.0%	8.2%	6.9%
Study Size					
Small (<100)	28	49%	-5.5 - 32.0%	11.6%	12.0%
Large (100+)	29	51%	0.5 - 12.8%	6.6%	6.0%
Study Duration**					
Shorter (≤ 6 months)	31	57%	0.5 -32.0%	10.1%	9.3%
Longer (> 6 months)	23	43%	-5.5 - 21.0%	7.5%	7.2%
Total	57	100%	-5.5 - 32.0%	9.1%	8.5%

*In order to assess savings by region, Hutton's study is divided into U.S. and Canadian components.
**Study duration is reported for 54 studies.

The era and the size of the study reveal some interesting energy savings trends. Older studies performed during the Energy Crisis Era (prior to 1995) achieved higher levels of feedback-related energy savings (11.0%) compared to newer studies performed during the Climate Change Era (8.2%). The effect of study era may reflect the broader public concern over energy resources following the oil embargoes of the 1970s and the dramatic increases in energy prices that followed. This contrasts dramatically to the low levels of public concern over climate change.
In addition to era-related effects, not surprisingly the size of the study is also important in assessing feedback related energy savings. Studies with larger sample sizes (100+) generally show lower levels of feedback-related energy savings. Since the findings of larger studies tend to be more generalizable to the larger population these findings are particularly relevant to efforts aimed at estimating potential feedback-related energy savings. According to our review, average energy savings across large-sample studies is roughly 6.6% compared to average savings of 11.6% across small-sample studies.

Finally, as discussed above energy savings also vary as a function of study duration. Longer studies (>6 months) tend to achieve lower rates of household energy savings when compared with shorter studies (≤6 months). Our review found that average household energy savings for longer studies were on the order of 7.7%, while savings for shorter studies averaged 10.1%. This discrepancy is likely a reflection of study design decisions associated with the shorter studies which are often performed during summer months when electricity consumption is at its highest.

Effects of Study Era, Size, and Duration.

- To what degree is the effect of study era on energy savings influenced by study size and duration? Is the effect of study size on energy savings influenced by the duration of the study? Or are the savings effects of study duration influenced by the size of the study?

As shown in Table 13, a comparison of energy savings across eras shows that average and median energy savings are consistently lower during the Climate Change Era, regardless of the study size or the duration of the study. The only exception to this trend appears when comparing average energy savings for small studies. However, even among small studies, median energy savings are lower in the Climate Change Era.

Table 13. Energy Savings by Study Era, Size and Duration

	Energy Crisis Era			Climate Change Era			Total		
	Average Savings	Median Savings	No. of Studies	Average Savings	Median Savings	No. of Studies	Average Savings	Median Savings	No. of Studies
STUDY SIZE									
Small (≤100)	11.3%	12.9%	14	12.2%	9.0%	14	11.6%	12.0%	28
Large (>100)	8.2%	8.6%	7	6.1%	6.0%	22	6.6%	6.0%	29
Total	10.3%	11.0%	21	8.2%	6.9%	36	9.1%	8.5%	57
STUDY DURATION									
Short (≤ 6 months)	11.7%	12.9%	12	9.3%	7.6%	19	10.1%	9.3%	31
Long (>6 months)	8.4%	8.8%	9	7.3%	7.0%	14	7.8%	7.4%	23
Total	10.3	11	21	8.2%	6.9%	33	9.1%	8.5%	54

Table 14 breaks out energy savings by study size and duration with the goal of assessing whether 1) the effects of study size on energy savings are influenced by the duration of the study, or 2) the effects of the study duration on energy savings are influenced by the size of the study. Bivariate assessments indicated that energy savings were greater for both smaller and shorter studies.

An assessment of all three variables indicates that smaller feedback studies tend to result in higher energy savings in both short and long studies. These findings confirm the trend found in the bivariate assessment. However longer research studies do not consistently result in smaller levels of savings. As shown in Table 14, among the larger studies estimates of average household level savings are roughly the same for both short and long studies. These findings are not entirely consistent with the bivariate estimates presented in Table 12 and suggest that energy savings estimates from small studies are likely to be more highly influenced by the length of the study.

Table 14: Energy Savings by Study Size and Duration

	Small (≤100)			Large (>100)			Total		
	Average Savings	Median Savings	Number of Studies	Average Savings	Median Savings	Number of Studies	Average Savings	Median Savings	Number of Studies
DURATION									
Short (≤6 months)	13.3%	13.0%	18	6.6%	6.0%	13	10.1%	9.3%	31
Long (>6 months)	8.7%	7.2%	9	6.7%	6.3%	14	7.7%	7.4%	23
Total	11.6%	12.0%	27	6.6%	6.0%	27	9.1%	8.5%	54

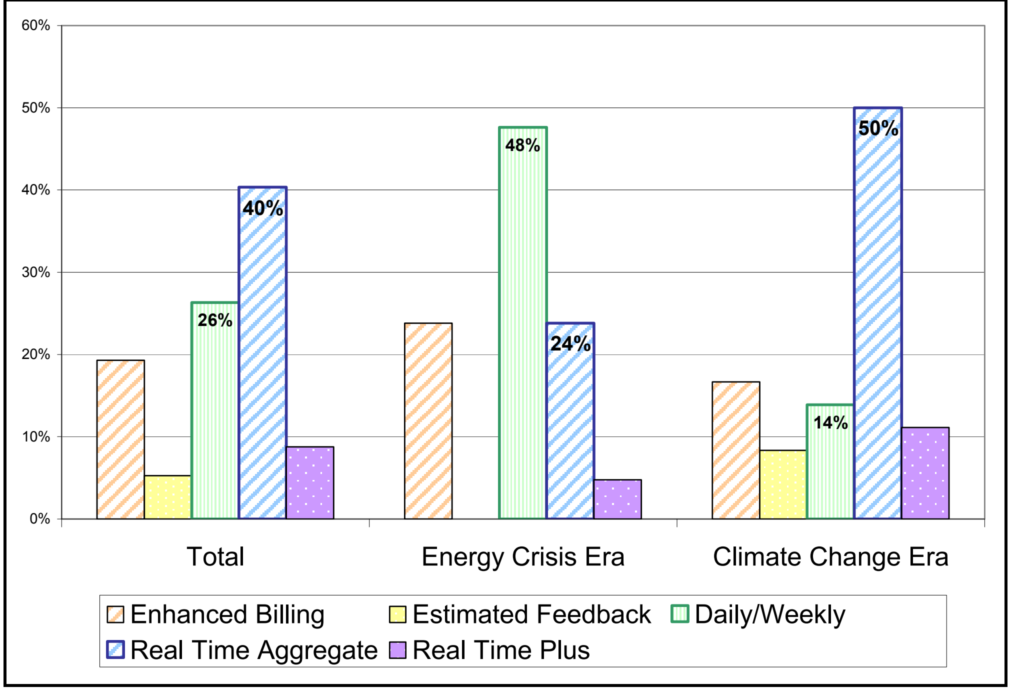
Effects of Feedback Type, Study Era, Size, and Duration.

- To what degree is the effect of feedback type on energy savings influenced by study era, study size, or study duration?

As a first step, we illustrate the relationship between feedback type and study era to assess the degree to which research on certain types of feedback has been more or less prominent during each of the two eras. Figure 15 clearly shows that while research on daily/weekly feedback predominated during the Energy Crisis Era, research on aggregate, real-time feedback has predominated during the current Climate Change Era.

Notably, as utility plans to quickly deploy smart meter technologies continue to take shape, the growing interest in real time feedback and real-time plus feedback mechanisms is likely to continue to expand as well. These trends are likely to also be catalyzed by the growing investments and interest in the increasing number of in-home feedback technologies and by the increasing affordability of these devices. Given this growing interest in real-time technologies, future research should give more attention to understanding the significant variation in energy savings that has resulted from the application of real-time feedback technologies.

Figure 15. Feedback Savings Categories by Study Era



Given this relationship between feedback type and study era, this section also seeks to further explore the degree to which feedback-related energy savings vary by the type of feedback after other factors are taken into consideration. Here we explore the potential effects of study era, size and duration.

Data from our bivariate assessment indicates that certain types of feedback produce greater energy savings than others. More specifically, energy savings associated with studies that employed daily/weekly feedback and real-time plus feedback were shown to be higher than energy savings associated with other types of feedback. This section explores whether these relationships remain regardless of study era and study size.

Table 15 presents average energy savings by study era and size. As shown, real time plus feedback and daily/weekly feedback show the greatest energy savings among the older studies, however the same pattern does not hold true among the newer, Climate Change Era studies. Among the newer studies aggregate real-time feedback and real-time plus feedback show the greatest savings at 12% and 9.2% respectively.

In terms of the relationship between type of feedback and study size, Table 15 clearly indicates that enhanced billing interventions and estimated feedback programs tend to be larger in size, while programs that provide real-time plus feedback have involved relatively few households. Interventions involving daily/weekly feedback and real-time aggregate feedback include both smaller and larger studies. Notably daily/weekly feedback results in more savings than real-time aggregate feedback regardless of whether the study is large or small. These findings support the initial bivariate assessment of energy savings by type of feedback.

Finally, it is worth noting that among the older studies savings from daily/weekly feedback exceed those of aggregate real-time mechanisms and continue to rival their savings in the Climate Change Era. While the two types of feedback seem to generate comparable levels of energy savings, daily/weekly approaches to feedback have tended to rely less on automation-based mechanisms for providing energy consumption feedback. As such, they have also been less likely to be implemented on a large scale.[33] Interestingly, this is not the result of some defining feature of this approach to feedback, but instead is simply a question of program design. Daily/weekly feedback could be automated through the use of internet technologies or through the use of smart meter technologies. This observation is important for two reasons. First in her review of feedback-related studies, Darby (2006) notes that indirect forms of feedback such as daily/weekly feedback appear to be *better than* direct feedback for demonstrating the energy impacts associated with changes in space heating and cooling, household composition, and investments in energy efficiency measures or high consuming appliances. Second, providing households with weekly feedback may be less costly than providing them with direct feedback because it eliminates the need for in-home displays

Given that daily/weekly feedback approaches appear to achieve roughly the same level of energy savings as aggregate-level real time feedback approaches, further study on this topic seems warranted. Given these findings, it is also worth noting that while daily/weekly feedback approaches dominated feedback studies during the energy crises era, they have not received much attention during the Climate Change Era. Instead, recent research has been dominated by studies of aggregate-level, real-time feedback.

Table 15. Savings Based on Feedback Type, Study Era, and Study Size

	ERA				STUDY SIZE			
	Energy Crisis (<1995)		Climate Change (1995+)		Small (<100)		Large (100+)	
Type of Feedback	Average Savings	No. of Studies	Average Savings	No. of Studies	Average Savings	No. of Studies	Average Savings	No. of Studies
Enhanced Billing	7.5%	5	3.8%	6	n.a.	1	5.2%	10
Estimated Feedback	n.a.	0	6.8%	3	n.a.	0	6.8%	3
Daily/Weekly	12.1%	10	8.4%	5	12.4%	10	8.7%	5
Real Time Aggregate	7.8%	5	9.2%	18	10.7%	12	6.7%	11
Real Time Plus	12.9%	1	12.0%	4	12.2%	5	n.a.	0
Total	10.3%	21	8.2%	36	11.6%	28	6.4%	29

[33] Only 4 of the 15 studies using daily/weekly feedback had sample sizes exceeding 200 households.

The final assessment in this section considers the relationship between feedback type and energy savings when controlling for study duration. As shown in Table 16, energy savings associated with enhanced billing and estimated feedback continue to be lower than the other types of feedback regardless of study duration. Energy savings associated with daily/weekly feedback continues to rival or (in the case of the longer studies) surpass the savings associated with real-time feedback. And the energy savings from real-time plus approaches provides the greatest savings. These findings confirm earlier bivariate assessments.

Table 16: Feedback Type by Study Duration

	Shorter Studies (≤ 6 months)			Longer Studies (>6 months)		
Feedback Type	**Average Savings**	**Median Savings**	**N**	**Average Savings**	**Median Savings**	**N**
Enhanced Billing	6.0%	6.0%	2	5.1%	5.0%	8
Estimated Feedback	6.8%	6.8%	3	n.a.	n.a.	0
Daily/Weekly Feedback	10.1%	10.3%	13	16.5%	16.5%	2
Real Time Feedback	11.5%	7.7%	9	7.3%	7.0%	12
Real Time Plus	12.2%	12.5%	4	n.a.	n.a.	1
Total	10.4%	9.6%	31	7.5%	7.2%	23

Effects of Feedback Type and Regional Context

- To what degree is the effect of feedback type on energy savings influenced by the geographical context of the study?

Due to the sparseness of the data in many of the cells, assessing the effects of feedback on energy savings by region is speculative at best. Nevertheless, some trends from the U.S. and Europe can be assessed. As shown in Table 17, in the U.S. energy savings from daily/weekly feedback (11.2% energy savings on average) clearly exceed those from aggregate, real-time feedback (7.9% energy savings on average). These same trends cannot be assessed in other regions due to a lack of data. Also of note, energy savings from enhanced billing tend to be higher in Europe than in the United States. These findings are not surprising given historical billing trends in many European countries in which bills were provided on a quarterly basis or even less frequently. The introduction of enhanced billing in Europe has generally been synonymous with an increase in billing frequency and the combination of more frequent and better information is likely to result in greater savings than changes in billing information alone.

Table 17: Feedback Type by Region

	United States*		Canada		Europe		Other		Total	
Region	Avg. Savings	N	Avg. Savings	N	Avg. Savings	N	Avg. Savings	N	Avg. Savings	N
Enhanced Billing	1.7%	5	6.0%	1	7.7%	5	n.a.	0	5.2%	11
Estimated Feedback	n.a.	1	n.a.	0	6.8%	2	n.a.	0	6.8%	3
Daily/Weekly	11.2%	10	0.0%	1	13.0%	3	3.7%	1	11.0%	15
Real Time Aggregate	7.9%	17	7.9%	6	12.3%	1	n.a.	0	8.6%	23
Real Time Plus	n.a.	1	12.9%	1	15.0%	1	10.5%	2	12.2%	5
Total	8.5%	34	7.3%	9	10.0%	12	8.2%	3	9.1%	57

* In order to explore feedback type by region, results from Hutton et al. 1986 were separated by region.

Effects of Regional Context, Era, Size, and Duration

- To what degree is the effect of regional context influenced by the era, size and duration of the study?

As noted earlier in Table 12, with the exception of Canada, median energy savings show limited variation across regions. Average energy savings are highest in Europe (10.0%), followed by the U.S. (8.8%) and Canada (7.3%). Median energy savings are roughly equal in the U.S. (8.5%) and Europe (8.5%) but are noticeably lower in Canada (6.5%).

Nevertheless, important patterns begin to emerge from a closer examination of the relationship between regional context and feedback-related energy savings. Table 18 summarizes the effects of region on energy savings after controlling for study era and study size. These findings show that feedback-related energy savings from studies performed during the Climate Change Era are highest in Japan and Australia (10.5%) followed by savings in Europe (9.1%), Canada (8.1%) and the U.S. (7.4%).[34] While all three regions experienced higher energy savings during the Energy Crisis Era, the difference in energy savings across the two eras is most pronounced for the United States where average savings during the Energy Crisis Era was 10.8% while savings during the Climate Change Era are only 7.4%. An even larger gap exists when median energy savings are assessed.

Table 18. Energy Savings by Region, Study Era, and Study Size

	ERA				STUDY SIZE			
	Energy Crisis Era (<1995)		Climate Change Era (1995+)		Small (<100)		Large (100+)	
Study Location	Average Savings	Number of Studies	Average Savings	Number of Studies	Average Savings	Number of Studies	Average Savings	Number of Studies
United States	10.8%	13	7.4%	19	11.9%	18	5.2%	14
Canada	8.7%	2	8.1%	7	10.1%	5	6.5%	4
Europe	11.2%	5	9.1%	8	18.0%	2	8.3%	11
Other	3.7%	1	10.5%	2	8.2%	3	n.a.	0
Total	10.3%	21	8.2%	36	11.6%	28	7.7%	29

The difference in energy savings by region raises important research questions as to the potential causal drivers behind the variation. Such drivers may include different policy positions on the issue of climate change, different levels of government support for the diffusion of smart grid technologies and/or the adoption of people-centered approaches to energy savings, or important differences in cultural values and norms.

Similar to the assessment of regional savings by era, an assessment of feedback-related savings within larger-sample studies also reveals larger average savings for Europe (8.3%) compared to the U.S. (5.2%) and Canada (6.5%).

In our final assessment, we consider the effect of region on energy savings by study duration. As shown in Table 19, average energy savings in the United States exceed those observed in Canada, Europe and elsewhere when regional comparisons are made across studies of shorter duration. However, there are important differences in these patterns when comparing regional energy savings for longer studies. Among the longer studies (studies greater than 6 months) savings are much greater in Europe (10.8%), followed by Canada (8.0%) and the United States (4.6%).

[34] These same trends are observed when median energy savings are assessed.

Table 19: Energy Savings by Region and Study Duration

Feedback Type	Shorter Studies (≤ 6 months)			Longer Studies (>6 months)		
	Average Savings	Median Savings	N	Average Savings	Median Savings	N
United States	12.0%	11.0%	19	4.6%	3.0%	12
Canada	8.6%	7.7%	5	8.0%	5.5%	4
Europe	8.7%	7.3%	4	10.8%	10.0%	7
Other	8.2%	9.0%	3	n.a.	n.a.	0
Total	10.4%	9.6%	31	7.5%	7.2%	23

Overall, our meta-review suggests that while additional research is required to better understand the broad variation in energy savings associated with specific types of feedback, existing research indicates:

1. Feedback-related energy savings achieved during the current Climate Change Era tend to be smaller than energy savings achieved during the Energy Crisis Era. These effects are consistent for all types of feedback with the exception of aggregate, real-time feedback. This pattern is particularly pronounced for the United States but is also observable in Europe and Canada.
2. Smaller studies are associated with larger estimates of feedback-related energy savings than larger studies.
3. Within the smaller studies, energy savings tend to be larger for shorter studies than for longer studies; however this trend is not observed for larger studies in which energy savings are roughly the same for longer and shorter studies.
4. Research on daily/weekly feedback predominated during the Energy Crisis Era, while research on aggregate, real-time feedback has predominated during the current Climate Change Era.
5. Real time plus feedback and daily/weekly feedback show the greatest energy savings among the older studies, however the same pattern does not hold true among the newer, Climate Change Era studies. Among the newer studies aggregate real-time feedback and real-time plus feedback show the greatest savings at 12% and 9.2% respectively although savings from daily/weekly feedback continue to be substantial. However, these real-time studies were generally of short-duration and/or with small sample sizes. Further large long-term studies are needed before conclusions can be drawn.
6. Energy savings associated with daily/weekly feedback exceed savings associated with aggregate, real-time feedback in studies of longer duration.
7. In the United States energy savings from daily/weekly feedback (11.2%) clearly exceed those from aggregate, real-time feedback (7.9%). [These same trends cannot be assessed in other regions due to a lack of data.]
8. Energy savings from enhanced billing tend to be higher in Europe than in the United States. These findings are not surprising given historical billing trends in many European countries in which bills were provided on a quarterly basis or even less frequently.
9. Feedback-related energy savings from studies performed during the Climate Change Era are highest in Japan and Australia (10.5%) followed by savings in Europe (9.1%), Canada (8.1%) and the U.S. (7.4%).[35] While all three regions experienced higher energy savings during the Energy Crisis Era, the difference in energy savings across the two eras is most pronounced for the United States where average savings during the Energy Crisis Era was 10.8% while savings during the Climate Change Era are only 7.4%.

[35] These same trends are observed when median energy savings are assessed.

10. When assessments are limited to longer and larger studies (which are more likely to produce generalizable findings), average energy savings in the U.S. are smaller than those observed in Europe and in Canada.

Of particular relevance is the finding that energy savings during the current Climate Change Era are noticeably smaller in the United States than in Europe. This difference is likely the result of important difference in the way in which climate change is portrayed and discussed among policy leaders and the general level of concern about climate change across the general population.

Another important finding concerns the range of energy savings associated with different types of feedback and the implications of these finding for state-wide and nation-wide energy savings. The findings clearly indicate that the largest average household energy savings are likely to be achieved through the use of Real-Time, Real-Time Plus, and Daily/Weekly feedback interventions. Alternatively, Enhanced Billing can provide a relatively low-cost and easy to implement alternative means of providing household level feedback despite the lower household level energy savings associated with this type of feedback.

While it is critically important to understand how energy savings vary by the type of feedback, a second essential consideration is the likely level of household engagement associated with each of these types of feedback. Ultimately, utility-wide or community-wide energy savings are dependent on the rate of household participation. As shown in Table 18, evidence suggests that participation rates are significantly higher for programs that are designed using an opt-out (as opposed to opt-in) principle. Feedback programs that employ opt-out designs have been shown to achieve participation rates of 75 to 85% while opt-in programs typically achieve participation rates well under 10%. The amenability of Enhanced Billing, Daily/Weekly Feedback, Real-Time Feedback, and Real-Time Plus feedback programs to opt-out designs can dramatically increase the likelihood of their success in achieving considerably larger overall energy savings. As shown in Table 20, once participation rates are taken into consideration, Real-Time Plus programs appear to generate the largest aggregate level savings (as high as 12%) followed by Real-Time feedback programs (6%) and Enhanced Billing programs (nearly 5%). Notably, however, the investment costs of Enhanced Billing programs are substantially lower than those associated with the implementation of either Real-Time or Real-Time Plus programs that require advanced metering equipment and in-home displays.

Table 20: Potential Aggregate Level Energy Savings from Feedback Interventions

	Average Household Savings	Participation Plan	Participation Rate	Overall Savings	Participation Rate	Overall Savings
Enhanced Billing	5.6%	**Opt out**	75.0%	4.2%	85.0%	4.8%
Estimated Feedback	6.8%	Opt in	5.0%	0.3%	10.0%	0.7%
Daily/Weekly Feedback	11.0%	Opt in	5.0%	0.6%	10.0%	1.1%
Real Time Feedback	7.0%	Opt in	5.0%	0.4%	10.0%	0.7%
Real Time Feedback	7.0%	**Opt out**	75.0%	5.3%	85.0%	6.0%
Real Time Plus Feedback	14.0%	Opt in	5.0%	0.7%	10.0%	1.4%
Real Time Plus Feedback	14.0%	**Opt out**	75.0%	10.5%	85.0%	11.9%

Note: This chart is based on our multi-continent sample; savings in the U.S. are likely lower.

In addition, it is important to recognize the effect of sample size and duration in correctly assessing the feedback-related energy savings of any feedback approach. As shown earlier in this report, larger, more generalizable studies suggest more modest savings and longer studies are better able to capture the seasonal variations in energy end uses and their impact on feedback-related energy savings. Future studies should ensure maximum generalizability through the design of appropriately sized research studies and their implementation over a period of 12 months or longer.

D. Demand Response and Feedback-Induced Energy Savings

Among the potential benefits of advanced metering technologies and their associated behavior responses are their potential contributions to, and enhancement of, utility-based demand-side management (DSM) programs. DSM programs include a wide range of efforts to understand and manage customer demand for energy resources, with the goal of reshaping the quantity or pattern of energy use. "Demand response" is one type of demand-side management strategy that involves the use of pricing structures, programs, and related technologies and services to encourage consumers to reduce their consumption at critical times in response to market information. Market information may take the form of time-variable energy pricing, non-price incentives and notifications of system supply problems. Market mechanisms also include demand bidding auctions, in which utilities offer customers a payment for reducing power demand by a set amount, usually achieved by shutting down or otherwise cycling off certain equipment when necessary. In other words, demand response is a type of "load management"—a broader term encompassing any effort taken by a utility (or customer) to modify power demand (kilowatts or kW) at any particular time. Utilities have a long history of operating demand-side management programs—in some cases such programs date back to the 1970s or even earlier.

In addition to the goal of avoiding blackouts, one of the primary purposes of demand response is to avoid the significantly greater costs associated with meeting the dramatic increases in energy demand that are often associated with high temperatures and increased demand for air conditioning. During times of peak demand, prices of electricity as exchanged on wholesale markets can increase many fold. At such times it may be much less costly for utilities to reduce electricity demand through a variety of load management options than to meet demand through the purchase of additional electricity resources. The adoption of "demand response" actions by electricity customers can be an effective, cost-effective means for utilities and system operators to meet system demands.

Importantly, advanced metering technologies provide new means of enabling a variety of demand response and other load management options. Advanced metering—coupled with both advanced control and communications technologies—enhances the ability of utilities and system operators to monitor and control customer power demands. Such enhanced capabilities provide strong incentives for utilities to invest in smart grid technologies. Other important drivers include the benefits of automated meter reading and related customer data collection. [36]

1. Synergies and Conflicts between Energy Efficiency and Demand Response

There are both similarities and differences between energy efficiency programs and demand response programs. Both types of programs affect customer energy use. However, their ultimate objectives differ. While demand-response programs tend to focus on reducing peak or kilowatts (kW) of demand *during specific times* when reliability may be threatened or wholesale market prices are high (typically 100 hours or fewer during an entire year), efficiency programs tend to focus on cost-effective reductions in *overall, year-round* customer energy use in kilowatt-hours (kWh). Stated perhaps a bit differently, demand response programs generally curtail energy use (such as reducing lighting levels or shifting energy consumption to off-peak hours) for relatively short periods a few times a year. Energy efficiency programs, on the other hand, reduce consumption through ongoing measures employed at all times a given energy-using device or system is operating (such as replacing lighting systems with more energy-efficient ones).

The differences in program objectives between energy efficiency and demand response are evident as shown in a recent national survey of DSM programs. The National Action Plan for Energy Efficiency (FERC 2009) reported that, in 2008, only 43 out of the 1,707 energy efficiency, demand response and load management programs in the United States and Canada targeted both energy efficiency and demand response savings (Goldman, Reid and Levy 2009). Just as a program may introduce meters to inform a utility without considering customer behavior, a program may adjust demand without reducing energy use. Several examples appear earlier in this report in the section on "Feedback Type and Savings" (Sexton et al. 1987; Case et al. 2008). In general, an energy efficiency program is likely to reduce demand (kilowatts) in addition to saving energy (kilowatt-hours), but a demand response program may not necessarily save energy (Goldman, Reid and Levy 2009).

[36] Other more narrow financial reasons for utility management enthusiasm for advanced metering are the ability to make substantial capital additions to rate base to pay for the equipment and the opportunity to reduce labor costs.

Demand response typically relies on two types of consumer behavior: conservation responses and load shifting (a third option for customers is to generate power locally; in this report we only are examining demand-side measures). A conservation response involves reducing the wasteful use of energy or forgoing some type of energy amenity. Turning off lights, raising the allowed temperature for air conditioning, or turning off an air conditioner are examples. Load shifting involves changing the time of use of a device to a period when the cost of running that device may be lower. For instance, a customer may run a dishwasher or clothes washing machine at night instead of during the day. Load shifting generally yields no overall energy or kWh savings. Conservation responses can result in lower overall energy use, although this depends on the nature of the response and any resulting "rebound" effect at a later time. Nemtzow et al. (2007) note two types of customer actions which typically do not result in load shifting or rebound at a later, off-peak time. The first of these is dimming of light levels (either dimming light output or switching off some fixtures). Clearly customers do not later "over-light" an area to compensate for being slightly "underlit" during the demand response event or period. The other type of response includes those that occur at the end of a work day (or occupancy period in a household). If the amount of air conditioning is reduced, for example, late in the occupied period (working day), the cooling system—if programmed to go into an unoccupied (warmer) mode—will not "make up" the earlier reduced cooling demand during a demand response event.

Understanding the relationship between advanced metering, energy efficiency, demand response and net energy savings is vitally important because there are many potential synergies and potential conflicts between these types of programs. Potential *synergies* include:

- Advanced metering technologies that can enable demand response can also be used with advanced controls to manage energy use year-round;
- Energy efficiency can reduce demand permanently, at peak as well as non-peak times;
- Focusing on peak demand reductions can help identify inefficient and non-essential energy uses that could be reduced at other times, thus resulting in broader energy savings and demand reduction;
- Experience from demand-response activities can increase awareness of energy efficiency opportunities;
- Customers who participate in demand-response programs may be prime candidates for participating in energy efficiency programs (and vice versa); and
- Program marketers can communicate more effectively with customers about their energy use by addressing integrated approaches to energy management—that is addressing both peak demand (kilowatts) and overall energy use (kilowatt-hours) (Goldman, Reid and Levy 2009).

Perhaps the most important synergy may be that participation in a demand-response program, particularly one that features feedback and automated control devices, can help customers to better understand their energy use and its costs (Pratt et al. 2010). This learning process can encourage customers to take additional actions (Goldman, Reid and Levy 2009). Nemtzow et al. (2007) echo this attribute of demand response as it relates to overall energy use and associated behavior:

> *We believe that the most significant and positive relationship between DR [demand response] and energy consumption is that DR increases energy awareness and provides feedback for consumers on their usage behavior.*

Unfortunately, the nature of demand response can also potentially create conflicts with energy efficiency objectives. For example, there is room for confusion in marketing messages and other communications to customers about programs and services. A recent survey of public awareness of energy terms showed that the term “demand response” is not widely recognized (Wimberley 2009). The distinction between demand response programs—which focus on shorter periods—and year-round energy efficiency programs can create some confusion because different building systems, equipment, and decision-making strategies are involved in reaching these two fundamentally different goals.

If utilities implement metering programs with a “demand response” focus, they may achieve results that are different from the outcomes they would encounter with an “energy efficiency” perspective. Depending on the program design, there can be potential structural conflicts between demand response and energy efficiency for certain types of programs and services. For example, if utility customers are paid on the basis of the amount of load they can temporarily reduce when called upon, as measured from a business-as-usual “baseline,” there can be a disincentive to take permanent energy efficiency actions that might lower the baseline. Also, the potential for reduced revenue from reducing overall energy use can discourage utilities from improving energy efficiency and lead them to prefer demand response programs (Pratt et al. 2010).

For pricing-based demand-response programs, the nature of the conflict is different. Measurement of baselines is not an issue for dynamic pricing—customers pay for energy costs based on the rates at the time of use. However, if off-peak prices are sufficiently low, that can reduce customer interest in saving energy at other times. Demand-response programs that feature off-peak rate discounts as an incentive could have the same effect.

Marketing messages for demand response and energy efficiency also tend to differ. Unlike demand response programs, energy efficiency programs usually promote streamlined energy use within a “business as usual” scenario and do not typically advocate for conservation actions that require substantial changes in customer activities. In other words, energy efficiency programs emphasize having the same levels of energy amenities (such as indoor space cooling or lighting levels) but ask consumers to employ more energy-efficient technologies in achieving them. In contrast, demand response programs require that customers engage in conservation actions on a temporary basis even though these actions may require changes in their schedules, lifestyles, and business operations (Goldman, Reid and Levy 2009).

Notably, recent research suggests that business customers harbor measurable reservations about their potential participation in demand response programs. According to a survey of a small set of companies (Goldman, Reid and Levy 2009), customer believe that:

- Demand response benefits are uncertain;
- Demand response is "something done for the utility's benefit," not for customers' benefit; and
- Demand response may unacceptably reduce energy services below acceptable levels.

Customer perceptions towards demand response versus energy efficiency demonstrate the distinct objectives of each type of program as well as the costs and benefits of each. Customers who are particularly receptive to using energy efficiency to manage costs and control energy use may not see many additional benefits from participation in demand response programs. If customers have already taken actions to make their operations highly energy-efficient, there just may not be much "extra" demand to reduce at critical periods. In addition, customers often recognize that the benefits of energy efficiency accrue at all times a device or technology is being used, not just during limited times as might be the case for demand responses.

Demand response programs can be designed to employ energy use feedback to guide time-of-use decisions. Utilities typically promote demand response programs as a means of saving money by modifying the demand for energy resources in response to specific market signals. As this meta-review has shown, however, cost saving is just one of several means of motivating energy smart behaviors. Similar savings may also result from the application of non-financial means of motivating change such as, goal setting or social norms).

To summarize, evidence from past studies suggests that energy efficiency and demand response programs would benefit from better integration. Moreover, a more integrated approach has recently been recommended by the National Action Plan for Energy Efficiency (FERC 2009) and is currently being explored in a limited number of states and utility-sector DSM programs.

Despite the potential benefits of better integration, however, when integration is not possible, efforts should focus on overall energy savings rather than peak-load shifting. Stated most simply, it does not make sense to seek to merely alter the timing of an inefficient load. The optimal approach should pursue all cost-effective means of reducing waste and inefficiencies before pursuing any remaining opportunities for peak load reductions.

In the next section we examine program experiences with demand response in terms of their implications for energy efficiency and overall energy savings.

2. Program Experience

In their 2005 review of related research, York and Kushler found a significant lack of primary research on the relationship between energy efficiency and demand response, as illustrated in the following excerpt:

> *…[W]e found that there is almost no published research on the issue of how demand-response programs affect energy use during off-peak periods and overall building/facility energy use and energy efficiency. There is some mostly anecdotal evidence that suggests certain types of technologies capable of enabling demand response during peak demand periods can also realize energy and demand savings in off-peak periods. We were not able to determine the extent that customers are using these technologies actively as a means of achieving broader energy savings because this simply has not been a research focus within the industry.*

In a similar review of demand response programs, King and Delurey (2005) came to somewhat different conclusion:

> *An extensive review of demand response programs and their conservation effect, which we define as the change in total monthly or annual energy consumption attributable to the program, shows that although the primary intended effect of demand response programs is to reduce electricity use during times of peak load, the vast majority of demand response programs also yields a small conservation effect.*

To the extent that many demand response programs are focused on system reliability when market conditions suggest severe economic costs are necessary to meet customer demand, energy savings may be small as York and Kushler (2005) suggest. At the same time, to the extent that programs focus on a total reduction in wasteful energy consumption over a longer period of time, a greater electricity savings might be expected. With respect to short-term impacts, the evidence is somewhat mixed. While some studies suggest that (when combined with appropriate feedback mechanisms), demand response programs can yield a modest level of overall savings, other studies have found no significant change in overall energy use. In a recent review of a relatively extensive set of studies, Nemtzow et al. (2007) conclude:

> *The new evidence from around the United States and abroad that has become available in the two years since that review [King and Delurey 2005] further increases confidence in the conclusion that DR reduces total electricity consumption, principally (but not exclusively) during peak periods, but consistently, and has the potential to be a major indirect factor in increasing overall energy efficiency nationally.*

Their conclusion represents perhaps the most affirmative case made by demand response advocates. In terms of programs targeted at peak load reduction, the field is starting to accumulate sufficient evidence to draw some tentative conclusions about AMI metering and time-differentiated pricing as a load management strategy. Several recent studies suggest that significant reductions in peak energy use have been achieved in residential sector pilot tests of AMI meters with peak pricing regimes, but the same studies indicate virtually no savings in overall annual energy use (Charles River Associates 2005; PSE&G 2008; CL&P 2009) To quote the authors of the Charles River

Associates study of the California Statewide Pricing Pilot: "People increased energy use during off-peak periods by almost exactly the same amount that they decreased energy use during peak periods."

In their analysis, York and Kushler (2005) identified and profiled three residential demand response programs that offered alternate pricing options to motivate customers.[37] Most of these residential demand response programs involve some type of time-differentiated pricing, such as "critical peak pricing." The programs provide the metering and customer monitoring technologies that inform customers of times when electricity costs are high. How customers are expected to respond to such information varies; in some cases, the responses could be automated. In other cases, customers would have to take action manually.

The residential customers in these demand response programs were generally able to reduce their energy costs by reducing power demand during high-price periods. Relevant actions taken by customers included raising temperatures for air conditioning or turning off air conditioners. Conservation and load shifting were the main sources of energy savings. However, some customers also took a few "energy efficiency" steps such as replacing incandescent light bulbs with compact fluorescents.

A more recent alternate pricing program employed a somewhat simplified monitoring and display technology to inform customers of energy costs at a given time. In this case, a visual indicator, the Ambient Energy Orb, provided signals to customers by changing its color. The orbs were tested in Maryland, using several pricing options; customers reduced their peak loads, but only lowered their total electricity use by 0.5% (Case et al. 2008). The results suggest that customers simply shifted their energy use to off-peak hours.

Table 21 summarizes a set of key recent studies on demand response programs for residential customers that provided advanced metering, feedback and some type of incentives for changing energy use patterns (see Appendix C for a more complete listing of the demand response program results).

Table 21. Key Studies on Recent Demand Response Programs

Type of Program	Energy Efficiency and Conservation Programs [N=46]	Peak and TOU Programs (1977-2010) [N=11]		Recent Peak and TOU Programs (2004-2010) [N=9]	
Reported Energy Savings	**Overall Energy Savings**	**Overall Energy Savings**	**Peak Savings**	**Overall Energy Savings**	**Peak Savings**
Average	9.8%	2.4%	13.3%	3.7%	15.7%
Median	9.3%	0.5%	13.3%	3.3%	17.0%
Minimum	1.2%	-5.5%	1.2%	0.0%	5.5%
Maximum	32.0%	8.6%	23.3%	8.6%	23.3%

Looking at the results of these and other studies, it appears that the use of AMI in conjunction with some kind of time-differentiated pricing or financial incentives for reducing demand during critical periods generally can have a significant impact in reducing peak period electricity use. Including all 11 studies identified in this meta-review both the median and the average peak (kW) savings are about 13%. Looking at the 9 studies since the year 2000, the median peak or demand response (kW) savings jump to 17% while the median increases to only 15.7%. Looking at overall energy savings

[37] The three programs reviewed in the ACEEE study are: (1) New York Energy $mart, Westchester $mart Homes Pilot; (2) Energy-Smart Pricing Plan, Community Energy Cooperative, Commonwealth Edison; (3) Power Choice, Sacramento Municipal Utility District and California Energy Commission.

for the more recent set of studies shows a much smaller but still significant 3.7% average kWh savings and a 3.3% median kWh savings. These savings are generally achieved as a result of multiple interventions including feedback, time of use rates, and/or incentives. Implicit in these findings is a clear caveat: there is insufficient data to arrive at any firm estimate to compare effectiveness of demand response programs on overall energy savings. The main points from these findings are: (1) these programs need to be collecting and reporting information concerning overall energy savings; and (2) savings are not negligible but are clearly lower than savings associated with other types of feedback programs.

If one considers the pricing design typically used in such programs, these results are not surprising. These demand response with advanced metering pilots commonly employ extremely high peak period rates for a relatively small number of hours (e.g., "critical peak pricing"), but discounted (often deeply discounted) "off-peak" prices. There is often an overall "price signal" that would tend to discourage year-round energy efficiency improvements as compared to the normal "flat rate". Absent other specific interventions (e.g., information & incentives) there is little reason to expect such programs to produce overall energy efficiency savings.

3. Combining Energy Efficiency and Demand Response Goals

The full meta-review found in this study shows that utilities and program developers can leverage behavior change and advanced metering to simultaneously address demand response, energy efficiency, and system reliability in ways that save both consumers and utilities money. This synergy between program objectives might increase the overall energy savings and any needed reduction in peak demand.

Since the distinction between demand response and energy efficiency is likely to be unclear to many customers, packaging programs together seems logical (Pratt et al. 2010). As of 2009, five organizations in the United States—Otter Tail Power, Xcel Energy, Duke Energy, NYSERDA and Austin Energy—have combined the branding and advertising of these two types of programs. In 2008, the California Public Utilities Commission set a goal of delivering programs that integrate energy efficiency, demand response, energy management, and locally-generated energy; these plans include advanced metering. Pacific Gas & Electric now offers integrated audits that address this goal (Goldman, Reid and Levy 2009).

Advanced metering initiatives, if supplemented with other strategic program and behavioral interventions, provide the theoretical opportunity to increase both energy savings (through conservation and efficiency measures) and peak load savings (through conservation and load shifting activities). Notably, however, the studies reviewed for this report indicate that programs focused exclusively on demand response tend to forego the much larger potential residential-sector energy savings associated with broader DSM strategies. A multidimensional behavioral approach to program design—including demand response and energy efficiency—would increase the potential for customer savings and offer other significant societal benefits. (See Section IV of this report for an estimate of the full scale of potential energy savings associated with advanced metering and feedback initiatives.)

E. New Habits, Lifestyles, and Choices

While it is clear that advanced metering initiatives and other programs that provide residential consumers with feedback regarding their energy consumption can result in significant reductions in energy use, few studies have explored what customers are choosing to do to bring about these reductions. In a 2004 study of the impact of a pilot residential time-of-use pricing program in Sacramento, California, researchers explored this question in some detail. Although the survey results are not based on a representative sample, the study's findings provide some preliminary insights as to the ways in which people choose to change their habits, lifestyles and choices in ways that result in energy savings.

Participation in the program was voluntary and most participants chose to participate either because they wanted to save money (88%) or because they wanted the ability to control their energy usage (54%). In addition, roughly one-third indicated that their participation was motivated by a concern for the environment. In terms of actual energy savings, the study's findings showed that 86% of participants used less energy during high or critical periods and that 67% of participants used less energy overall. Energy use during critical price periods declined by 16%, while overall energy use declined by 4%. But how did people achieve these savings?

As shown in Table 22 (below), households engaged in a variety of different activities to save energy. Nearly all participants (95%) reported engaging in new habits to minimize energy use during critical price periods. The principal strategy involved shifting usage to nonpeak periods. In particular participants were less likely to use air conditioners, dishwashers, and clothes washers during peak periods. They also reported taking fewer showers or baths during these periods and cooking indoors less often.

Respondents also reported taking energy stocktaking behaviors including repairing air ducts (8%) and changing the default temperatures on their thermostats (42%). Among the respondents who saved the most energy overall were those that invested in energy efficient products. More than half of all participants (59%) invested in compact fluorescent light bulbs. A smaller proportion of households invested in more costly energy efficiency upgrades including new windows (11%), a new refrigerator (9%), a new air conditioner (5%), or added insulation (5%).[38]

Table 22. Categories of Change and Behaviors

Type of Change	Behavior	Percent
New Habits	Shifted Usage	95%
	Checked thermostat display for critical periods	83%
Energy Stocktaking	Repaired air ducts	8%
	Changed default temperatures on thermostat	42%
Low-cost Investments	Installed CFLs	59%
Higher-cost Investments	Replaced single with dual-pane windows	11%
	Replaced inefficient refrigerator	9%
	Replaced inefficient air conditioning	5%
	Installed ceiling or wall insulation	5%

These findings contrast with an earlier and larger study of conservation behaviors by residential consumers during and after the 2000-2001 California energy crisis (Lutzenhiser et al. 2003). The 2003 study used data obtained from 1666 in-depth telephone interviews with randomly selected residential households in five major California utility service territories. Some interesting findings from the 2003 study indicate that "more than 75% of households participating in the survey reported taking one or more conservation actions", and that reductions in energy demand were largely due to changes in behavior (65-70%) as opposed to investments in hardware solutions or on-site generation projects (25-30%). Table 23 shows reported conservation behaviors. Note that the top three behaviors involved changes in habits and routines as opposed to consumer choices.

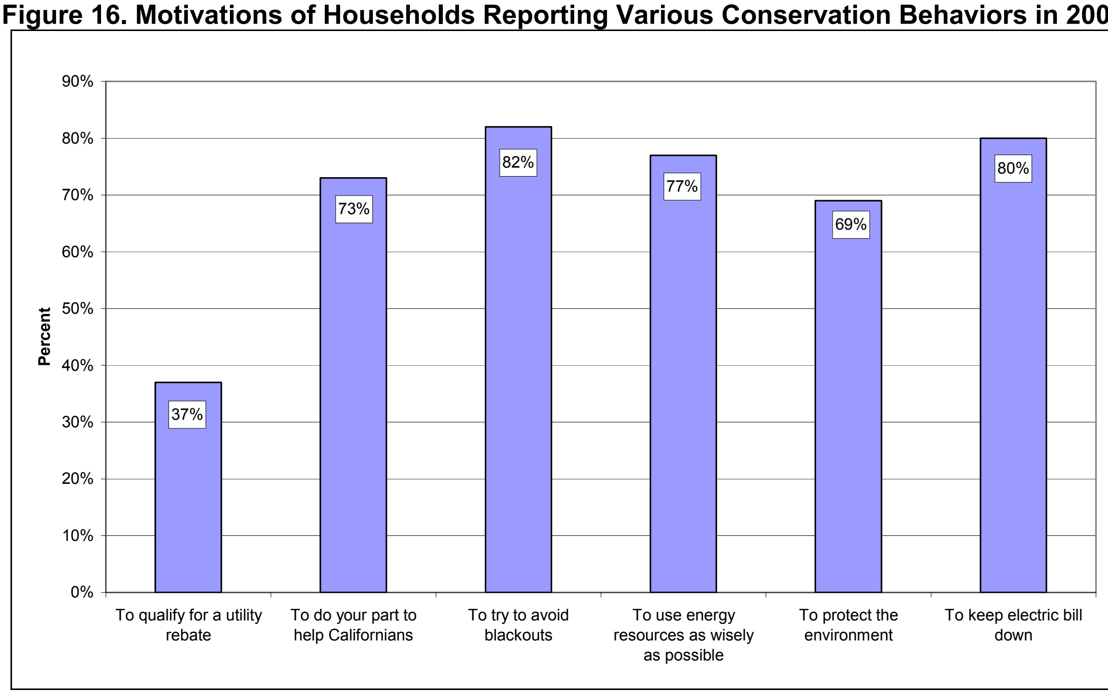
[38] Higher-cost investments were relatively rare despite the fact that the sample population was found to have higher incomes compared to the general population in the same geographic area. More specifically, 50% of pilot participants had annual incomes over $100,000 per year compared to 12% of people in the general population.

Table 23. Behaviors as a Function of Technology Categories

Type of Behavior	Description	Percent
Lights Behaviors	Behaviors related to turning off lights or using fewer lights	65.5%
Other Heat/Cool Behaviors	Behaviors related to heating and cooling other than not using the AC at all (e.g., using AC less, using ceiling fans, changing thermostat, etc)	48.5%
Small Equipment Behaviors	Behaviors related to household appliances (using them less, turning them off and unplugging them)	32.2%
Light Bulbs	Hardware related purchase/use of CFLs or other energy saving bulbs	22.2%
Peak Behaviors	Behaviors related to using energy during off-peak hours	20.0%
H20 Behaviors	Behaviors related to using less water or using less hot water (e.g., shorter showers, wash in cold/warm water, turn water heater down, etc)	12.2%
Appliances	Hardware-related purchased/use of new non-fixed appliances (e.g., refrigerator, washer/dryer, window AC, fans, etc.)	10.4%
Turning off AC	Behavior related to not using the AC at all	9.6%
Shell Improvement	Hardware related to one-time improvements to the house (e.g., windows, insulation, a new piece of fixed equipment such as water heater, AC, furnace, etc.)	7.9%
Large Equipment Behaviors	Behaviors related to pools, spas, irrigation motors (e.g., turn off, use less often)	6.0%

Another important difference between the two studies involved the question of motivation. In the 2003 study (Lutzenhiser et al.), survey respondents reported that their conservation efforts were motivated by a wide variety of factors. While minimizing energy costs was among the principal motivators, respondents also reported being motivated by their desire to avoid blackouts (82%), use energy resources as wisely as possible (77%), do their part to help Californians (73%), and protect the environment (69%). According to the report, “qualifying for a utility rebate was the least common motivation, and available utility rebates were not relevant to most of the actions consumers took.”

Figure 16. Motivations of Households Reporting Various Conservation Behaviors in 2001



Thirteen of the studies reviewed for this report also provided some information regarding the actions that people reported taking in order to save energy. In nearly all cases, people reported that they were more likely to turn of lights when not in use. Among the other frequently reported behaviors were: reducing heating/cooling demand by adjusting the thermostat, turning of the air conditioning, installing energy efficient light bulbs, and reducing the use of the clothes dryer, dishwasher and oven. On the other hand, people were much less likely to report reducing their use of electronic devices such as televisions, stereos and computers although they did report a willingness to turn off computers and monitors when not in use. Table 24 indicates the frequency of different energy saving behaviors as reported by the various studies. Caution should be used in interpreting the results since many of these programs provided specific energy saving tips or suggestions as to the actions that households could or should take to save energy and these tips may influence reported behaviors.

The findings from these studies suggest that behavior-related energy savings opportunities are available in the residential sector, that people are willing to change their energy-related behaviors, and that feedback is likely to be an effective mechanism for unlocking potential energy savings. Among the types of energy efficiency and conservation behaviors, investments in new equipment and appliances appeared more likely within more affluent populations and are generally undertaken in conjunction with a change of residence or a remodel or part of a stylistic (as opposed to functional) upgrade (Lutzenhiser et al. 2003). For the larger population, households appear to be more likely to reduce energy consumption through changes in habits and routines or through energy stock-taking behaviors. Importantly, these energy-conservation behaviors are likely to be motivated by a variety of factors including self-interest (energy bill savings) as well as civic concerns and altruistic motives (Lutzenhiser et al. 2003). These findings suggest that narrowly defined energy-efficiency programs aimed at the installation of new, more energy-efficient technologies alone (the practice of traditional utility programs) are likely to realize only a small fraction of potential behavior-related residential energy savings. Similarly, programs that limit their appeal to self-interest alone are unlikely to leverage the broad range of factors that motivate people to action.

Table 24: Relative Frequency of Reported Energy-Saving Behaviors

Behavior		Frequency
Conservation Behaviors		
L&E	Turned off lights	VH
L&E	Install energy efficient light bulbs	MH
L&E	Used task lighting	L
L&E	Reduced Television use	M
L&E	Reduced use of Stereo	ML
L&E	Reduced use of Computer CPU	M
L&E	Reduced use of Computer Monitor	M
L&E	Reduced use of stand-by settings	M
H&C	Turned off AC	MH
H&C	Turned down electric space heating	M
H&C	Reduced heating/cooling demand (thermostat)	VH
H&C	Reduced the number of hours heating is on	L
H&C	Reduce number of rooms heated/cooled	L
H&C	Pulled Window Shades	L
APL	Turned down refrigerator thermostat	M L
APL	Opened refrigerator less often	M L
APL	Reduced use of clothes washer	M
APL	Used cold water wash in clothes washer	M
APL	Reduced use of clothes dryer	H
APL	Reduced temperature on dryer	ML
APL	Reduced use of electric range	M
APL	Reduced use of electric oven	MH
APL	Reduced use of microwave oven	L
APL	Reduced use of dishwasher/only full loads	MH
APL	Used cold/short cycle on dishwasher	ML
HWT	Reduced hot water demand	L
HWT	Turned down water heater	L
HWT	Reduced number or length of showers	M
HWT	Turned down electric water heating	ML
OTHR	Reduced use of Hot tub	M L
OTHR	Turned off pool filter	L
OTHR	Reduced use of ventilation fans	L
OTHR	Ironed in batches	L
OTHR	Turned off pool pump	L
OTHR	Reduced meat consumption	M L
OTHR	Reduced food waste	M L
OTHR	Transport mode shifting	L

VH=very high, H=high, MH=medium high, M=medium, ML=medium low, L=low

F. Section Conclusions

A variety of different types of feedback programs can be employed to provide energy consumers with information about their energy consumption patterns. Some types of feedback programs rely on AMI technologies while others do not. In general, feedback programs are useful tools because they make modern energy resources such as electricity and natural gas more visible to consumers, and they provide the information necessary to empower consumers to change their behaviors and actively manage their energy consumption. As a result, feedback has been shown to generate an average household energy savings of roughly 4 to 12%[39]—a slightly tighter range than Darby's (2006) estimated 5 to 15% savings.

Energy Saving Behaviors. Once people receive information about their energy consumption patterns, there are a wide variety of things they can do to reduce their energy consumption. Energy savings are typically achieved as a result of three categories of action: 1) simple changes in routines and habits, 2) infrequent and low-cost energy stocktaking behaviors (i.e., replacing incandescent bulbs with CFLs, weather stripping, etc.), and 3) consumer investments in new energy-efficient appliances, devices and materials. Evidence from existing studies suggests that most of the energy savings achieved through feedback programs results from changes in behaviors (not investments) although people who invest tend to save the most energy. (Current patterns may be a function of program design.) Additional evidence suggests that energy saving strategies are likely to vary by income level such that higher income households are more likely to purchase new energy efficient appliances, windows, and devices while lower income households are more likely to engage in energy stocktaking behaviors or change their energy use habits and routines.

Feedback Type. Regardless of the actions taken, some types of feedback appear to be more effective than others in generating more substantial energy savings. As shown in Tables 12, 15, and 16, existing studies suggest that daily/weekly feedback and real-time plus feedback tend to generate the highest savings per household. Median energy savings for studies employing these two approaches were both above 10% (11% and 14%, respectively). Studies that used estimated and real time feedback strategies generated savings on the order of 7%, while programs that relied on enhanced billing strategies achieved savings of 5.5%. Nevertheless, it is also important to keep in mind Darby's insight that some types of feedback appear to be more effective for certain end uses than others. In particular, Darby (2006) suggests that indirect forms of feedback tend to be better suited to help households understand the effects of changes in space heating, household composition, and the effect of investments in new appliances and building shell upgrades. On the other hand, direct forms of feedback (real-time and real-time plus) tend to be better suited for understanding energy savings associated with smaller end uses such as turning of the lights, the television, or the computer.

Program Era. Not surprisingly feedback-related energy savings vary across time. Research on the effects of feedback strategies spans four decades and two important eras: the energy crisis era of the 1970s and 80s and the Climate Change Era of the 1990s and the first decade of the new century. Notably, feedback-induced energy savings are lower in the Climate Change Era than during the energy crisis era, regardless of the feedback strategy employed. This is important because studies that compare feedback-related savings across all four decades may result in inflated expectations regarding potential energy savings today.

Feedback-Inducing Savings and Household Participation. At a more aggregate level (national, state, city, utility, community), the savings implications of different types of feedback depend on both average household energy savings and the overall level of household participation. Importantly, participation rates are significantly higher for programs that are designed using an opt-out (as opposed to opt-in) design, and the amenability of Enhanced Billing, Real-Time Feedback, and Real-Time Plus feedback programs to opt-out designs increases the likelihood of their success in achieving

[39] While feedback-induced energy savings during the current Climate Change Era have averaged between 4 and 12%, feedback-induced energy savings across all eras averaged between 6 and 14%.

dramatically larger overall energy savings. As shown in Table 20, once participation rates are taken into consideration, Real-Time Plus programs appear to generate the largest savings (as high as 12%) followed by aggregate, real-time feedback programs (6%) and enhanced billing programs (about 5% using our international sample, approximately 2% when using our U.S. sample). Notably, however, the investment costs of Enhanced Billing programs are substantially lower than those associated with the implementation of either Real-Time or Real-Time Plus programs because the latter require advanced metering equipment and in-home displays.

Motivational Elements. Feedback-induced energy savings and overall rates of household participation are malleable and can be enhanced through the use of motivational elements such as the use of goal setting, commitments, competitions, and social norms. Research by Nolan et al. (2008) and Schultz et al. (2007) suggest that the use of social norms can result in household energy savings of 5.7 to 10% and that the use of both descriptive and injunctive norms is important in shaping household energy behaviors. Despite the evidence of enhanced savings, however, relatively few feedback projects have incorporated these noneconomic levers. OPOWER has been a pioneer in the application of social norm research in conjunction with its innovative home energy reports. More research is needed to explore the potential power of these (and other) non-economic incentives and the degree to which they can enhance household energy savings.

Regional Context and Feedback-Induced Savings. Feedback seems to be more effective in generating household energy savings in some regional contexts than in others. More specifically, the evidence suggests that during the Climate Change Era (1990-2010), feedback programs in Western Europe have generated greater energy savings. As shown in Table 18, European savings during this Era averaged 10.5% while the average savings of U.S. feedback programs was 3 percentage points lower (7.4%). The reason for these differences is unclear although differences in political leadership and culture are likely to play an important role. A more narrowly focused, comparative analysis might reveal additional means of enhancing feedback-related savings in the United States.

Effects of Study Size. Even though existing studies suggest significant energy savings can be attained through the implementation of feedback programs, a closer examination reveals the need for caution in estimating the size of potential savings. As stated earlier actual household savings is likely to vary according to the type of feedback, according to temporal and regional contexts, and according to program design. In addition, results from this meta-review suggest that when applied on a large scale, households may or may not achieve the level of savings associated with past studies. Interestingly, a comparison of studies with larger and smaller sample sizes suggests that feedback-induced energy savings in larger studies are more modest than those found in smaller studies. Given that the larger studies tend to include a more representative sample of households, these findings may suggest that large-scale feedback programs are also likely to experience more modest savings. While these results are far from conclusive, future research is likely to prove valuable in answering this question.

Study Duration and the Persistence of Energy Savings. Our assessment of the relationship between study duration and feedback-related energy savings reveals that average energy savings are higher for shorter studies (10.1%) than for longer studies (7.7%). Our subsequent assessment of the relationship between duration effects and persistence revealed interesting insights. Evidence from the 27 studies that measured within-study persistence of feedback effects suggests that feedback-related energy savings are often persistent, although multiple studies also suggest that the persistence of energy savings may rely on the continued provision of feedback. Our assessment of the discrepancy between duration and persistence revealed that the lower rates of savings associated with shorter studies are not a reflection of the persistence of energy savings but instead reflect the inability of shorter studies to capture seasonal variations in energy end uses.

Demand Response and Peak versus Off-Peak Savings. The effectiveness of feedback initiatives in generating household energy savings is dramatically influenced by the focus of the program. Programs that are focused on peak load savings are generally successfully in shifting energy use from peak periods to off-peak periods but overall energy savings are dramatically lower. Results from the meta-review suggest that programs focused on time of use rates and reducing consumption during periods of peak demand save considerably less energy than programs focus on promoting energy conservation and efficiency. More specifically, data from existing studies indicate that the overall energy savings from programs focused on peak load shifting have averaged around 3%, while programs focused on promoting conservation and efficiency have averaged around 10%.

Habits, Lifestyles and Choices. The review of the literature suggest that behavior-related energy savings opportunities are available in the residential sector, that people are willing to change their energy-related behaviors, and that feedback is likely to be an effective mechanism for enabling people to achieve a greater proportion of potential energy savings. Among the types of energy efficiency and conservation behaviors, investments in new equipment and appliances appeared more likely within more affluent populations and are generally undertaken in conjunction with a change of residence or a remodel or part of a stylistic (as opposed to functional) upgrade. For the larger population, households appear to be more likely to reduce energy consumption through changes in habits and routines or through energy stock-taking behaviors. Importantly, these energy-conservation behaviors are likely to be motivated by a variety of factors including self-interest (energy bill savings) as well as civic concerns and altruistic motives. These findings suggest that narrowly defined energy-efficiency programs aimed at the installation of new, more energy-efficient technologies alone (the practice of traditional utility programs) are likely to realize only a small fraction of potential behavior-related residential energy savings. Similarly, programs that limit their appeal to self-interest alone are unlikely to leverage the broad range of factors that motivate people to action.

IV. Potential Feedback-Induced Energy Savings

Given the findings of the meta-review, what level of the potential energy savings might be achieved within the full residential sector at the national level? Do the energy savings suggested by the meta-review translate into a net positive economic benefit for residential consumers? This section explores that question by mapping the findings from the various studies into a reasonable set of scenarios that help examine both the potential costs and benefits of achieving a range of feedback-induced electricity savings.

To set the foundation of the assessment that follows, the analysis begins with the projected economy-wide electricity consumption as reported by the Energy Information Administration's Annual Energy Outlook 2010 (EIA 2009a). In this case the assumption is that residential electricity use grows from 1,388 billion kWh in 2010 to 1,637 billion kWh by 2030, or about 0.8% annually. The analysis then uses a Monte Carlo simulation to explore: (i) an annual range of new customer participation in utility-sponsored conservation and efficiency feedback programs, and (ii) four different program designs and their range of impacts on annual customer electricity savings.

The assumption is that while "smart meters" are likely to be installed in nearly all customer premises by 2030, absent specific policies or standards, their use is likely to be limited to managing the grid and peak demand more efficiently, and also to monitor, track, and bill customer electricity consumption as a utility cost-saving measure. In other words, the use of advanced meters may not be used to encourage the more efficient use of electricity throughout the entire year and across all customer end uses. In this Monte Carlo exercise each of the four alternative electricity consumption scenarios is associated with a specific type of feedback and is based on a randomization of feedback-related savings and participation rates (within a specified range) as they apply to that type of feedback.

Given these assumptions, the Monte Carlo exercise then runs a total of 10,000 simulations for each of the four scenarios to explore the potential impact over a time horizon that runs from 2010 through 2030. Adapting the relevant data on savings and participation from Tables 12 and 20 earlier in this study, Table 24 highlights the key assumptions used to generate each of the four alternative scenarios.

Table 24. Key Assumptions for Policy Impact Scenarios

Primary Feedback Mechanism	Range of Savings	Range of Participation
A. Enhanced Billing	2 to 6%	90 to 95%
B. Real Time (opt in)	4.5 to 12%	3 to 8%
C. Real Time (opt out)	4.5 to 12%	65 to 75%
D. Well-Designed, Behavior-Savvy Program[40]	6 to 18%	70 to 80%
Key Technology Costs		
Unit Technology Cost	None for Scenario A. For the remaining scenarios, initially $500 per customer declining to $350 by 2030.	
Program Cost	For scenario A, an average four cents per kWh. For the remaining cases, initially 25% of technology cost declining to 15% by 2030.	

Notes: The savings ranges in this analysis are based on the overall multi-continent sample. Savings in the U.S. have tended to be lower and hence this analysis implicitly assumes that with continued program development, savings in the U.S. can approximate the overall multi-continent results. The unit technology cost estimates do note include the cost of establishing a "smart grid" but instead cover in-home costs of monitors, with or without a smart grid.

Also highlighted in Table 24 are the technology and program implementation costs per participating customer. For Scenario A, the assumption was that no customer meter or similar technology was required to implement the program. Rather, following the program efforts such as those implemented by OPOWER, Energy Efficiency 2.0 and others, the costs are purely program costs which might be amortized at the rate of four cents per kWh. For the other three scenarios, the technology costs as generally drawn from the discussion in section II of this study, and reflect a high initial price tag of $500 for each participating customer, including costs faced by both the utility and the customer.

The presumption is that costs associated with smart grid expenses are sunk costs that would be made regardless of customer participation in feedback-induced energy efficiency programs. Hence, the technology costs reflected in this scenario analysis are incremental costs necessary to bring customers into full participation in a specific program (exclusive of potential investments that might be made to generate electricity savings beyond what we might term for this analysis as a "pure feedback response").

Other than for Scenario A, the per customer investment is, in effect, a weighted cost across all residential consumers and is assumed to decline by 30% by the year 2030 as economies of scale and new production and deployment techniques are introduced. A further assumption for Scenarios B through D is that utility program costs initially will be 25% of the per unit technology costs but declining to 15% by 2030 as the program builds momentum and both utilities and customers gain experience in working with the new technologies and feedback mechanisms.

In brief, Scenario A reflects the lower rate of savings that is associated with enhanced billing programs, but assumes a relatively high rate of participation. Scenarios B and C highlight more aggressive levels of potential savings associated with real time feedback. Scenario B assumes a very low participation rate associated with programs that require consumers to "opt in", while Scenario C assumes a higher participation rate associated with programs that begin with universal participation but allow consumers to "opt out". Finally, Scenario D explores the potential efficiency gain—assuming the deployment of some of the most effective feedback technologies in combination with behavior-savvy motivation strategies and high participation rates.

With these assumptions, Table 25 highlights the key results of each scenario as the Monte Carlo simulations randomly select from the range of participation levels and electricity savings. The table shows the estimated outputs from each set of the 10,000 scenario simulations, including estimated savings per customer by 2030, estimated residential end-use electricity savings by 2030, and the expected net present value of total costs and total energy bill savings (represented in constant 2008 dollars discounted 5% annually).

[40] Well designed feedback approaches effectively integrate multiple, non-economic motivational strategies and include both direct and indirect forms of feedback and (ideally) real-time, appliance-level feedback.

Table 25. Major Results from the Policy Scenarios

Scenario Impacts by 2030	A	B	C	D
Reference Case Electricity Demand (billion kWh)	1,637	1,637	1,637	1,637
Reference Case Electricity Customers (millions)	146	146	146	146
Participating Feedback Customers (millions)	88	6	72	75
Total Electricity Savings (billion kWh)	40	6	68	103
Savings per Participant (kWh)	458	986	942	1369
Savings per Participant (percent of reference case)	4.1%	8.8%	8.4%	12.2%
Total Electricity Savings (percent of reference case)	2.5%	0.4%	4.2%	6.3%
Total Cost (million constant 2008 dollars, 2010 -2030)	$8,150	$1,909	$21,631	$22,489
Energy Bill Savings (million constant 2008 dollars, 2010 -2030)	$22,398	$3,510	$37,878	$57,050
Total Resource Cost Test Ratio	2.75	1.84	1.75	2.54

The numbers reported in Table 25, and the study as a whole, should be interpreted as exploring the cost-effective residential electricity savings that could potentially be achieved by 2030—under a variety of assumptions about the types of feedback mechanisms and programs implemented, and given the overall market acceptance of those programs. In this analysis, it is likely that the error range for any particular estimate in each of the scenarios studied is large. This remains the case even with the reliance on the many studies reviewed. With that caveat a number of critical insights emerge from the data reported in Table 25.

The first critical insight is that advanced metering, together with active customer participation in well-designed utility feedback programs, can save consumers and businesses a lot of money. Depending on the breadth and effectiveness of program design, and with the set of program assumptions described above, individual consumer savings in these exploratory scenarios might range from roughly 4 to 12% of electricity consumption annually. The sector-wide savings might range from 0.4 to 6% annually. Over the 20-year time horizon 2010 through 2030 the present value of technology and program costs might range from roughly $2 to $22 billion dollars while saving the economy a total of $4 to $57 billion (assuming a 5% real discount rate).[41]

Using a total resource cost test (in effect, examining total economy-wide costs and total economy-wide energy bill savings), the benefit-cost ratio appears to range from a low of about 1.75 in Scenario C to a high of 2.75 in Scenario A (which means that the 2.5% savings in Scenario A appears to be highly cost-effective since it will return an average savings of $2.75 for every dollar of technology and program costs expended over the 20-year period). At the same time, however, the very high benefit-cost ratio in Scenario A results from a cost-effective program design (i.e., enhanced billing) that generates only a very small response per consumer. Thus, even with a 90 to 95% rate of participation, the impact across the entire residential sector is relatively small. On the other hand, the smaller but still positive benefit-cost ratios in Scenarios B and C reflect real-time feedback programs that elicit a greater responsiveness from consumers (about an 8-9% savings). But Scenario B is an "opt-in" design in which only 3 to 8% of households are assumed to participate. Hence, the total savings across the entire residential sector are a very small 0.4%. For Scenario C which uses an "opt-out" design, however, the full residential sector might generate a 4.2% savings. Finally, Scenario D explores the possibilities of a more proactive approach that is designed to elicit a larger individual response (averaging a 12% savings) from a large group of customers (with a participation ranging

41 The electricity bill savings assume an annual residential retail rate for electricity as reported in the Annual Energy Outlook 2010 (EIA 2009a) for each of the years in this analysis. Over full 20-year time horizon of this analysis, the average rate is about 10.9 cents per kWh (in 2008 dollars). Had the analysis used the average generation or wholesale cost of electricity instead of the annual consumer retail rate, both the present value of the savings and the TRC might have been about 70% of the values reported here. On the other hand, this heuristic exercise also omits the full array of consumer benefits that are likely to emerge be reflected from efficiency improvements (see, for example, Amann 2006). Hence, use of the retail electricity rate provides a useful proxy for estimating other benefits from the cost-effective reduction in electricity consumption patterns.

from 70 to 80%). In this case, the residential sector might generate as much as a 6.3% savings from feedback programs while still maintaining a highly net positive 2.54 benefit-cost ratio.

The critical insight from this Monte Carlo assessment is that the design of feedback program clearly matter. Given the technologies, the many program design elements, and the different levels of participation that might be envisioned, it seems clear that feedback programs are more likely than not to deliver a cost-effective electricity savings within the residential sector. And the economy-wide benefits are likely to expand as program designs effectively integrate multiple, non-economic motivational strategies, and as they include both direct and indirect forms of feedback and (ideally) real-time, appliance-level feedback.

One final question that might yet be explored is to ask how important are the estimated 0.4 to 6.3% residential sector savings from feedback programs, especially as they might compare to other recent estimates of national electricity savings potential from all sectors at some point in the future? Since household consumption is about one-third of total economy-wide electricity use, the implied residential electricity savings might be as little 0.1 to 2.0%. If examined only through this lens, the savings, indeed, might seem paltry compared to the larger potential savings that could be achieved through comprehensive energy efficiency policies that are associated with economy-wide electricity savings estimates. One recent ACEEE study, for example, found a cost-effective electricity savings potential as high as 27% (Laitner 2009b). Based on this simple comparison, we might conclude that it might make sense to move directly to a technology-based policy perspective since it is likely to achieve a 13 to 270 times greater impact. Alternatively, as suggested by McKenzie-Mohr (2010), expanding feedback programs could catalyze a social and cultural shift that might result in even greater efficiency gains that complement other policy mechanisms—should we choose to explore that possibility, and should we choose to make the necessary investments that, in turn, will develop that opportunity.

Table 26. Residential Sector Impacts from Enhanced Billing Programs

Year	Total Electricity Use (Bln kWh)	Total Customers (Mln)	Feedback Customers (Mln)	Feedback Savings (Bln kWh)	Technology Investment Cost ($2008 Mln)	Program Cost ($2008 Mln)	Total Annual Cost ($2008 Mln)	Avoided Cost ($2008 Mln)
2010	1,388	124	0.0	0.0	0	0.0	0	0
2011	1,407	126	4.1	1.9	0	74.1	74	189
2012	1,416	127	8.3	3.7	0	149.3	149	396
2013	1,394	125	12.4	5.6	0	223.2	223	599
2014	1,394	125	16.5	7.4	0	297.3	297	798
2015	1,400	125	20.7	9.3	0	372.1	372	997
2016	1,412	126	24.8	11.2	0	447.1	447	1,207
2017	1,421	127	29.0	13.1	0	523.4	523	1,420
2018	1,436	128	33.3	15.0	0	600.5	601	1,628
2019	1,455	130	37.6	17.0	0	678.3	678	1,833
2020	1,471	131	41.9	18.9	0	757.3	757	2,057
2021	1,485	133	46.3	21.0	0	838.0	838	2,288
2022	1,501	134	50.7	23.0	0	919.0	919	2,515
2023	1,518	136	55.2	25.0	0	1,001.3	1,001	2,750
2024	1,538	137	59.7	27.1	0	1,085.2	1,085	2,989
2025	1,553	139	64.3	29.2	0	1,170.0	1,170	3,219
2026	1,573	141	68.9	31.4	0	1,256.0	1,256	3,471
2027	1,591	142	73.6	33.6	0	1,343.0	1,343	3,731
2028	1,612	144	78.4	35.8	0	1,431.4	1,431	3,996
2029	1,623	145	83.2	38.0	0	1,520.6	1,521	4,298
2030	1,637	146	88.0	40.3	0	1,610.7	1,611	4,597
2030	AvgCustUse	11,191		NPV at a 5.0% disount rate =			$8,150	$22,398
	AvgCustSave	458					**TRC Ratio =**	2.75

Monte Carlo Scenario Impacts in 2030*	Bln kWh	% Total
Minimum Savings	30.6	1.9%
Average Savings	40.3	2.5%
Maximum Savings	49.0	3.0%

* based on 10,000 simulations
Assuming a random customer savings of 2-6%

Table 27. Residential Sector Impacts from Opt In Real Time Feedback Programs

Year	Total Electricity Use (Bln kWh)	Total Customers (Mln)	Feedback Customers (Mln)	Feedback Savings (Bln kWh)	Technology Investment Cost ($2008 Mln)	Program Cost ($2008 Mln)	Total Annual Cost ($2008 Mln)	Avoided Cost ($2008 Mln)
2010	1,388	124	0.0	0.0	0	0	0	0
2011	1,407	126	0.3	0.3	124	30	154	30
2012	1,416	127	0.5	0.6	122	29	151	62
2013	1,394	125	0.8	0.9	118	27	145	94
2014	1,394	125	1.1	1.2	174	39	213	125
2015	1,400	125	1.5	1.5	172	38	209	156
2016	1,412	126	1.8	1.8	113	24	138	189
2017	1,421	127	2.0	2.1	112	23	136	222
2018	1,436	128	2.4	2.4	167	34	201	255
2019	1,455	130	2.8	2.7	166	33	199	287
2020	1,471	131	3.0	3.0	110	21	131	323
2021	1,485	133	3.3	3.3	109	21	130	359
2022	1,501	134	3.7	3.6	162	30	192	394
2023	1,518	136	4.1	3.9	161	29	190	431
2024	1,538	137	4.4	4.3	107	19	126	468
2025	1,553	139	4.7	4.6	106	18	124	504
2026	1,573	141	5.1	4.9	158	26	185	544
2027	1,591	142	5.4	5.3	105	17	122	584
2028	1,612	144	5.8	5.6	157	25	181	626
2029	1,623	145	6.1	6.0	103	16	119	673
2030	1,637	146	6.4	6.3	102	15	118	720
2030	AvgCustUse	11,191		NPV at a 5.0% disount rate =			$1,909	$3,510
	AvgCustSave	986					**TRC Ratio =**	1.84

Monte Carlo Scenario Impacts in 2030*	Bln kWh	% Total
Minimum Savings	4.7	0.3%
Average Savings	6.3	0.4%
Maximum Savings	8.1	0.5%

* based on 10,000 simulations
Assuming a random customer savings of 4.5-12%

Table 28. Residential Sector Impacts from Opt Out Real Time Feedback Programs

Year	Total Electricity Use (Bln kWh)	Total Customers (Mln)	Feedback Customers (Mln)	Feedback Savings (Bln kWh)	Technology Investment Cost ($2008 Mln)	Program Cost ($2008 Mln)	Total Annual Cost ($2008 Mln)	Avoided Cost ($2008 Mln)
2010	1,388	124	0.0	0.0	0	0	0	0
2011	1,407	126	3.3	3.1	1,606	391	1,997	320
2012	1,416	127	6.6	6.3	1,587	377	1,965	669
2013	1,394	125	10.0	9.4	1,652	383	2,035	1,012
2014	1,394	125	13.3	12.6	1,507	340	1,848	1,349
2015	1,400	125	16.8	15.7	1,602	353	1,955	1,684
2016	1,412	126	20.2	18.9	1,530	328	1,859	2,041
2017	1,421	127	23.5	22.1	1,457	305	1,762	2,400
2018	1,436	128	27.1	25.4	1,558	317	1,875	2,753
2019	1,455	130	30.7	28.7	1,550	308	1,858	3,102
2020	1,471	131	34.3	32.0	1,485	288	1,773	3,482
2021	1,485	133	38.0	35.4	1,527	288	1,815	3,870
2022	1,501	134	41.7	38.9	1,516	279	1,795	4,254
2023	1,518	136	45.3	42.4	1,398	251	1,649	4,654
2024	1,538	137	49.0	45.9	1,446	253	1,699	5,055
2025	1,553	139	52.7	49.5	1,434	244	1,679	5,445
2026	1,573	141	56.5	53.1	1,426	237	1,663	5,870
2027	1,591	142	60.5	56.8	1,470	238	1,708	6,310
2028	1,612	144	64.5	60.5	1,463	231	1,693	6,758
2029	1,623	145	68.5	64.3	1,395	215	1,609	7,268
2030	1,637	146	72.3	68.1	1,331	200	1,530	7,774
2030	AvgCustUse	11,191			NPV at a 5.0% disount rate =		$21,631	$37,878
	AvgCustSave	942					**TRC Ratio =**	1.75

Monte Carlo Scenario Impacts in 2030*	Bln kWh	% Total
Minimum Savings	53.7	3.3%
Average Savings	68.1	4.2%
Maximum Savings	83.8	5.1%

* based on 10,000 simulations

Assuming a random customer savings of 4.5 to 12.0%

Table 29. Residential Sector Impacts from Well-Designed, Behavior-Savvy Programs

Year	Total Electricity Use (Bln kWh)	Total Customers (Mln)	Feedback Customers (Mln)	Feedback Savings (Bln kWh)	Technology Investment Cost ($2008 Mln)	Program Cost ($2008 Mln)	Total Annual Cost ($2008 Mln)	Avoided Cost ($2008 Mln)
2010	1,388	124	0.0	0.0	0	0	0	0
2011	1,407	126	3.6	4.7	1,791	436	2,228	482
2012	1,416	127	7.3	9.5	1,771	421	2,191	1,005
2013	1,394	125	10.7	14.2	1,593	369	1,962	1,521
2014	1,394	125	14.0	18.9	1,565	353	1,919	2,029
2015	1,400	125	17.4	23.7	1,545	340	1,885	2,537
2016	1,412	126	21.1	28.5	1,644	353	1,996	3,075
2017	1,421	127	24.8	33.3	1,625	340	1,965	3,616
2018	1,436	128	28.5	38.2	1,614	329	1,942	4,143
2019	1,455	130	32.3	43.2	1,605	319	1,924	4,667
2020	1,471	131	35.8	48.2	1,485	288	1,773	5,242
2021	1,485	133	39.4	53.4	1,472	278	1,750	5,828
2022	1,501	134	43.0	58.6	1,462	269	1,731	6,410
2023	1,518	136	46.8	63.8	1,506	270	1,776	7,008
2024	1,538	137	50.5	69.1	1,446	253	1,699	7,614
2025	1,553	139	54.4	74.5	1,487	253	1,741	8,202
2026	1,573	141	58.5	80.0	1,532	254	1,786	8,845
2027	1,591	142	62.6	85.6	1,522	247	1,769	9,508
2028	1,612	144	66.8	91.2	1,515	239	1,754	10,183
2029	1,623	145	70.8	96.9	1,446	223	1,669	10,950
2030	1,637	146	74.9	102.6	1,433	215	1,648	11,713
2030	AvgCustUse	11,191			NPV at a 5.0% disount rate =		$22,489	$57,050
	AvgCustSave	1369					**TRC Ratio =**	2.54

Monte Carlo Scenario Impacts in 2030*	Bln kWh	% Total
Minimum Savings	79.9	4.9%
Average Savings	102.6	6.3%
Maximum Savings	127.3	7.8%

* based on 10,000 simulations

Assuming a random customer savings of 6.0 to 18.0%

V. CONCLUSIONS

The development of an advanced metering infrastructure and new feedback technologies and programs offers important opportunities for empowering residential consumers to reshape their energy use practices and better manage their energy consumption. However, not all feedback programs are alike and differences in the type of feedback, the design of the program, and other factors are likely to have a significant impact on the scope of energy savings that result from these efforts. This section summarizes the lessons drawn from the findings presented in all sections of this report; it identifies and discusses several important unresolved questions pertaining to feedback research; and it provides some recommendations to policymakers and utility experts working on feedback-related issues.

A. Lessons Learned

Providing households with frequent, ongoing, and meaningful feedback regarding their energy consumption practices results in significant residential sector energy savings while engaging people to become part of the energy solution. However, not all feedback technologies, programs, and contexts are the same, and our findings indicate that these differences help determine the likely effectiveness of feedback in reducing energy consumption. In this section we highlight some of the principal lessons gleaned from our research. We begin with a discussion of insights associated with feedback mechanisms and technologies and then go on to discuss what past studies can tell us about potential feedback-related energy savings. We conclude this section with a summary of insights concerning the potential impact of residential feedback on future energy consumption in the United States.

Lessons Regarding Feedback Technologies

Advanced Metering Initiatives (AMI) represent just one of several means of providing households with real-time feedback. For many people, the relatively recent expansion of utility interest in AMI and the palpable excitement over the promise of Smart Grid technologies has sparked a new or renewed interest in providing households with detailed energy use information. As a result many energy practitioners are increasingly likely to associate feedback with AMI technologies. However, feedback can be provided by a variety of different means and mechanisms, and it doesn't require advanced metering technologies. For example, several, ongoing enhanced billing programs are providing residential consumers with useful feedback as well as energy saving tips. These types of programs typically generate a lower range of energy savings but high levels of participation. Other types of feedback technologies including many different types of whole house (aggregate level) energy monitoring devices can be installed regardless of the presence of an advanced utility meter and can provide households with real-time measures of aggregate level energy consumption. In addition, current research is underway to develop new feedback technologies [42]that will be able to disambiguate appliance-specific energy signals and thereby provide real-time, appliance-specific feedback for major appliances without the use of advanced metering technologies. Recognizing the diverse array of feedback mechanisms and technologies is important for several reasons but especially because the roll out of AMI technologies will take years to complete and because it isn't yet clear whether utilities will provide consumers with the tools they need to access to their own energy consumption data. In the meantime many other viable opportunities exist to provide households with useful feedback.

The success of the smart grid, advanced metering, and energy management and home automation technologies depends heavily on consumer acceptance and participation. Despite the existence of significant barriers, research suggests that the utilities may be starting to recognize that significant numbers of consumers may actually <u>want</u> to play a role in energy management and that this interest may be profitable for utilities to use as means of enhancing demand-side

[42] These technologies will be available within a relatively short time horizon.

management programs. Nevertheless, most utilities are not equipped to deploy complex home automation systems or behavioral solutions. As such, partnerships and cooperative endeavors between utilities and third-party providers are likely to be needed in order to maximize consumer participation and consumer satisfaction.

Third-party providers are likely to be important players in feedback solutions whether working in conjunction with or independently of utilities. A variety of third-party providers have already developed different types of tools and technologies for providing households with feedback regarding their energy consumption patterns and new players are rapidly entering the market. Many of these third-party providers are already working with utilities to test and refine their products, while a variety of other providers have made their products available directly to consumers through the retail market or online. Historical evidence suggests that while some proportion of utilities may provide consumers with in-home energy displays, they are unlikely to work independently to provide consumers with contextual information, non-financial incentives and motivational mechanisms, or tailored recommendations for saving energy. Instead, utilities have opted to partner with third-party providers and we anticipate that this trend will continue into the future.

Feedback gadgets alone are unlikely to maximize household energy savings. Instead, the most effective forms of feedback are likely to include both products and services that provide consumers with a combination of detailed, frequent and ongoing energy consumption information as well as a meaningful context within which to interpret the information, a variety of motivational tools, and tailored suggestions for reducing energy consumption.

The best feedback approaches are likely to be incremental in nature and will "evolve" as technologies become more sophisticated. Given the wide range of available feedback technologies and the ongoing research on new feedback devices, automation technologies and in-home energy management systems, it is currently impossible to determine what future feedback initiatives are likely to look like or which devices and approaches are likely to generate the most savings. Given these uncertainties, today's programs should maintain as much flexibility as possible and be designed with change in mind. At the same time, existing approaches should be used to the maximum extent possible. For instance, existing approaches that use statistical methods to analyze multiple data sources should be implemented now. These approaches can provide feedback using existing hardware such as computers, mobile phones, and televisions. In addition, investments should be made in new feedback mechanisms with the goal of testing and learning from existing approaches, build a knowledge base, and provide the means for the development of more advanced feedback and automation technologies as well as their increased affordability. A technology voucher system may provide consumers with the most choice and flexibility in determining which approach is most effective in meeting their needs.

The future of home energy management is likely to involve a complex network of wireless, consumer-controlled, home automation systems; although some automation devices can begin to be installed now. Home energy management can be greatly facilitated through "set and forget" systems that allow consumers to program their use of specific appliances and devices including their water heater, furnace, and pool pump. Such systems maintain consumer control in determining appliance settings as well as in determining when appliances should cycle on or cycle off. The benefit lies in both the ability of these devices to eliminate the requirement that consumers remember to manually set their preferences on a daily basis and in consumers' active involvement in designing tailored energy solutions.

Lessons Concerning Feedback-Related Energy Savings

Average Household Energy Savings. A variety of different types of feedback programs have been shown to generate significant energy savings in the residential sector. Notably, however, since 1995 most studies across our international sample have documented average household savings of 4 to 12%, with savings a little lower in the U.S.. While more research is needed to truly understand the causes of the variation in savings, program design elements, geographical/cultural context, and population characteristics are all likely to play a role.

Energy Saving Behaviors are Varied. Once people receive information about their energy consumption patterns, there are a wide variety of things they can do to reduce their energy consumption. Energy savings are typically achieved as a result of three categories of action: 1) simple changes in routines and habits, 2) infrequent and low-cost energy stocktaking behaviors (i.e., replacing incandescent bulbs with CFLs, weather stripping, etc) , and 3) consumer investments in new energy-efficient appliances, devices and materials. Evidence from existing studies suggests that most of the energy savings achieved through feedback programs results from changes in behaviors (not investments) although people who invest tend to save the most energy. (Current patterns may be a function of program design.) Additional evidence suggests that energy saving strategies are likely to vary by income level such that higher income households are more likely to purchase new energy efficient appliances, windows, and devices while lower income households are more likely to engage in energy stocktaking behaviors or change their energy use habits and routines.

The Effects of Feedback Type**.** Regardless of the actions taken, some types of feedback appear to be more effective than others in generating more substantial energy savings. As shown in Tables10, 13, and 14, existing studies suggest that daily/weekly feedback and real-time plus feedback tend to generate the highest savings per household. Median energy savings for studies employing these two approaches were both above 10% (11% and 14%, respectively). However, these estimates are dominated by studies with small sample-sizes and short duration; further studies with large sample sizes and longer duration are needed before conclusions can be drawn. Studies that used estimated and real time feedback strategies generated savings on the order of 7%, while programs that relied on enhanced billing strategies achieved savings of 5.5%. Nevertheless, it is also important to keep in mind Darby's insight that some types of feedback appear to be more effective for certain end uses than others. In particular, Darby (2006) suggests that indirect forms of feedback tend to be better suited to help households understand the effects of changes in space heating, household composition, and the effect of investments in new appliances and building shell upgrades. On the other hand, direct forms of feedback (real-time and real-time plus) tend to be better suited for understanding energy savings associated with smaller end uses such as turning of the lights, the television, or the computer.

The Impact of Program Era**.** Not surprisingly feedback-related energy savings vary across time. Research on the effects of feedback strategies spans four decades and two important eras: the energy crisis era of the 1970s, 1980s and the first half of the 1990s, and the Climate Change Era beginning in 1995 and spanning the first decade of the new century. Notably, feedback-induced energy savings are lower in the Climate Change Era than during the energy crisis era, regardless of the feedback strategy employed. This is important because studies that compare feedback-related savings across all four decades may result in inflated expectations regarding potential energy savings today.

Feedback-Induced Savings and Household Participation**.** At a more aggregate level (national, state, city, utility, community), the savings implications of different types of feedback depend on both average household energy savings and the overall level of household participation. Importantly, participation rates are significantly higher for programs that are designed using an opt-out (as opposed to opt-in) design, and the amenability of Enhanced Billing, Real-Time Feedback, and Real-Time Plus feedback programs to opt-out designs increases the likelihood of their success in achieving dramatically larger overall energy savings. As shown in Table 18, once participation rates are taken into consideration, Real-Time Plus programs appear to generate the largest savings (as high as 12%) followed by aggregate, real-time feedback programs (6%) and enhanced billing programs (nearly 5% using the results of our multi-continent sample, about 2% when considering only the U.S. sample). Notably, however, the investment costs of Enhanced Billing programs are substantially lower than those associated with the implementation of either Real-Time or Real-Time Plus programs because the latter require advanced metering equipment and in-home displays.

Motivational Elements and Program Effectiveness. Feedback-induced energy savings and overall rates of household participation are malleable and can be enhanced through the use of motivational elements such as the use of goal setting, commitments, competitions, and social norms. Research by Nolan et al. (2008) and Schultz et al. (2007) suggest that the use of social norms can result in household energy savings of 5.7 to 10% and that the use of both descriptive and injunctive norms is important in shaping household energy behaviors. Despite the evidence of enhanced savings, however, relatively few feedback projects have incorporated these noneconomic levers. OPOWER has been a pioneer in the application of social norm research in conjunction with its innovative home energy reports. More research is needed to explore the potential power of these (and other) non-economic incentives and the degree to which they can enhance household energy savings.

***Regional Context and Feedback-Induced Savings*.** Feedback seems to be more effective in generating household energy savings in some regional contexts than in others. More specifically, the evidence suggests that during the Climate Change Era (1990-2010), feedback programs in Western Europe generated much greater levels of energy savings than in the United States. As shown in Table 16, European savings during this Era averaged 10.5% while the average savings of U.S. feedback programs was 3 percentage points lower (7.4%). The reason for these differences is unclear although differences in political leadership and culture are likely to play an important role. A more narrowly focused, comparative analysis might reveal additional means of enhancing feedback-related savings in the United States.

Effects of Study Size*.* Even though existing studies suggest significant energy savings can be attained through the implementation of feedback programs, a closer examination reveals the need for caution in estimating the size of potential savings. As stated earlier actual household savings is likely to vary according to the type of feedback, according to temporal and regional contexts, and according to program design. In addition, results from this meta-review suggest that when applied on a large scale, households may or may not achieve the level of savings associated with past studies. Interestingly, a comparison of studies with larger and smaller sample sizes suggests that feedback-induced energy savings in larger studies are more modest than those found in smaller studies. Given that the larger studies tend to include a more representative sample of households, these findings may suggest that large-scale feedback programs are also likely to experience more modest savings. While these results are far from conclusive, future research is likely to prove valuable in answering this question.

Study Duration and the Persistence of Energy Savings. Our assessment of the relationship between study duration and feedback-related energy savings reveals that average energy savings are higher for shorter studies (10.1%) than for longer studies (7.7%). However, our subsequent assessment of the relationship between duration effects and persistence also revealed interesting insights. Evidence from the 27 studies that measured within-study persistence of feedback effects suggests that feedback-related energy savings are often persistent, although multiple studies also suggest that the persistence of energy savings may rely on the continued provision of feedback. Our assessment of the discrepancy between duration and persistence revealed that the lower rates of savings associated with shorter studies are not a reflection of the persistence of energy savings but instead reflect the inability of shorter studies to capture seasonal variations in energy end uses.

Demand Response and Peak versus Off-Peak Savings. The effectiveness of feedback initiatives in generating household energy savings is dramatically influenced by the focus of the program. Programs that are focused on peak load savings are generally successfully in shifting energy use from peak periods to off-peak periods but overall energy savings are dramatically lower.

Results from the meta-review suggest that programs focused on time of use rates and reducing consumption during periods of peak demand save considerably less energy than programs focus on promoting energy conservation and efficiency. More specifically, data from existing studies indicate that the overall energy savings from programs focused on peak load shifting have averaged around 6%, while programs focused on promoting conservation and efficiency have averaged around 10%.

Changes in Habits, Lifestyles and Choices. The review of the literature suggest that behavior-related energy savings opportunities are available in the residential sector, that people are willing to change their energy-related behaviors, and that feedback is likely to be an effective mechanism for enabling people to achieve a greater proportion of potential energy savings. Among the types of energy efficiency and conservation behaviors, investments in new equipment and appliances appeared more likely within more affluent populations and are generally undertaken in conjunction with a change of residence or a remodel or part of a stylistic (as opposed to functional) upgrade. For the larger population, households appear to be more likely to reduce energy consumption through changes in habits and routines or through energy stock-taking behaviors. Importantly, these energy-conservation behaviors are likely to be motivated by a variety of factors including self-interest (energy bill savings) as well as civic concerns and altruistic motives. These findings suggest that narrowly defined energy-efficiency programs aimed at the installation of new, more energy-efficient technologies alone (the practice of traditional utility programs) are likely to realize only a small fraction of potential behavior-related residential energy savings. Similarly, programs that limit their appeal to self-interest alone are unlikely to leverage the broad range of factors that motivate people to action.

Potential Impact on Feedback on U.S. Energy Consumption

Three Scenarios of Feedback-induced Energy Savings in the Residential Sector were examined. On a national scale, our estimates indicate that feedback programs for the residential sector might generate electricity savings that range from as little as 0.4% for programs that use enhanced billing to more than 6% of total residential electricity consumption for programs that widely deploy strategies with the largest savings. By 2030 the high end of this range—assuming well-designed programs that are fully integrated throughout the residential sector—might provide the equivalent of 100 billion kilowatt-hours of electricity savings on an annual basis.

Nationwide, the magnitude of feedback-related energy savings will depend heavily on the type of feedback provided, the overall level of participation in feedback programs, and program design elements.

B. Unresolved Questions

Persistence of Feedback-Induced Energy Savings

One of the most widespread concerns regarding the energy-saving effects of feedback is concerned with the likelihood that these effects will persist over time. Unfortunately there is a lack of sufficient high quality data to answer this question conclusively. Nevertheless, evidence from our meta-review of the 27 studies that measured within-study persistence suggests that feedback-related energy savings do often persist and in some cases may even increase over time[43]. Notably, however, multiple studies also suggest that the persistence of energy savings may rely on the continued provision of feedback. In other words, evidence suggests that people need persistent feedback to evaluate their energy consumption patterns across seasons and to periodically re-evaluate the impact of their changing patterns of energy end uses. Moreover, given that most U.S. homeowners change residence every 5 to 7 years (and renters more frequently), people also need the means to assess the energy consumption patterns of their new dwelling. Fortunately, the proliferation of powerful information and communications technologies has made persistent feedback relatively easy to provide and relatively inexpensive. From enhanced billing to in-home energy displays to internet-based sources of information, there is a wide range of mechanisms for providing households with persistent feedback.

While existing evidence suggests that residential feedback can result in persistent energy savings, more research on this topic is clearly needed. Future research should be designed to test the effect of feedback over a period of 24 months or more, and program evaluations should systematically assess and report on the ways in which energy savings vary across time. Additional research should

[43] The longest period for which the persistence of energy savings was assessed was three years.

explore the ways in which persistence varies according to feedback type and program characteristics. For example, are energy savings associated with enhanced billing or real-time feedback likely to be more persistent? Can the promising savings for daily/weekly feedback and real-time plus feedback shown in short-term and small-sample studies be demonstrated in large-sample, long-term studies? Are in-home displays or web-based applications better for eliciting persistent energy-saving practices? To what degree does the incorporation of certain program characteristics such as goal setting, commitments, competitions, and norms create an increased likelihood that savings will persist? And finally, what accounts for shifting rates of energy savings over time? To what degree do changes in energy savings result from seasonal variations in energy end uses, the growing number of energy end uses, or a relapse in smart energy practices?

Program Design and the Incorporation of Social and Behavioral Insights

Some of the studies reviewed for this report (as well as a variety of studies outside the purview of this report) suggest that feedback-related energy savings may be enhanced through the integration of certain program design features that incorporate insights from the social and behavioral sciences. Typically, these design features provide households with motivation and encouragement to take action and change their energy use practices. Some of the more popular features include the use of individual and group goals, the use of public and private commitments, the use of competitions, and the use of descriptive and injunctive social norms. Each of these design features is built on the recognition that even when households are provided with information about *how* they can reduce their energy consumption, they are unlikely to act on that information unless they are provided with a reason *why* they should invest the time and energy to do so. These design features could provide a potential alternative to time-of-use pricing mechanisms and other energy pricing penalties that are likely to have significant financial implications for some undefined subset of the population. Unfortunately, only a small number of studies reviewed here have incorporated or reported on any of these potential design elements, and there has been very little research on the potential effects of these and other social and behavioral science insights to date.[44] Further exploration is clearly needed.

Habits, Lifestyles and Choices

While it is clear that advanced metering initiatives and other programs that provide residential consumers with feedback regarding their energy consumption can result in significant reductions in energy use, few studies have explored what customers are choosing to do to bring about these reductions. Most of the recent data that have been collected have come from demand response studies and rely on self-reported data. It is unclear whether the same types of behavior change are likely to result from feedback programs aimed at overall energy savings, or whether other data collection methodologies are likely to reveal discrepancies between reported and actual behaviors. Existing data suggest that most energy savings have come from changes in habits and routines as opposed to energy stocktaking or investments in energy efficient products, however these findings are tenuous given the inadequate number of studies that have collected and reported detailed information regarding the ways in which people are change their behaviors. Future studies need to provide a better understanding of the behavioral changes that underlie feedback-related savings as well as consider how the constellation of energy-saving behaviors may shift over time. For example, are people more likely to achieve saving through new habits and routines in the short term but more likely to make investments in energy efficiency in the medium- or long-term? Future meta-reviews might also explore the relationship between feedback type and the types of energy-saving behaviors that they are likely to elicit. For example research by Darby (2006) suggests that indirect forms of feedback tend to be better suited to help households understand the effects of changes in space heating, household composition, and the effect of investments in new appliances and building shell upgrades, while direct forms of feedback (real-time and real-time plus) tend to be better suited for understanding energy savings associated with smaller end uses such as turning of the lights, the

[44] One exception is the growing interest in the use of social norms. OPOWER is among the companies that are systematically using social norms research in the design of their Home Energy Reports. Nevertheless, the net effect of social norms cannot be evaluated from their programs since all households receive a combined package of information which includes information concerning normative trends as well as a variety of energy saving tips and other information.

television, or the computer. These findings suggest that the very energy saving behaviors that result from indirect and direct forms of feedback may also vary in parallel.

Population Segmentation and Variation in Energy Practices and Savings
Very little research has explored the ways in which feedback-induced energy savings (and the underlying shifts in behaviors) vary across different segments of the population. Of the studies that do explore these relationships, findings suggest that greater levels of energy savings tend to be associated with higher levels of education and income, larger houses and those with more people, households with strong environmental values, and younger households. Plausible explanations of these relationships suggest that households with higher levels of education and income are likely to have a stronger sense of self-efficacy and greater access to resources, and that larger houses and higher levels of income may be associated with higher levels of energy waste prior to feedback interventions. Similarly, more youthful households and those with stronger environmental values may have a better understanding of link between personal behaviors and environmental outcomes. An initial assessment of these relationships is provided by EPRI in their 2009 report on residential electricity use feedback. According to their review, "some tenuous associations have emerged, but these need to be more thoroughly verified; this is a shortcoming of the current body of research that should be a focal point of future research initiatives." In this meta-review, we also note that the types of behaviors that people choose to engage in so as to reduce their energy consumption are also likely to vary in important ways. Perhaps most notably, preliminary evidence suggests that lower income households and renters are more likely to reduce their energy consumption through shifts in behaviors and routines, higher-income households and homeowners are more likely to invest in energy efficiency products. While more research on this topic is clearly needed, preliminary evidence suggests that while feedback can help reduce energy consumption across a wide variety of households, certain households may be more interested, more motivated or more capable and these differences matter in determining the range of energy savings that can be achieved.

The Source of Regional Variations in Energy Savings
As noted earlier in this report, feedback seems to be more effective in generating household energy savings in some regional contexts than in others. In fact, the evidence suggests that during the past 15 years, feedback programs in Western Europe have generated much larger average energy savings than those in the United States (10.5% versus 7.4%, respectively). The reason for these differences is unclear although differences in political leadership and culture are likely to play an important role. Other important differences might include the use of more effective program structures, the presence of synergistic government programs, or the enhanced availability of funding and services. A more in-depth, comparative study of the mechanisms and resources used in the translation of feedback into energy savings might help reveal important insights that could be applied toward increased energy savings in the United States.

C. Recommendations to Policymakers and Utilities

While the findings from this meta-review are many, the principal finding is that most studies performed in the current Climate Change Era across our multi-continent sample have resulted in average household energy savings of 4 to 12% and that well-designed feedback programs of the future could perhaps result in even greater savings. The following recommendations are offered to maximize potential feedback-induced energy savings.

- Provide all U.S. households with access to enhanced billing information immediately. Enhanced billing provides a low-cost means of reducing residential energy consumption by as much as 3.5% and could be implemented nationwide in an extremely short time frame without the need for technology investments.

- Explicitly recognize and address the importance of energy feedback mechanisms associated with smart grid deployment by ensuring that household level feedback is an integral part of advanced metering initiatives for all utilities.

- Provide real-time feedback to all households that have advanced meters. Real-Time data can be provided through the use of in-home displays, web-based tools or other means easily and quickly once advanced meters have been installed.

- Remove barriers to third-party providers of feedback technologies and services and encourage partnerships between third-party providers, utilities, governments and others working on providing feedback to households.

- Remove regulatory barriers for utility investments in energy efficiency and their ability to claim evaluated feedback-related energy savings.

- Support a diverse array of feedback programs that provide mutable and incremental approaches and that allow for maximum flexibility to integrate new feedback and automation technologies in the future. Invest in multiple programs and approaches to assess the effectiveness of different approaches.

- Invest in research to determine which types of technologies, services, structures and programs are most effective and document current best practices.

- Provide basic automation technologies to households in conjunction with the installation of in-home displays. Provide households with the ability to automate their preferences through the use of consumer controlled programs and settings.

- Use social and behavioral insights in program design. Apply existing social science insights with regard to goal setting, commitment, competitions and social norms to enhance the effectiveness of current programs and document their impact on program participation and energy savings.

- Focus feedback programs on overall energy savings as opposed to reductions in peak demand. Maximize energy and carbon savings by encouraging households to reduce overall energy consumption as opposed to simply shifting their use of energy to non-peak periods.

- Address behavioral as well as technological means of reducing household energy consumption. Programs should encourage households to consider engaging in a wide variety of energy saving behaviors rather than simply promote investments in energy efficient products. Significant energy savings can be achieved through the adoption of new habits, lifestyles and routines, as well as efforts to assess and address how low-cost home improvements can reduce energy waste.

- Implement rigorous and consistent research protocols to evaluate feedback programs and maximize cumulative knowledge concerning the effectiveness of different approaches to providing feedback (see EPRI 2010 on this topic). In particular, further studies are needed with large sample sizes, that examine savings over periods of a year or more, and that then examine savings persistence over multi-year periods. Such studies should particularly target daily/weekly feedback and real time plus feedback, two approaches that the limited data available indicate are particularly promising.

- It would also be useful to conduct additional research on why recent savings are higher in Europe, and whether there are lessons from Europe that could be usefully transferred to the U.S.

- Promote the development of new feedback technologies and services through the use of competitions, collaborations, and partnerships.

- Establish energy feedback performance standards for homes and then allow consumers to choose from a range of feedback technologies and services.

VI. References

ABIresearch. 2009. Home Automation and Security: Cellular Technologies Intersect with ZigBee, Z-Wave, HomePlug, LonWorks, and EnOcean [Electronic Version]. Market Report, 95, from http://www.abiresearch.com/research/1003235-Home+Automation+and+Security

Abrahamse, W., L. Steg, C. Vlek, & T. Rothengatter. 2005. “A review of intervention studies aimed at household energy conservation.” *Journal of Environmental Psychology*, 25: 273-291.

Abrahamse, W., L. Steg, C. Vlek, & T. Rothengatter. 2007. “The effect of tailored information, goal setting, and tailored feedback on household energy use, energy-related behaviors, and behavioral antecedents.” *Journal of Environmental Psychology*, 27: 265-276.

[ADM] ADM Associates. 2009. “The Impact of Home Electricity Reports.” Report prepared for the Sacramento Municipal Utility District. Sacramento, CA: ADM Associates.

Alcott Hunt. 2009. “Social Norms and Energy Conservation.” Available at: http://web.mit.edu/allcott/www/papers.html.

Allen, D. & K. Janda. 2006. “The Effects of Household Characteristics and Energy Use Consciousness on the Effectiveness of Real-Time Energy Use Feedback: A Pilot Study.” In *Proceedings of the ACEEE 2006 Summer Study on Energy Efficiency in Buildings*, 7: 1–12. Washington, D.C.: American Council for an Energy-Efficient Economy.

Amann, Jennifer Thorne. 2006. *Valuation of Non-Energy Benefits to Determine Cost-Effectiveness of Whole-House Retrofits Programs: A Literature Review*. Washington, DC: American Council for an Energy-Efficient Economy.

Asch, S.E. 1956. “Studies of independence and conformity: A minority of one against a unanimous majority.” *Psychological Monographs 70: 1-70.*

Ayers, Ian, Sophie Raseman, and Alice Shih. 2009. “Evidence from Two Large Field Experiments that Peer Comparison Feedback can Reduce Residential Energy Usage.” Working Paper 15386. Cambrige, MA: National Bureau of Economic Research. Available at: www.nber.org/papers/w15386.

Barbose G., C. Goldman & B. Neenan. 2005. “A survey of utility experience with real time pricing; implications for policymakers seeking price responsive demand.” In *Proceedings of the ECEEE 2005 Summer Study on Energy Efficiency*, 7:089. European Council for an Energy-Efficient Economy.

Barr, S., A.W. Gilg & N. Ford. 2005. “The Household Energy Gap: Examining the Divide Between Habitual- and Purchase-related Conservation Behaviours.” *Energy Policy,* 33(11): 1425–1444.

Battalio, Raymond C., John H. Kagel, Robin C. Winkler, and Richard A. Winett. 1979. “Residential Electricity Demand: An Experimental Study.” *The Review of Economics and Statistics* 61 (2): 180-189.

Becker, Lawrence J. 1978. “Joint Effect of Feedback and Goal Setting on Performance: A Field Study of Residential Energy Conservation.” *Journal of Applied Psychology* 63 (4): 428-433.

Benders, R.M.J., R. Kok, H.C. Moll, G. Wiersma, & K. J. Noorman 2006. "New Approaches for Household Energy Conservation—In Search of Personal Household Energy Budgets and Energy Reduction Options." *Energy Policy* 34 (18): 3612–3622.

Bittle, R.G., R. Valesano, & G. Thaler. 1979. "The Effects of Daily Cost Feedback on Residential Electricity Consumption." *Behavior Modification* 3(2): 187–202.

Bittle, Ronald G., Robert M. Valesano, and Greg M. Thaler. 1979-80. "The Effects of Daily Feedback on Residential Electricity Usage as a Function of Usage Level and Type of Feedback Information." *Journal of Environmental Systems* 9(3): 275-287.

Boardman B, S. Darby, G. Killip, M. Hinnells, C.N. Jardine, J. Palmer & G. Sinden. 2005. "*40% House*." Oxford, UK: Environmental Change Institute, University of Oxford.

Boardman, B. & S. Darby. 2000. "Effective Advice: Energy Efficiency and the Disadvantaged." Oxford, UK: Environmental Change Institute, University of Oxford.

Brandon G. & A. Lewis. 1999. "Reducing Household Energy Consumption: a Qualitative and Quantitative Field Study." *Journal of Environmental Psychology* 19(1): 75-85.

Carroll, Ed and Mark Brown. 2009. "Research to Inform Design of Residential Energy Use Behavior Change Pilot." Conservation Improvement Program Presentation for the Minnesota Office of Energy Security. (July) Franklin Energy.

Carroll, Ed, Eric Hatton, and Mark Brown. 2009. "Residential Energy Use Behavior Change Pilot." CMFS project code B21383. (April) Franklin Energy.

Case, M., M. Butts, & W. Harbaugh 2008. *AMI/Smart Energy Pricing (SEP) Update Presentation—October 15 2008*. Baltimore, Md.: Baltimore Gas and Electric.

Caves, D. & L. Christensen 1980. "Residential Substitution of Off-Peak for Peak Electricity Usage Under Time of Use Prices." *Energy Journal* 1(2): 85–142.

Ceniceros, B. & W. Bos. 2009. *Insights and Questions: Customer Response to the Home Electricity Reports, Results from SMUD's (Sacramento Municipal Utility District's) Normative Messaging Pilot.*

[Census] United States Census Bureau. 2004. *United States 2000.* http://www.census.gov/main/www/cen2000.html. Washington, D.C.: U.S. Census Bureau.

[Census] United States Census Bureau. 2009. *Computer and Internet Use in the United States: October 2007.* http://www.census.gov/population/www/socdemo/computer.html. Washington, D.C.: U.S. Census Bureau.

CEPro. 2008. "The Ultimate Guide to Home Automation 2008." *CE Pro Magazine*.

CEPro. 2009. "The Ultimate Guide to Home Automation 2009 [Electronic Version]." *CE Pro Magazine*, from http://www.cepro.com/whitepapers/details/ultimate_guide_to_home_automation_2009/

Charles River Associates. 2005. "Impact Evaluation of the California Statewide Pricing Pilot – Final Report.

Chetty, M., D. Tran, & R. Grinter. 2008. "Getting to Green: Understanding Resource Consumption in the Home." In *Proceedings of the ACM 2008 International Conference*: 242–241.

Cialdini, R.B. and N.J. Goldstein. 2004. "Social Influence: Compliance and conformity." *Annual Review of Psychology* 55: 591-621.

CITA. 2008. Wireless Quick Facts. Retrieved June 3, 2009, from http://www.ctia.org/media/industry_info/index.cfm/AID/10323

[CL&P] Connecticut Light and Power Company. 2009. "Results of CL&P Plan-It-Wise Energy Pilot." Docket 05-10-03 RE01: Compliance Order No. 4.

Cornes, R. 1992. *Duality and Modern Economics*, Cambridge: Cambridge University Press.

Darby, S. 1999. "Energy advice—what is it worth?" In *Proceedings of the ECEEE 1999 Summer Study on Energy Efficiency*, 3: 05. European Council for an Energy-Efficient Economy.

Darby, S. 2000. "Making it obvious: Designing feedback into energy consumption." In *Proceedings of the 2nd International Conference on Energy Efficiency in Household Appliances and Lighting.* http://www.eci.ox.ac.uk/lowercf/naples/NAPLES2000-SD.pdf. Naples, Italy: Italian Association of Energy Economists/ ECSAVE Programme.

Darby, S. 2006. "The Effectiveness of Feedback on Energy Consumption: A Review for DEFRA of the Literature on Metering, Billing and Direct Displays." http://www.defra.gov.uk/environment/climatechange/uk/energy/research/pdf/enegyconsump-feedback.pdf. Oxford, UK: Environmental Change Institute, University of Oxford.

Darby, S. 2008. "Why, What, When, How, Where, and Who? Developing UK Policy on Metering, Billing and Energy Display Devices." In *Proceedings of the ACEEE 2008 Summer Study on Energy Efficiency in Buildings,* 7: 70-81. Washington, D.C.: American Council for an Energy-Efficient Economy

De Leon, Iser G. and R. Wayne Fuqua. 1995. "The Effects of Public Commitment and Group Feedback on Curbside Recycling." *Environment and Behavior* 27 (2): 233-250.

De Young, R. 1993. "Changing behaviour and making it stick: the conceptualistion and management of conservation behaviour." *Environment and behaviour* 25 (4), 485-505

DEFRA. 2008. "A Framework for Pro-Environmental Behaviours." DEFRA, Business Resource Efficiency and Consumers Division, London, UK.

Delage, Michael. 2009. April 17, 2009 In-depth Interview with Michael Delage, Energate, VP of Product Management.

Dobbyn J. & G. Thomas 2005. "Seeing the light: the impact of microgeneration on the way we use energy. Qualitative research findings." London, UK: Hub Research Consultants, on behalf of the Sustainable Consumption Roundtable.

Dobson, J. K. & J. D. A. Griffin. 1992. "Conservation Effect of Immediate Electricity Cost Feedback on Residential Consumption Behavior." In *Proceedings of the ACEEE 1992 Summer Study on Energy Efficiency in Buildings*, 10: 33–35. Washington, D.C.: American Council for an Energy-Efficient Economy.

[DOE] U.S. Department of Energy. 2009. "The Smart Grid: An Introduction." http://www.oe.energy.gov/1165.htm Washington, D.C.: Department of Energy

Donnelly, Kat A.. 2009. "Energy Feedback: Technologies, Applications, and System Interfaces" [Electronic Version]. Affordable Comfort Institute Northwest Conference Presentation, February

3-5, 2009, from http://www.affordablecomfort.org/images/Events/48/Courses/1224/OPP_5_2009_ACI_KDonnelly.ppt.pdf

DRAM. 2009. *Demand Response and Advanced Metering Coalition (DRAM) Definitions.* Retrieved May 10, 2009, from http://www.dramcoalition.org/id19.htm

Dwyer, W.O., F.C. Leeming, M.K. Cobern, B.E. Porter & J.M. Jackson. 1993. "Critical review of behavioural interventions to preserve the environment: research since 1980." *Environment and behaviour* 25 (3) 275-321.

Dyson, C., S. Samiullah, T. Rasmussen, & J. Cavalli. 2005. "Can Programmable Thermostats be Part of a Cost-Effective Residential Program Portfolio?" In *Proceedings of the International Energy Program Evaluation Conference*, 2B.

EEI. 2009. *State Energy Efficiency Regulatory Frameworks, June* 2009 [Electronic Version]. The Edison Foundation: Institute for Electric Efficiency, from http://www.edisonfoundation.net/iee/issueBriefs/IEE_StateRegulatoryFrame_0609.pdf

Efficiency 2.0. 2009. *Climate Culture: Live Smarter.* Retrieved May 16, 2009, from http://www.climateculture.com/about

Egan, C. 1999. "Graphical displays and comparative energy information: what do people understand and prefer?" In *Proceedings of the ECEEE 1999 Summer Study on Energy Efficiency*, 2: 13. European Council for an Energy-Efficient Economy.

Ehrhardt-Martinez, Karen. 2009. "Evaluation of Positive Energy's Home Energy Report Program Implemented in Conjunction with the Sacramento Municipal Utility District." Washington, DC: American Council for an Energy-Efficient Economy.

Ehrhardt-Martinez, Karen, and John A. "Skip" Laitner. 2009. "Breaking Out of the Economic Box: Energy Efficiency, Social Rationality and Noneconomic Drivers of Behavioral Change." In *Proceedings of the ECEEE 2009 Summer Study on Energy Efficiency.* La Colle sur Loup, France: European Council for an Energy-Efficient Economy.

[EIA] Energy Information Administration. 2009a. *Annual Energy Outlook 2010*. http://www.eia.doe.gov/oiaf/aeo/index.html. Washington, D.C.: U.S Department of Energy, Energy Information Administration.

[EIA] Energy Information Administration. 2009b. *2005 Residential Energy Consumption Survey (RECS)*. http://www.eia.doe.gov/emeu/recs/. Washington, D.C.: U.S. Department of Energy, Energy Information Administration.

Elburg, H. 2008. "Smart Metering and Consumer Feedback: What Works and What Doesn't." In *Proceedings of the ACEEE 2008 Summer Study on Energy Efficiency in Buildings*, 2: 349–360. Washington, D.C.: American Council for an Energy-Efficient Economy.

Elliott, J., M. Martinez, J. Mitchell-Jackson, & C. Williamson. 2006. "The California Bill Analysis Pilot: Using Web-Based Bill Analysis as a Tool to Reduce On-Peak Demand." In *Proceedings of the ACEEE 2006 Summer Study on Energy Efficiency in Buildings*, 2: 94–105. Washington, D.C.: American Council for an Energy-Efficient Economy.

[EPRI] Electric Power Research Institute. 1984. "Survey of Conditional Energy Demand Models for Estimating Residential Unit Energy Consumption Coefficients." EPRI EA-ER10. Palo Alto, California: Electric Power Research Institute.

[EPRI] Electric Power Research Institute. 2008a. "Characterizing and Quantifying the Societal Benefits Attributable to Smart Metering Investments." EPRI 2008. 1017006. Palo Alto, CA: Electric Power Research Institute.

[EPRI] Electric Power Research Institute. 2008b. "Technology Brief: Residential Energy Display Devices." EPRI 2008. 1016972. Palo Alto, CA: Electric Power Research Institute.

[EPRI] Electric Power Research Institute. 2008c. "Technology Brief: Residential Energy Display Devices: Utility Pilot Update." EPRI 2008. 1016088. Palo Alto, CA: Electric Power Research Institute.

[EPRI] Electric Power Research Institute. 2008d. "Automation and Control Protocols in Residential and Commercial Buildings: A Scoping Study Leading to the Development of Open Standards Based Communications." EPRI 2008. 1016113. Palo Alto, CA: Electric Power Research Institute.

[EPRI] Electric Power Research Institute. 2009. "Residential Electricity Use Feedback: A Research Synthesis and Economic Framework." Report 1016844. Palo Alto, CA: Electric Power Research Institute.

[EPRI] Electric Power Research Institute. 2009. "Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S. (2010-2030)." Palo Alto, California: Electric Power Research Institute.

[EPRI] Electric Power Research Institute. 2010. "Guidelines for Designing Effective Energy Information Feedback Pilots: Research Protocols." Report 1020855. Palo Alto, California: Electric Power Research Institute. (April)

Farhar, Barbara and Colleen Fitzpatrick. 1989. "Effects of Feedback on Residential Electricity Consumption: A Literature Review." Golden, Colorado: Solar Energy Research Institute.

Faruqui, Ahmad and Dan Harris. 2009. "Lessons from Demand Response: Trials and Potential Savings for the EU." Presentation for the Naval and Military Club, London, Great Britain. (October 12th)

Faruqui, Ahmad and Sanem Sergici. 2009. "Household Response to Dynamic Pricing of Electricity – A Survey of the Experimental Evidence." The Brattle Group.

Faruqui, Ahmad and Lisa Wood. 2008. The Brattle Group, Quantifying the Benefits of Dynamic Pricing in Mass Markets [Electronic Version]. Edison Electric Institute. Retrieved January 2008, from http://www.eei.org/industry_issues/electricity_policy/quantifying_benefits_final.pdf.

Fehrenbacher, Katie. 2009a. Energy-Use Software to Rival Google's? Efficiency 2.0 keeps a low profile as it develops elaborate algorithms —its "secret sauce" – to curb energy use and rival the big guys [Electronic Version]. Business Week, from http://www.businessweek.com/technology/content/jul2009/tc20090728_008663.htm

Fehrenbacher, Katie. 2009b. FAQ: Smart Grid [Electronic Version]. Earth2Tech. Retrieved May 8, 2009, from http://earth2tech.com/2009/01/26/faq-smart-grid/

Fehrenbacher, Katie. 2009c. Microsoft Enters the Smart Hohm [Electronic Version]. GigaOm, from http://gigaom.com/2009/06/24/microsoft-enters-the-smart-hohm/

[FERC] Federal Energy Regulatory Commission. 2008a. *2008 Assessment of Demand Response and Advanced Metering.* Washington, D.C.: Federal Energy Regulatory Commission.

[FERC] Federal Energy Regulatory Commission. 2008b. "Federal Energy Regulatory Commission Assessment of Demand Response & Advanced Metering, Staff Report and Excel Data, December 29. 2008." http://www.ferc.gov/industries/electric/indus-act/demand-response/2008/survey.asp. Washington, D.C.: Federal Energy Regulatory Commission

[FERC] Federal Energy Regulatory Commission. 2009. "A National Assessment of Demand Response Potential." Prepared by The Brattle Group – Feeman, Sullivan & Co., and Global Energy Partners, LLC.

Fischer, C. 2007. "Influencing Electricity Consumption via Consumer Feedback: A Review of Experience." In *Proceedings of the ECEEE 2007 Summer Study on Energy Efficiency*, 9: 1873–1884. European Council for an Energy-Efficient Economy.

Frank, Andy. 2009. June 3, 2009 In-depth Interview with Andy Frank, Executive Vice President, Business Development, Efficiency 2.0

Frost & Sullivan. 2007. "Advances in Smart Meters and Smart Grids (Technical Insights)." http://www.frost.com/prod/servlet/report-homepage.pag?repid=D0BA-01-00-00-00.

Gallen, Christine. 2009. Home Automation System Shipments to Reach 2.8 Million in 2011 [Electronic Version]. Market Report. Retrieved May 15, 2009, from http://www.abiresearch.com/press/1416-Home+Automation+System+Shipments+to+Approach+2.8+Million+in+2011

Galvin Electricity Initiative. 2007. "The Path to Perfect Power: New Technologies Advance Consumer Control." Palo Alto, CA: Galvin Electricity Initiative.

Gaskell G, P. Ellis & R Pike.1982. "The energy literate consumer: the effects of consumption feedback and information on beliefs, knowledge and behaviour." London, UK: Dept of Social Psychology, London School of Economics.

Geller, E.S., T.D. Berry, T.D. Ludwig, R.E. Evans, M.R. Gilmore, and S.W. Clark. 1990. "A Conceptual Framework for Developing and Evaluating Behavior Change Interventions for Injury Control." *Health Education Research: Theory and Practice* (5): 125-137.

Geller, E.S. 2002. "The Challenge of Increasing Proenvironmental Behavior." In *Handbook of Environmental Psychology: 525-540.* R.G. Bechtel and A. Churchman (Eds). New York: Wiley.

Goldman, Charles, Michael Reid, and Roger Levy. 2009. *Coordination of Energy Efficiency and Demand Response: A Resource of the National Action Plan for Energy Efficiency*. Draft.

Griskevicius, V., R.B. Cialdini, & N.J. Goldstein. 2008. "Social Norms: An Underestimated and Underemployed Lever for Managing Climate Change." *International Journal for Sustainability Communication*, 3, 5-13.

Haakana, M., L. Sillanpää, & M. Talsi. 1997. "The Effect of Feedback and Focused Advice on Household Energy Consumption." In *Proceedings of the ECEEE 1997 Summer Study on Energy Efficiency*, 4: 1–11. European Council for an Energy-Efficient Economy.

Hayes, Steven C. and John D. Cone. 1977. "Reducing Residential Electrical Energy Use: Payments, Information, and Feedback." *Journal of Applied Behavior Analysis* 10 (3): 425-435.

Henryson J., T. Hakansson & J. Pyrko. 2000. "Energy efficiency in buildings through information—Swedish perspective." *Energy Policy* 28, 169-180

Holmes, L. 2008. "Home Energy Displays: Highlights from the Nevada Product Trials." Presentation for the Southwest Energy Efficiency Project. Boulder, Colo.: Southwest Energy Efficiency Project.

Honebein, P.C., R.F. Cammarano, & K.A. Donnelly. 2009. "Will Smart Meters Ripen or Rot? Five First Principles for Embracing Customers as Co-Creators of Value." Electricity Journal, 22 (5): 39-44.

Horst, G. R. 2006. "Woodridge Energy Study & Monitoring Pilot." http://uc-ciee.org/pubs/ref_etd.html. Whirlpool Corporation.

Howe, Jeff. 2008. *Crowdsourcing: Why the Power of the Crowd Is Driving the Future of Business.* Crown Business.

Hutton, R. B., G. A. Mauser, P. Filiatrault, & O. T. Ahtola. 1986. "Effects of Cost Related Feedback on Consumer Knowledge and Consumption Behavior: A Field Experimental Approach." *The Journal of Consumer Research* 13(3): 327–336.

Hydro One Networks Inc. 2008. "Hydro One Networks' Time-of-Use Pilot Project Results." Report EB-2007-0086. http://www.oeb.gov.on.ca/documents/cases/EB-2004-0205/smartpricepilot/TOU_Pilot_Report_HydroOne_20080513.pdf. Toronto, Ontario, Canada: Hydro One Networks.

IBM. 2007. "Ontario energy board smart price pilot: Final report." http://www.oeb.gov.on.ca/documents/cases/EB-2004-0205/smartpricepilot/OSPP%20Final%20Report%20-%20Final070726.pdf Toronto, Ontario, Canada: Ontario Energy Board.

IPSOS Mori. 2007. "The Impact of Information Provision on Behaviour Change: Desk Research Review Conducted for energywatch by IPSOS Mori." London, UK: Energywatch.

Kantola, S., G. Syme, and N. Campbell. 1984. "Cognitive Dissonance and Energy Conservation." *Journal of Applied Psychology* 69(3): 416–421.

Karbo, P. & T.F. Larsen. 2005. "Use of Online Measurement Data for Electricity Savings in Denmark." In *Proceedings of the ECEEE 2005 Summer Study on Energy Efficiency*, 1.1804. European Council for an Energy-Efficient Economy.

Kasulis, J.J., D.A. Huettner & N.J. Dikeman. 1981. "The feasibility of changing electricity consumption patterns." *Journal of Consumer Research* 8, 279-290.

Kathan, D. 2008. "FERC Presentation: Advanced Metering Overview. Paper presented at the State Clean Energy-Environment Technology Forum." Washington, D.C.: Federal Energy Regulatory Commission

Katzev, R. D. & T. R. Johnson. 1987. *Promoting Energy Conservation: An Analysis of Behavioral Research.* Boulder, CO: Westview Press.

Kavazovic, Ogi. 2009. April 28, 2009 In-depth Interview with Ogi Kavazovic, Positive Energy, Director of Marketing.

Kay, Russell. 2009. QuickStudy: The smart grid. What is it, when will it get here, and what difference will it make? [Electronic Version]. Computer World. Retrieved May 11, 2009, from http://www.computerworld.com/action/article.do?command=viewArticleBasic&articleId=338125

Keesee, M. 2005. "Setting a new standard—the zero energy home experience in California." Sacramento, Calif.: Sacramento Municipal Utility District.

Keirstead, J. & B. Boardman. 2005. "Response to Ofgem consultation document 123/05" http://www.ofgem.gov.uk/temp/ofgem/cache/cmsattach/12425_12305_lcf.pdf

Keirstead, J. 2005. "Photovoltaics in the UK domestic sector: A Double-Dividend?" In *Proceedings of the ECEEE 2005 Summer Study on Energy Efficiency*, 6.054. European Council for an Energy-Efficient Economy.

Kempton, W. and L. Montgomery. 1982. "Folk Quantification of Energy." *Energy -- The International Journal 7 (10): 817-827.*

Kim, S., S. Oah & A.M. Dickinson. 2005. "The Impact of Public Feedback on Three Recycling-Related Behaviors in South Korea." *Environment and Behavior* 37: 258-274.

King, Chris and Dan Delurey. 2005. Energy Efficiency and Demand Response: Twins, Siblings or Cousins? *Public Utilities Fortnightly*: 54-61.

King, K. & P. Shatrawka. 1994. "Customer Response to Real-Time Pricing in Great Britain." In *Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings*, 2: 2194–2203. Washington, D.C.: American Council for an Energy-Efficient Economy.

Laitner, John A. "Skip", Karen Ehrhardt-Martinez, and Vanessa McKinney. 2009a. "Examining the Scale of the Behaviour Energy Efficiency Continuum." in *ECEEE 2009 Summer Study: Act! Innovate! Deliver! Reducing Energy Demand Sustainably*. La Colle sur Loup, France: European Council for an Energy-Efficient Economy.

Laitner, John A. "Skip", Christopher Poland Knight, Vanessa McKinney, and Karen Ehrhardt-Martinez. 2009b. *Semiconductor Technologies: The Potential to Revolutionize U.S. Energy Productivity.* Washington, DC: American Council for an Energy-Efficient Economy.

Laitner, John A. "Skip", and Karen Ehrhardt-Martinez. 2008. *Information and Communication Technologies: The Power of Productivity; How ICT Sectors Are Transforming the Economy While Driving Gains in Energy Productivity.* Washington, D.C.: American Council for an Energy-Efficient Economy.

Latane, B. and J.M. Darley 1970. "The unresponsive bystander: Why doesn't he help?" New York: Appleton-Century-Crofts.

Leeds, David J. 2009. The Smart Grid in 2010: Market Segments, Applications, and Industry Players [Electronic Version]. GTM Research, Greentech Media, Inc., from http://www.gtmresearch.com/report/smart-grid-in-2010

Levy, Roger. 2005. Meter Scoping Study [Electronic Version]. California Energy Commission, from www.ucop.edu/ciee/dretd/references/documents/meterscope.pdf

Lu, Ed. 2009. May 19, 2009, Energized about our first Google PowerMeter partners [Electronic Version]. The Official Google Blog, from http://googleblog.blogspot.com/2009/05/energized-about-our-first-google.html

Lucero, S. 2009. "Home Automation: Most Potential Customers Want to Remotely Monitor Their Homes, Some Will Pay Between $1,000 and $5,000. http://www.abiresearch.com/products/insight/Home_Automation_3a_Most_Potential_Customers_Want_to_Remotely_Monitor_Their_Homes_2c_Some_Will_Pay_Be. New York, NY: ABIresearch.

Lutzenhiser, Loren, Rick Kunkle, James Woods, and Susan Lutzenhiser. 2003. "Conservation Behavior by Residential Consumers during and After the 2000-2001 California Energy Crisis."

Appendix A in *Public Interest Energy Strategies Report*. (100-03-012F). California Energy Commission.

Lutzenhiser, Loren. 2009. "Behavioral Assumptions Underlying California Residential Sector Energy Efficiency Programs." Report prepared for the California Institute for Energy and Environment (CIEE) and the California Public Utility Commission. Oakland, CA: CIEE.

Macey, S.M. & M.A. Brown. 1983. "Residential Energy Conservation: The Role of Past Experience in Repetitive Household Behavior." *Environment and Behavior* 15(2): 123-141.

MacLellan, D. 2008. "PowerCost Monitor Pilot—NSTAR." In *Proceedings of the 2008 Behavior, Energy, and Climate Change Conference.* http://piee.stanford.edu/cgi-bin/docs/behavior/becc/2008/presentations/19-5E-03-NSTAR_Power_Cost_Monitor_Pilot.pdf

Martinez, M.S. & C.R. Geltz. 2005. "Utilizing a pre-attentive technology for modifying customer energy usage." In *Proceedings of the ECEEE 2005 Summer Study,* 7: 3–11. European Council for Energy-Efficient Economy.

Maxwell, K. 2002. "Friends: The role of peer influence across adolescent risk behaviors." *Journal of Youth and Adolescence* 31: 267-277.

McCalley, L.T. & C.J.H. Midden. 2002. "Energy Conservations through Product-Integrated Feedback: The Roles of Goal-Setting and Social Orientation." *Journal of Economic Psychology* (23) 589-603.

McCalley, L.T. 2006. "From Motivation and Cognition Theories to Everyday Applications and Back Again: The Case of Product-Integrated Information and Feedback." *Energy Policy* 34(2): 129-137.

McClelland, Lou and Stuart W. Cook. 1979-80. "Energy Conservation Effects of Continuous In-home Feedback in All-Electric Homes." *Journal of Environmental Systems* 9: 169-173.

McKenzie-Mohr, Doug. Personal Communication. January 6, 2010.

Meadows, D. 2008. *Thinking in systems: a primer.* White River Junction, VT: Chelsea Green Publishing.

Microsoft. 2009. About Microsoft hohm beta version. from http://www.microsoft-hohm.com/Home/Default.aspx

Mountain, D. 2006. *The Impact of Real-Time Feedback on Residential Electricity Consumption: The Hydro One Pilot*. Mountain Economic Consulting and Associates Inc.: Ontario

Mountain, D. 2008. "Real-Time Feedback and Residential Electricity Consumption: British Columbia and Newfoundland and Labrador Pilots." Ontario, Canada: Mountain Economic Consulting and Associates Inc.

Mueller, Richard W. 2009. April 28, 2009, In-depth Interview with Richard W. Mueller, Widefield Technology, Inc., President.

Nagel, Paul. 2009. April 23, 2009, In-depth Interview with Paul Nagel, Vice President of Strategic Development, and DeAnn Zebelean, Public Relations Director, Control4.

Neenan, B. & R. Hemphill. 2008. "Benefits of Smart Metering Investments." *The Electricity Journal* 21(2): 32–45.

Nemiroff, L.S., & McKenzie-Mohr, D. 1992. "Determinants and distinguishing variables of pro-disarmament behavior and responsible environmental behavior." *Journal of Social Behavior and Personality*, 7(1): 1-24.

Nemtzow, David, Dan Delurey, and Chris King. 2007. "The Green Effect: How Demand Response Programs Contribute to Energy Efficiency and Environmental Quality." *Public Utilities Fortnightly*. March.

Nielsen, L. 1993. "How to get the birds in the bush into your hand: Results from a Danish research project on electricity savings." *Energy Policy* 21(11): 1133–1144.

Nolan, J. M., P. W. Schultz, R. B. Cialdini, N. J. Goldstein & V. Griskevicius. 2008. *Personality and Social Psychology Bulletin* 34 (7): 913-923.

Norton, Bill. 2008. "Final Report for: PowerCost Monitor Pilot Program Evaluation." Prepared by Opinion Dynamics Corporation for National Grid, NSTAR Electric, and the Western Massachusetts Electric Company. Waltham, MA: Opinion Dynamics.

OFGEM. 2006. "Domestic metering innovation." Consultation document 20/06

OFGEM. 2008. "Energy Demand Research Project—Review of Progress." http://www.ofgem.gov.uk/MARKETS/RETMKTS/METRNG/SMART/Documents1/EDRP_June_2008_Public_progress_report_final.pdf

Olsen, Kirsten. 2009. April 17, 2009 In-depth Interview with Kirsten Olsen, Google.org, Product Manager.

Owen, G. & J. Ward. 2006. "Smart meters: commercial, policy and regulatory drivers." http://www.sustainabilityfirst.org.uk/docs/smart%20meters%20pdf%20version.pdf London, UK: Sustainability First.

Pallack, M., D. Cook, and J. Sullivan. 1980. "Commitment and Energy Conservation." In L. Bickman (ed.) *Applied Social Psychology Annual* 1: 235-253. Beverly Hills, CA: Sage.

Parker, D. S., D. Hoak, A. Meier & R. Brown. 2006. "How Much Energy Are We Using? Potential of Residential Energy Demand Feedback Devices." In *Proceedings of the ACEEE 2006 Summer Study on Energy Efficiency in Buildings*, 1: 211–222. Washington, D.C.: American Council for an Energy-Efficient Economy

Parker, D. S., D. Hoak, & J. Cummings. 2008. "Pilot Evaluation of Energy Savings from Residential Energy Demand Feedback Devices." Report FSEC-CR-1742-08 Washington, D.C.: U.S. Department of Energy.

Petersen, J., V. Shunturov, K. Janda, G. Platt & K. Weinberger. 2007. "Dormitory Residents Reduce Electricity Consumption when Exposed to Real-Time Visual Feedback and Incentives." *International Journal of Sustainability in Higher Education*, 8(1): 16.

PG&E. 2009. Home Area Network (HAN) Overview Presentation [Electronic Version], from http://www.edisonfoundation.net/IEE/reports/index.htm

PikeResearch. 2009. Home Energy Management Users Will Reach 28 Million by 2015. *The Smart Grid Observer,* (December 10, 2009). Retrieved from http://www.pikeresearch.com/newsroom/home-energy-management-users-will-reach-28-million-by-2015

Porteous, P. 2010. February 9, 2010, Personal Communication with CEO of Blue Line Innovations Inc.

Pratt, R. G., et al. 2010. *The Smart Grid: An Estimation of the Energy and CO2 Benefits. Revision 1*. Richland, WA: Pacific Northwest National Laboratory.

Pruitt, B. 2005. "Salt River Project M-Power." Presentation at the Second Annual Workshop for Energy Efficiency Program Design and Implementation in the Southwest.http://www.swenergy.org/workshops/2005/PRESENTATION%20%20Pruitt%20SRP%20M-Power.pdf. Boulder, Colo.: Southwest Energy Efficiency Project.

[PSE&G] Public Service Electric and Gas. 2008. "MyPower Pricing Pilot Program Final Evaluation Report." Presented at the EEI E Forum on Dynamic Pricing Pilots and Rollouts. (November 13)

Reiss, P. & M. White. 2005. "Household Electricity Demand, Revisited." *The Review of Economic Studies* 72: 853–883.

Roberts, S. & W. Baker. 2003. "Towards effective energy information: improving consumer feedback on energy consumption." A report to Ofgem. Bristol, UK: Centre for Sustainable Energy.

Roberts, S., H. Humphries & V. Hyldon. 2004. "Consumer preferences for improving energy consumption feedback." Report for Ofgem. Bristol, UK: Centre for Sustainable Energy.

Robinson, Jennifer. 2007. "The Effect of Electricity-Use Feedback on Residential Consumption: A Case Study of Customers with Smart Meters in Milton, Ontario." Master's Thesis. Waterloo Ontario, Canada: University of Waterloo.

Russell Kay. 2009. "QuickStudy: The smart grid. What is it, when will it get here, and what difference will it make?" http://www.computerworld.com/action/article.do?command=viewArticleBasic&articleId=338125. *Computer World.*

Ruth, Mike. 2009. May 8, 2009, In-depth Interview with Mike Ruth, Tendril, Senior Director Product Strategy.

Schultz, P. Wesley, Jessica M. Nolan, Robert B. Cialdini, Noah J. Goldstein, and Vladas Griskevicius. 2007. "The Constructive, Destructive, and Reconstructive Power of Social Norms." *Psychological Science* 18(5): 429-434.

Schwarz, P., T. Taylor, M. Birmingham & S. Dardan. 2002. "Industrial Response to Electricity Real-Time Prices: Short Run and Long Run." *Economic Inquiry* 40(4): 597– 610.

Scott, Kate. 2008. "Energy Trust of Oregon Home Energy Monitor Pilot." November 19, 2008. In Proceedings of the 2008 Behavior, Energy, and Climate Change Conference. http://piee.stanford.edu/cgi-bin/docs/behavior/becc/2008/presentations/19-5E-01-Energy_Trust_of_Oregon_Home_Energy_Monitor_Pilot.pdf

Seaver, W. Burleigh and Arthur H. Patterson. 1976. "Decreasing Fuel-Oil Consumption Through Feedback and Social Commendation." *Journal of Applied Behavior Analysis*. 9 (2): 147-152.

Seligman, C., J. M. Darley & L. J. Becker. 1978. "Behavioral Approaches to Residential Energy Conservation." *Energy and Buildings* 1(3): 325–337.

Seligman, C., L. Becker & J. Darley. 1981. "Encouraging Residential Energy Conservation through Feedback." *Advances in environmental psychology,* 3: 93–114.

Sexton R. & T. Sexton. 1987. "Theoretical and Methodological Perspectives on Consumer Response to Electricity Information." *The Journal of Consumer Affairs*. 21: 238–256.

Sexton, R. J., N. Brown-Johnson & A. Konakayama. 1987. “Consumer Response to Continuous-display Electricity-use Monitors in a Time-of-use Pricing Experiment.” *Journal of Consumer* Research 14(1): 55–62.

Shirky, Clay. 2008. Here Comes Everybody: The power of organizing without organizations: Penguin Group.

Sipe, Brien and Sarah Castor. 2009. “The Net Impact of Home Energy Feedback Devices.” Portland, OR: Energy Trust of Oregon.

SmartGridNews. 2009. July 6, 2009 News Roundup: Control4 Gets $17.3M to Develop Smart Grid Products [Electronic Version]. Smart Grid News, from http://www.smartgridnews.com/artman/publish/news/Control4_Gets_17_4_M_in_Funding_for_Smart_Grid_Products_Smart_Plugs_Get_Even_Smarter_IEC_Working_on_Smart_Grid_Standards_for_Vehicle_Charging-623.html.

Smith, Rebecca. 2009. Smart Meter, Dumb Idea? New devices promise to cut energy use by giving customers more information. Critics say they aren't worth the cost. [Electronic Version]. Wall Street Journal, Business Section. Retrieved May 5, 2009, from http://online.wsj.com/article/SB124050416142448555.html

Sonderegger, R.C. 1978. “Movers and Stayers: the resident's contribution to variation across houses in energy consumption for space heating.” *Saving Energy in the Home: Princeton’s Experiments at Twin Rivers*. Ed. Robert H. Socolow. Ballinger Publishing Company: Cambridge 1978 207-230.

Spaur, Matthew. 2009. April 27, 2009 In-depth Interview with Matthew Spaur, Itron, Inc. AMI Business Development.

Staats, H., E. van Leeuwen, & A. Wit. 2000. “A longitudinal study of informational interventions to save energy in an office building.” *Journal of Applied Behavior Analysis* 33, 1, 101-104.

Staats, H., P. Harland, & H.A.M. Wilke. 2004. “Effecting Durable Change: A Team Approach to Improve Environmental Behavior in the Household.” *Environment and Behavior* 36(3): 341–367.

Staats, H.J. & P. Harland. 1995. “The EcoTeam program in the Netherlands. Study 4: longitudinal study on the effects of the EcoTeam Program on environmental behavior and its psychological backgrounds.” Leiden, Netherlands: Centre for Energy and Environmental Research, Faculty of Social and Behavioural Sciences, Leiden University

Stein, L. 2004. “Final Report—California Display Pilot Technology Assessment.” Boulder, CO: Primen Inc.

Stern, P. C. 1992. “What psychology knows about energy conservation.” *American Psychologist* 47(10): 1224–1232.

Sullivan, Michael J. 2009. Using Experiments to Foster Innovation and Improve the Effectiveness of Energy Efficiency Programs, Freeman, Sullivan & Co., CIEE Behavior and Energy Program, Edward Vine, Program Manager [Electronic Version]. California Institute for Energy and Environment and the California Public Utilities Commission’s Energy Division, from http://ciee.ucop.edu/energyeff/behavior.html

Sulyma, Iris, Ken Tiedemann, Marc Pedersen, Mark Rebman, and Min Yu. 2008. “Experimental Evidence: A Residential Time of Use Pilot.” In *Proceedings of the ACEEE 2008 Summer Study on Energy Efficiency in Buildings,* 2: 292–304. Washington, D.C.: American Council for an Energy-Efficient Economy

Summit Blue. 2009. "Impact Evaluation of Positive Energy SMUD Pilot Study: Final Report." (May) Mary Klos, Principal Investigator. Boulder, CO: Summit Blue Consulting.

Taylor, T. and P. Schwarz. 1990. "The Long-Run Effects of a Time-of-Use Demand Charge." *The Rand Journal of Economics* 21(3): 431–445.

Taylor, T., P. Schwarz & J. Cochell 2005. "24/7 Hourly Response to Electricity Prices: Pricing with up to Eight Summer's Experience." *Journal of Regulatory Economics* 27(3): 235–2262.

Thinking Home v2.1 is here! 2009. Retrieved May 30, 2009, from http://alwaysthinking.com/thinkingHome.html.

Ueno, T., F. Sano, O. Saeki & K. Tsuji 2006b. "Effectiveness of an Energy Consumption Information System on Energy Savings in Residential Houses Based on Monitored Data." *Applied Energy* 83(8): 166–183.

Ueno, T., K. Tsuji & Y. Nakano. 2006a. "Effectiveness of Displaying Energy Consumption Data in Residential Buildings: To Know Is to Change." In *Proceedings of the ACEEE 2006 Summer Study on Energy Efficiency in Buildings*, 7: 264–277. Washington, D.C.: American Council for an Energy-Efficient Economy

Ueno, T., R. Inada, O. Saeki & K. Tsuji 2005. "Effectiveness of displaying energy consumption data in residential houses: Analysis on how the residents respond." In *Proceedings of the ECEEE 2005 Summer Study*, 6.100. European Council for Energy-Efficient Economy.

Valente, T.W. & D.V. Schuster. 2002. "The public health perspective for communicating environmental issues." In *New tools for environmental protection: education, information and voluntary measures*, eds. Dietz T and Stern PC, New Academic Press, Washington DC.

van Houwelingen, J. T. & W. F. van Raaij. 1989. "The effect of goal setting and daily electronic feedback on in-home energy use." *Journal of Consumer Research* 16, 98–105.

van Raaij, W. F. and T. M. M. Verhallen. 1983. "A Behavioral Model of Residential Energy Use." *Journal of Economic Psychology* 3(1): 39–63.

Waddams-Price, C. 2002. "Prepayment meters: the consumer perspective." *Energy Action* 86, 14-15. Norwich, UK: Centre for Competition and Regulation, University of East Anglia.

Wagner, James Au. 2009. Stanford Professor Wants to Link Smart Meter Data to Online Game [Electronic Version]. Earth2Tech, from http://earth2tech.com/2009/01/15/stanford-prof-wants-to-link-smart-meter-data-to-online-game/

Wang, K. and J. Swisher. 2006. "Are Smart Homes More Efficient? Energy Impact of California's Residential Automated Demand Response Program." In *Proceedings of the 2006 ACEEE Summer Study on Energy Efficiency in Buildings.* Washington, D.C.: American Council for an Energy-Efficient Economy.

Wechsler, David. 2009. May 13, 2009, In-depth Interview with David Wechsler, Energy Hub, VP Business Development.

Wilhite, H. & R. Ling. 1995. "Measured energy savings from a more informative energy bill." *Energy and Buildings* 22(2): 145–155.

Wilhite, H. 2007. "Will Efficient Technologies Save the World? A Call for New Thinking on the Ways that End-Use Technologies Affect Energy Using Practices." In *Proceedings of the ECEEE 2007 Summer Study*, 1.043. European Council for Energy-Efficient Economy.

Wilhite, H., A. Hoivik & J. Olsen. 1999. “Advances in the use of consumption feedback information in energy billing: the experiences of a Norwegian energy utility.” In *Proceedings of the ECEEE 1999 Summer Study*, 2: 02. European Council for Energy-Efficient Economy.

Wimberly, Jamie. 2009. EcoPinion: Green Words Gone Wrong. Washington, DC: Ecoalign. http://www.ecoalign.com/node/332

Winett, Richard A., Joseph W. Hatcher, T. Richard Fort, Ingrid N. Leckliter, Susan Q. Love, Anne W. Riley, and James F. Fishback. 1982. “The Effects of Videotape Modeling and Daily Feedback on Residential Electricity Conservation, Home Temperature and Humidity, Perceived Comfort, and Clothing Worn: Winter and Summer.” *Journal of Applied Behavior Analysis* 15 (3): 381-402.

Wolf, Gene. 2008. "It's So Much More Than a Smart Meter." *Transmission & Distribution World,* 60(4), D8-D11. (Document ID: 1477853431).

Wood, G. & M. Newborough. 2003. “Dynamic Energy-consumption Indicators for Domestic Appliances: Environment, Behaviour and Design.” *Energy and Buildings* 35(8): 821–841.

Wood, G. & M. Newborough. 2007a. “Energy-use Information Transfer for Intelligent Homes: Enabling Energy Conservation with Central and Local Displays.” *Energy and Buildings* 39(4): 495–503.

Wood, G. and M. Newborough. 2007b. Influencing User Behaviour with Energy Information Display Systems for Intelligent Homes. *International Journal of Energy Resources,* 31, 56-78.

York, D. and M. Kushler. 2005. *Exploring the Relationship Between Demand Response and Energy Efficiency: A Review of Experience and Discussion of Key Issues.* Report U052. Washington, D.C.: American Council for an Energy-Efficient Economy.

APPENDIX A: SUMMARY TABLE OF 57 FEEDBACK STUDIES

Study Number	Author, Year	Region	Utility	Feedback Type(s)	In-Home Device/ Mechanism	Goal/ Focus	Sample Size (N)	Overall Savings
1	Abrahamse et al. 2007	Europe (Groningen, Netherlands)	n.a.	Estimated Feedback	Internet-based Tool	OES	189 (137 HH received feedback, of those 66HH received a group goal)	5.1% (control group used 0.7% more energy)
2	Alcott 2009	United States (MN)	Connexus and OPOWER Pilot	Enhanced Billing	Uses Home Energy Reports	OES	Total = 78,492; 39,217 HHs received reports (60% received monthly reports, 40% received quarterly reports	1.9% monthly; 1.1% quarterly
3	Allen and Janda 2006	United States (OH)	n.a.	Real Time Feedback (Aggregated)	The Energy Detective	OES	60 (10 with meters) (4 low income and 6 upper income)	Not significant
4	Ayers et al. 2009	United States (WA)	Puget Sound OPOWER Pilot	Enhanced Billing	Home Energy Reports	OES	84,000 (35,000 received reports, 25,000 monthly, 10,000 quarterly)	1.2% (1.25% for monthly elec and 1.05% for quarterly electric; 1.2% reductions in therms for both monthly and quarterly)

Study Number	Author, Year	Region	Utility	Feedback Type(s)	In-Home Device/ Mechanism	Goal/ Focus	Sample Size (N)	Overall Savings
5	Battalio et al. 1979	United States (Texas)	not specified	Daily/Weekly Feedback	none	OES	107 (17 high rebate, 20 low rebate, 24 feedback, 20 information, 26 control)	11 and 12% for groups receiving feedback and rebates. No sig. savings for feedback only group.
6	Benders et al. 2006	Europe (Netherlands)	n.a.	Estimated Feedback	Web-based Tool	OES	190 (137 experimental group, 53 control group)	8.5% in direct energy consumption; change in indirect energy consumption not sig.
7	Bittle et al. 1979	United States (IL)	n.a.	Daily/Weekly Feedback	Feedback provided via cards left in the mailbox.	OES	30 (15 test, 15 control)	4%
8	Bittle et al. 1979-80	United States (IL)	n.a.	Daily/Weekly Feedback	Cards were left with information on daily consumption or cumulative consumption.	OES	353 HH received feedback, no control group	9.6% for high electricity consumers

Study Number	Author, Year	Region	Utility	Feedback Type(s)	In-Home Device/ Mechanism	Goal/ Focus	Sample Size (N)	Overall Savings
9	Brandon and Lewis 1999	Europe (UK)	n.a.	Daily/Weekly Feedback	Some participants had computer-based feedback	OES	120 (there were 6 experimental groups and a control group, not clear how many HHs in control)	4.3% reduction compared with pretest. 12% lower compared to control group.
10	Carroll et al. 2009a	United States (NV)	Nevada Power and Sierra Pacific Power	Real Time Feedback (Aggregated)	Several: Kill-A-Watt, PowerCost Monitor, TED, Whole House Energy Monitor, The Energy Joule, In-Home Display, Power Cost Display Monitor	OES	200 (not clear if there is a control group)	5.5% (ranged from 0 to 48%)
11	Carroll et al. 2009b and Parker et al. 2008	United States (FL)	Florida Solar Energy Center	Real Time Feedback (Aggregated)	The Energy Detective	OES	22 (17 in final analysis)	7.4% (Savings range: +9.5% to -27.9%)
12	Case et al. 2008 (power point presentation) and Faruqui 2009 (BG&E pilot)	United States (MD)	BG&E Smart Energy Pricing Pilot	Real Time Feedback (Aggregated)	Ambient Energy Orb	Peak/TOU	1500 (675 without orbs, 625 with orbs (375 of these also had AC switch technologies)	DPP+orb= -0.03%, PTRL+orb=0.5%, PTRH+orb=0.6%
13	Connecticut Light and Power 2009a and 2009b	United States (CT)	CL&P Rate Pilot and Meter Study	Real Time Feedback (Aggregated)	Some homes received an Energy Orb; others had a Power Cost Monitor	Peak/ TOU	1,114 residential plus 137 in the control group (only 307 received an IHD or Orb) and 1123 C&I plus 63 in control group (409 received an Orb)	For Residential: Total monthly consumption increased by 0.2% for PTP and decreased 0.2% for PTR and TOU

Study Number	Author, Year	Region	Utility	Feedback Type(s)	In-Home Device/ Mechanism	Goal/ Focus	Sample Size (N)	Overall Savings
14	Dobson and Griffin 1992	Canada (Ontario)	Ontario Hydro	Real Time Plus Feedback (Appliance or Sub Meter Level)	Residential Electricity Cost Speedometer (computer-based feedback)	OES	100 all-electric houses (25 received feedback device)	12.9%
15	Ehrhardt-Martinez 2009, Summit Blue 2009, ADM 2009 and Ayers et al. 2009 (Ayers study is for 12 month treatment)	United States (CA)	SMUD	Enhanced Billing	Enhanced billing / home energy reports	OES	85,000 (35,000 received Home Energy Reports)	1.9% (ADM); Ayers et al. found 2.35% for monthly and 1.5% for quarterly
16	Elliott et al. 2006	United States (CA)	SCE, SDG&E and PG&E; [CA Bill Analysis Pilot (Part of CA Statewide Pricing Pilot)]	Estimated Feedback	No in-home device, information via web and mail.	Peak/TOU	270 (152 received feedback, 118 control)	Not significant
17	Haakana 1997	Europe (Finland)	n.a.	Daily/Weekly Feedback [monthly feedback was provided]	energy meters were installed in 40 appliances, HHs filled out information and sent it to utility	OES	105 HHs (23 received feedback as video, 27 feedback in literature, 29 feedback, 26 control)	6% savings for district heating (3-9% range) while control group increased 1-2%, 17-21% decrease in electricity consumption

Study Number	Author, Year	Region	Utility	Feedback Type(s)	In-Home Device/ Mechanism	Goal/ Focus	Sample Size (N)	Overall Savings
18	Hayes and Cone 1977	United States (WV)	Monongahela Power Company	Daily/Weekly Feedback	No in-home device. Electric consumption was measured by a watt meter in the basement of each building. Cards were left in mailboxes.	OES	80 (4 received direct feedback)	33% from payments, 18% from daily feedback, 19% from information
19	Horst 2006	United States (MI)	Whirlpool Woodridge Study	Real Time Plus Feedback (Appliance or Sub Meter Level)	Whirlpool Energy Monitor	Peak/TOU	4	not measured
20	Hutton et al. 1986	Canada (Montreal and Vancouver) and United States (Dallas, TX and Vacaville, CA)	not specified	Real Time Feedback (Aggregated)	Energy Cost Indicator	OES	784 (280 received monitor (92 in Quebec, 93 in B.C. and 95 in CA)	4.1% compared to control group in Quebec, 5% compared to control group in B.C. (for natural gas only), no savings found in CA.
21	Hydro One Networks Inc 2008	Canada (Ontario)	Hydro One	Real Time Feedback (Aggregated)	Real Time in home Display Monitor (not specified)	Peak/TOU	486 (153 with TOU and display; 177 with TOU and no display; 81 with display but not TOU; 75 control)	3.3% with TOU rates (7.6% with in-home devices and TOU), 6.7% for HHs with display but not TOU

Study Number	Author, Year	Region	Utility	Feedback Type(s)	In-Home Device/ Mechanism	Goal/ Focus	Sample Size (N)	Overall Savings
22	IBM 2007	Canada (Ontario)	Ontario Energy Board Smart Price Pilot	Enhanced Billing	no in-home display, feedback provided through enhanced statements and via the web	Peak/TOU	498 (125 in control group, 124-TOU, 125-CPP, 124-CPR)	6% overall savings (conservation by group = 6% for TOU, 4.7% for CPP, 7.4% for critical peak rebate)
23	Kantola et al. 1984	Other (Australia)	n.a.	Daily/Weekly Feedback	No in-home device, participants were simply told that they had high levels of consumption.	OES	118 (31-dissonance, 32-feedback, 30-tips, 25-control)	3-14% depending on the treatment (11.3-13.8% for dissonance group) (3-3.7% for feedback group) (4-11.6% for tips)
24	Karbo and Larsen 2005	Europe (Denmark)	Danish Electricity Saving Trust and Energi Fyn	Real Time and Real Time Plus Feedback (Appliance or Sub Meter Level)	Combines Electronic Energy Advisor with feedback on the pattern of HH consumption	OES	3,000 HHs received household level meters while 50 received meters that provide appliance-level feedback	Expects savings of at least 10% in 95% of installations
25	Kasulis et al. 1981	United States (Oklahoma)	Edmond Municipal Electric Company	Enhanced Billing	none	Peak/TOU	420 (60 in the control group)	not specified .
26	MacLellan 2008 and Norton 2008	United States (MA)	National Grid, NSTAR, Western Mass. Elec. Co.	Real Time Feedback (Aggregated)	Blue Line Power Cost Monitor	OES	3,113 units were sold and 2,210 HHs set up the PCMs	3% from installed PCMs

Study Number	Author, Year	Region	Utility	Feedback Type(s)	In-Home Device/ Mechanism	Goal/ Focus	Sample Size (N)	Overall Savings
27	Martinez & Geltz 2005	United States (CA)	SCE, SDG&E and PG&E; Information Display Pilot	Real Time Feedback (Aggregated)	Energy Orb and customized electronic newsletter	Peak/TOU	32 residential customers and 29 commercial customers	Not specified
28	McClelland and Cook 1979 (see EPRI reference)	United States (NC)	Carolina Power and Light	Real Time Feedback (Aggregated)	Fitch Energy Monitors	OES	101 (25 with monitors)	12%
29	Mountain 2006	Canada (Peterborough, Timmins, Lincoln, Barrie)	Hydro One's Real Time Monitoring Pilot	Real Time Feedback (Aggregated)	Blue Line PCM	OES	424 (382 with monitors 42 control HHs)	6.5%
30	Mountain 2008	Canada (New Foundland)	New Foundland Power Natl Rural Elec. Coop. Assoc.	Real Time Feedback (Aggregated)	Blue Line PCM	OES	68 (58 with monitors, 10 control)	18.1%
31	Mountain 2008	Canada (BC)	BC Hydro	Real Time Feedback (Aggregated)	Blue Line PCM	OES	60 (43 with monitors, 17 control)	2.7%
32	Nielsen 1993	Europe (Denmark)	Danish Energy Agency and AKF	Enhanced Billing	n.a.	OES	1,500 (it is unclear how many HHs completed each year of the study; appears that there is no control group)	10% for single family HH, 1% for flats. (8% and 7% for groups 2 and 3)
33	Nolan et al. 2008	United States (CA)	SDG&E	Daily/Weekly Feedback	none—used doorhangers	OES	981 (371 had read the doorhangers and were included in the final study) (271 had meter readings)	10% during the month that door hangers were distributed (significant). 7% in the following month (not significant)

Study Number	Author, Year	Region	Utility	Feedback Type(s)	In-Home Device/ Mechanism	Goal/ Focus	Sample Size (N)	Overall Savings
34	Parker et al. 2006	United States (FL)	Florida Solar Energy Center	Real Time Feedback (Aggregated)	Energy Viewer and the Energy Detective	OES	2 case studies	as high as 56% using the feedback device as a diagnostic tool
35	Parker et al. 2008	United States (FL)	Florida Power and Light; Florida Solar Energy Center	Real Time Feedback (Aggregated)	The Energy Detective	OES	17 (opportunity sample) Data from the Florida Power and Light Company's 2 million HHs were used as a control group.	7% (weather adjusted savings ranged from an increase of 9.5% to a savings of 27.9%) 11 homes showed savings; six showed increases.
36	Peterson et al. 2007	United States (OH)	n.a.	Real Time Feedback (Aggregated)	Custom Wireless data monitoring system with web based interface	OES	18 dormitories	32%
37	Pruitt 2005	United States (AZ)	Salt River Project PowerWise Pilot	Real Time Feedback (Aggregated)	SRP M-Power Monitor	OES	2,600 (unclear whether participant were compared to a control group)	12.8% (13.8% in summer, 11.1% in winter)
38	Robinson 2007	Canada (Ontario)	Milton Hydro	Daily/Weekly Feedback	Participants had smart meters and TOU pricing but did not have in-home devices. Instead they filled out a form on a weekly basis.	Peak/TOU	106 (only 72 in treatment group)	0% saving associated with feedback—measured after TOU pricing was already in effect. i.e., no net impact of feedback

Study Number	Author, Year	Region	Utility	Feedback Type(s)	In-Home Device/ Mechanism	Goal/ Focus	Sample Size (N)	Overall Savings
39	Schultz et al. 2007	United States (CA)	n.a.	Daily/Weekly Feedback	Doorhangers	OES	290 (no control group, 1/2 of HHs received descriptive norm message and 1/2 received descriptive plus injunctive norm)	descriptive norm group = decline of 5.7% for HHs consuming above avg, increase of 7.9% for HHs consuming below avg. When injunctive norm was added low consumers remained low.
40	Scott 2008 and Sipe and Castor 2009	United States	not specified	Real Time Feedback (Aggregated)	Blue Line Power Cost Monitor	OES	370 (HER participants compared to HHs receiving audits in 2008, early adopters compared to a random sample of OR HHs)	Savings not significant
41	Seaver and Patterson 1976	United States (PA)	n.a.	Enhanced Billing	n.a.	OES	122 (42 in control group, 35 information feedback, 45 feedback plus reward)	not reported
42	Seligman et al. 1978	United States (NJ)	n.a.	Real Time Feedback	Blue light indicator of low outdoor temperature	OES	40 (20 received information feedback and 20 received blue light feedback)	15.7%
43	Seligman et al. 1978	United States (NJ)	n.a.	Daily/Weekly Feedback	cards at kitchen window	OES	29 (15 in test group, 14 in control)	10.5%

Study Number	Author, Year	Region	Utility	Feedback Type(s)	In-Home Device/ Mechanism	Goal/ Focus	Sample Size (N)	Overall Savings
44	Seligman et al. 1978 and Becker 1978	United States (NJ)	n.a.	Daily/Weekly Feedback	cards at kitchen window	OES	100 (40 received feedback and had goals, 40 received no feedback but had goals, 20 in control group)	13.0%
45	Sexton et al. 1987	United States (CA)	Southern California Edison	Real Time Feedback (Aggregated)	Continuous Display Electricity-Use Monitors	Peak/TOU	481 (68 received the in-home monitor)	electricity demand increased 5.5% overall and 12% in off-peak periods. Demand declined 1.2% during peak periods.
46	Staats et al. 2004	Europe (Netherlands)	n.a.	Enhanced Billing	n.a.	OES	150 who completed T1 and T2 questionnaire.	5% immediately following test period, 8% 2 years later (with no subsequent intervention)
47	Staats, Van Leeuwen and Wit 2000	Europe (Netherlands)	n.a.	Daily/Weekly Feedback	n.a.	OES	384 offices	6%
48	Sulyma et al. 2008	Canada (British Columbia)	BC Hydro Power Smart Program	Real Time Feedback (Aggregated)	Blue line Monitors	Peak/TOU	2000 (307 received the Blue Line Display Monitor)	8.6%
49	Ueno et al. 2006a	Other (Japan)	n.a.	Real Time Plus Feedback (Appliance or Sub Meter Level)	Online Energy Consumption Information System	OES	9	9%

Study Number	Author, Year	Region	Utility	Feedback Type(s)	In-Home Device/ Mechanism	Goal/ Focus	Sample Size (N)	Overall Savings
50	Ueno et al. 2006b	Other (Japan)	n.a.	Real Time Plus Feedback (Appliance or Sub Meter Level)	Online Energy Consumption Information System	OES	19 (information terminals installed in 10 houses)	12% [Total electric consumption decreased by 18%, total gas consumption decreased by 9%]
51	van houwellingen 1989	Europe (Netherlands)	not specified	Real Time Feedback (Aggregated)	The Indicator	OES	325 (50 received displays 55 received monthly external feedback, 55 received self-monitoring chart, 55 received information about conservation, 55 in control group c2, 55 in control group c3)	HH w/display:12.3%, HH w/monthly feedback: 7.7%, HH that self monitored: 5.1%, HH w/info only: 4.3%
52	Wilhite and Ling 1995	Europe (Norway)	Oslo Energi	Enhanced Billing	n.a.	OES	1,286, it isn't clear how many were in control group, there was also attrition over the 3 yrs of the study	7.6% after 1st year 10% after 2nd year
53	Wilhite et al. 1999	Europe (Norway)	Oslo Energi and Stavanger Energi	Enhanced Billing	n.a.	OES	2,000	n.a.

Study Number	Author, Year	Region	Utility	Feedback Type(s)	In-Home Device/ Mechanism	Goal/ Focus	Sample Size (N)	Overall Savings
54	Wilhite et al. 1999	Europe (Norway)	Stavanger Energi	Enhanced Billing	n.a.	OES	2,000 participants were later compared to the broader population	8% after 2 years (participants reduced electricity consumption 4% while non-participants increased use 4%)
55	Winett et al. 1982 [Summer]	United States (VA)	n.a.	Daily/Weekly Feedback	n.a.	OES	54 (19 control, 35 treatment)	Summer Savings:15% for electricity, 34% for electricity for cooling
56	Winett et al. 1982 [Winter]	United States (VA)	n.a.	Daily/Weekly Feedback	n.a.	OES	83 (20 control, 63 treatment)	Winter Savings: 15% for electricity 25% for heating.
57	Wood and Newborough 2003	Europe (UK)	n.a.	Real Time Plus Feedback (Appliance or Sub Meter Level)	Energy Consumption Indicator (provides appliance specific info at time of use as well as weekly totals)	OES	44 (12 control, 12 information,10 feedback, 10 feedback & info)	15% (31 HHs saved more than 10%, 6 HHs saved more than 20%)

APPENDIX B: SUMMARY TABLE OF PERSISTENCE FINDINGS FROM 28 FEEDBACK STUDIES

Author, Year	Region	Feedback Type(s)	Overall Savings	Persistence Findings
Alcott 2009	United States (MN)	Enhanced Billing	1.9% monthly; 1.1% quarterly	Energy savings are found to persist over the duration of the study for HHs receiving monthly HERs. Energy savings among HHs receiving quarterly reports was found to decay somewhat in the months between reports, either because the information decays seasonally or because the reminder or motivational effects of the report decay over time.
Ayers et al. 2009	United States (WA)	Enhanced Billing	1.2% (1.25% for monthly elec and 1.05% for quarterly electric; 1.2% reductions in therms for both monthly and quarterly)	Energy savings appeared consistent over the course of the study.
Bittle et al. 1979	United States (IL)	Daily/Weekly Feedback	4%	Persistence was tested by assessing energy savings 3.5 weeks after feedback had been stopped. Average energy savings within the group of 15 HHs increased during the 3.5 weeks from 4% to 10%. (Small sample size makes it difficult to draw generalizable conclusions.)
Carroll et al. 2009a	United States (NV)	Real Time Feedback (Aggregated)	5.5% (ranged from 0 to 48%)	Savings persisted over the 6 month study for 85% of participants.
Dobson and Griffin 1992	Canada (Ontario)	Real Time Plus Feedback (Appliance or Sub Meter Level)	12.9%	Energy savings were stable and persistent of the 60 days following the installation of the in-home device.

Author, Year	Region	Feedback Type(s)	Overall Savings	Persistence Findings
Ehrhardt-Martinez 2009, Summit Blue 2009, ADM 2009 and Ayers et al. 2009 (Ayers study is for 12 month treatment)	United States (CA)	Enhanced Billing	1.9% (ADM); Ayers et al. found 2.35% for monthly and 1.5% for quarterly	Ayers: Energy savings were persistent; there was a significant decline in energy usage for the treatment group relative to the control group for all the months following the initial report mailing.
Haakana 1997	Europe (Finland)	Daily/Weekly Feedback [monthly feedback was provided]	6% savings for district heating (3-9% range) while control group increased 1-2%, 17-21% decrease in electricity consumption	Electricity savings persisted but were somewhat diminished in the second year. It isn't clear whether feedback continued in year two.
Hutton et al. 1986	Canada (Montreal and Vancouver) and United States (Dallas, TX and Vacaville, CA)	Real Time Feedback (Aggregated)	4.1% compared to control group in Quebec, 5% compared to control group in B.C. (for natural gas only), no savings found in CA.	Use of the feedback device declined over the course of the first few months of deployment. Persistence of energy savings was not assessed.
Kantola et al. 1984	Other (Australia)	Daily/Weekly Feedback	3-14% depending on the treatment (11.3-13.8% for dissonance group) (3-3.7% for feedback group) (4-11.6% for tips)	Savings persisted over the four weeks for the group that received feedback and also received the "cognitive dissonance message" Savings did not persist for the feedback only group. An important note is that feedback was not ongoing. The intervention consisted of a single instance of feedback.

Author, Year	Region	Feedback Type(s)	Overall Savings	Persistence Findings
MacLellan 2008 and Norton 2008	United States (MA)	Real Time Feedback (Aggregated)	2.9% average savings (range from 1.4 to 4.4%); avg savings from installed PCM=2.9%; average savings from distributed PCM = 1.9 to 2.9%	Participants were asked about their energy use behavior before using the PCM, immediately after using it, 2 to 6 months after receiving the PCM (Phase 1 survey) and 8 to 12 months after receiving the PCM (Phase 2 survey). In the Phase 1 survey 48% of HHs reported taking all of the steps taken since first receiving the PCM while 38% reported taking most of the steps. In the Phase 2 survey, 60% of HHs reported taking all of the steps taken since first receiving the PCM while 33% reported taking most of the steps. In terms of persistence of use of the PCM 73% of HHs who received the device reported using it (some people had installation problems) At the time of the Phase 1 and Phase 2 surveys use had declined to 49% and 34%. The frequency of looking at the PCM also declined over time. After first use 92% reported looking at the PCM once or more per day. This rate declined to 49% at the phase 1 survey and 32% at phase 2. Energy savings were only estimated on an annual basis.
McClelland and Cook 1979 (see EPRI reference)	United States (NC)	Real Time Feedback (Aggregated)	12%	Monitors are associated with lower consumption in all 11 months. The differences neither increase nor decrease over time, averaging about 12%, but do tend to be larger in low-consumption months. This suggests that the conservation actions taken by households with monitors primarily affected energy uses other than heating and cooling.
Mountain 2006	Canada (Peterborough, Timmins, Lincoln, Barrie)	Real Time Feedback (Aggregated)	6.5%	The results indicated that there was no reduction in conservation response throughout the duration of the study. In addition, 65% of survey respondents indicated that they planned to continue using the device in the future.
Mountain 2008	Canada (New Foundland)	Real Time Feedback (Aggregated)	18.1%	The results indicated that there was no reduction in conservation response throughout the duration of the study.
Mountain 2008	Canada (BC)	Real Time Feedback (Aggregated)	2.7%	The results indicated that there was no reduction in conservation response throughout the duration of the study.

Author, Year	Region	Feedback Type(s)	Overall Savings	Persistence Findings
Nielsen 1993	Europe (Denmark)	Enhanced Billing	10% for single family HH, 1% for flats. (8% and 7% for groups 2 and 3)	Savings appeared fairly consistent over the entire study for single family households. Savings in years 1-3 were 9, 10 and 11% for households receiving all measures; 7, 8 and 9% for HHs receiving all measures except consultant visit; and 6, 7 and 9% for all measures except tariff increases.
Nolan et al. 2008	United States (CA)	Daily/Weekly Feedback	10% during the month that door hangers were distributed (significant). 7% in the following month (not significant)	The effects of the normative feedback were significantly different from a combined measure of energy consumption from the nonnormative feedback groups after one month but not statistically significant after two months. Unfortunately because of the design of the study, the savings of the normative feedback group were not compared for significant differences with the control group, so it is not possible to say if they persisted over time. However, energy use within the normative feedback group remained consistently lower than the other groups at the end of the first and second measurement periods.
Peterson et al. 2007	United States (OH)	Real Time Feedback (Aggregated)	32%	Despite significantly warmer and brighter days, the average rate of dormitory electricity consumption during the post-competition period was similar to consumption levels during the competition period (241 vs 250 W/person, respectively). When the competition period ended, all advertising ceased and the lobby monitors were removed. However, real-time electricity consumption data continued to be updated on the dormitory Energy web site during the post-competition period and interest in the real-time data on the web remained high. During this two-week period the web site received a total of 1,187 hits (29% as much interest as during the competition).

Author, Year	Region	Feedback Type(s)	Overall Savings	Persistence Findings
Schultz et al. 2007	United States (CA)	Daily/Weekly Feedback	descriptive norm group = decline of 5.7% for HHs consuming above avg, increase of 7.9% for HHs consuming below avg. When injunctive norm was added low consumers remained low.	For households that initially consumed more energy than the neighborhood average, the combined descriptive-plus-injunctive feedback continued to produce a significant decrease in energy consumption relative to the baseline. For HHs that were consuming less than the average, the combined injunctive and descriptive norm maintained energy consumption at low levels.
Scott 2008 and Sipe and Castor 2009	United States	Real Time Feedback (Aggregated)	Savings not significant	66% of respondent reported using the energy monitor 6 months after its installation. While energy monitor use shows persistence, energy bill analysis indicates that the energy savings between groups were not significant at any of the three time periods measured 3, 6 and 9 months.
Sexton et al. 1987	United States (CA)	Real Time Feedback (Aggregated)	electricity demand increased 5.5% overall and 12% in off-peak periods. Demand declined 1.2% during peak periods.	Total KWh usage rose relative to nonmonitor HHs in 9 of the 10 months. Nearly all of the increase occurred in off-peak periods. Peak use declined in 6 of the 10 months resulting in a 1.2% average decrease in peak use.
Staats et al. 2004	Europe (Netherlands)	Enhanced Billing	5% immediately following test period, 8% 2 years later (with no subsequent intervention)	This study is focused on trying to understand the persistence of behavior change. It explores the use of Eco Teams to help participants internalize the motivation to partake in sustainable behaviors. The study reports on 38 different measures and finds that 19 changed in a proenvironmental direction (including energy use) at the end of the ETP. Moreover, these changes were retained or increased further during the subsequent 2 years. In terms of electricity, consumption was reduced by 4.6% after the 8 month intervention (but was not statistically significant) and by 7.6% (compared to the baseline) after 24 months (with no subsequent intervention).

Author, Year	Region	Feedback Type(s)	Overall Savings	Persistence Findings
Staats, Van Leeuwen and Wit 2000	Europe (Netherlands)	Daily/Weekly Feedback	6%	Short-term effects were assessed weekly and long-term effects were assessed 1 year after each of the two intervention periods. Improvements were observed in each intervention period with partial behavior maintenance 1 year later. Findings suggest the programs capacity to correct relapses in earlier pro-environmental behavior through continued feedback.
Ueno et al. 2006b	Other (Japan)	Real Time Plus Feedback (Appliance or Sub Meter Level)	12% [Total electric consumption decreased by 18%, total gas consumption decreased by 9%]	The number of keystrokes associated with the use of the in-home display were measured after eight months. Participants continued to check the monitor although less frequently. There isn't a clear relationship between monitor use and energy savings.
van houwellingen 1989	Europe (Netherlands)	Real Time Feedback (Aggregated)	HH w/display:12.3%, HH w/monthly feedback: 7.7%, HH that self monitored: 5.1%, HH w/info only: 4.3%	Monitors were removed after the one year experimental period. Energy use was measured during the 12 months following the intervention. The declines in energy use observed during the intervention period did not persist after the monitors were removed. Feedback only had an effect during the period that feedback was given. No long-term (habit formation or internalization) effect of feedback was found.
Wilhite and Ling 1995	Europe (Norway)	Enhanced Billing	7.6% after 1st year 10% after 2nd year	Experimental groups consumed 10% less electricity than the control group after year three—up from 7.6% at the end of year two.

Author, Year	Region	Feedback Type(s)	Overall Savings	Persistence Findings
Wilhite et al. 1999	Europe (Norway)	Enhanced Billing	8% after 2 years (participants reduced electricity consumption 4% while non-participants increased use 4%)	Darby (2006) reports that a review of billing in the Nordic countries found that the longer the duration of a trial and the more information available to the customer, the more persistent the effects were likely to be (Henryson et al. 2000). Darby concludes that "regular reminders of consumption can be a continuing influence, as well as reducing consumption in the first instance."
Winett et al. 1982 [Summer]	United States (VA)	Daily/Weekly Feedback	Summer Savings:15% for electricity, 34% for electricity for cooling	During the 10 week period following the intervention savings persisted. The group that received feedback only reduced consumption by 29% compared to the control group which reduced consumption by 11% (an 18% net savings). The group that received feedback and modeling reduced consumption by 37% compared to control group savings of 11% (a net savings of 26%). Net energy savings during the intervention period were 2% for the control group, 12% for the modeling group, 19% for the feedback only group, and 22% for the feedback+ modeling group. Albeit small samples and short follow up periods.
Winett et al. 1982 [Winter]	United States (VA)	Daily/Weekly Feedback	Winter Savings: 15% for electricity 25% for heating.	During the 6 months following the intervention there was persistence for the group that received feedback and modeling but not for the feedback only group. When compared to the control group, energy consumption for the feedback+ modeling group was 16% lower during the post-intervention period. This compares to net savings of 17% during the intervention period when compared with the control group.

APPENDIX C: SUMMARY TABLE OF DEMAND RESPONSE AND OVERALL SAVINGS FROM 11 FEEDBACK STUDIES

Author, Year	Feedback Type(s)	Overall Savings	OES	Region	Utility	Vintage of Study	Peak Savings	Sample Size (N)	Duration (months)
Case et al. 2008 (power point presentation) and Faruqui 2009 (BG&E pilot)	Real Time Feedback (Aggregated)	DPP+orb= -0.03%, PTRL+orb=0.5%, PTRH+orb=0.6%	0.005	United States (Maryland)	BG&E Smart Energy Pricing Pilot	June - Sept. 2008	17-33% (17-20% ,without the orb, 23-33% with the orb) DPP = 20.1%, DPP+orb+switching = 32.5%; PTRL=17.8%, PTRL+orb=23%, PTRL+orb+switch= 28.5%; PTRH=21%, PTRH+Orb=27%, PTRH+orb+switch=33%	Case et al. 2008 (power point presentation) and Faruqui 2009 (BG&E pilot)	Real Time Feedback (Aggregated)
Connecticut Light and Power 2009a and 2009b	Real Time Feedback (Aggregated)	For Residential: Total monthly consumption increased by 0.2% for PTP and decreased 0.2% for PTR and TOU	0.002	United States (CT)	CL&P Rate Pilot and Meter Study	June - Aug 2009	For Residential TOU= 1.6 to 3.1% PTR=7.0 to 17.8% PTP+102 to 23.3%	Connecticut Light and Power 2009a and 2009b	Real Time Feedback (Aggregated)
Elliott et al. 2006	Estimated Feedback	The percentage savings was not reported, however OES was found to be significant on weekends.		United States (CA)	SCE, SDG&E and PG&E; [CA Bill Analysis Pilot (Part of CA Statewide Pricing Pilot)]	2005	not significant	Elliott et al. 2006	Estimated Feedback
Horst 2006	Real Time Plus Feedback (Appliance or Sub Meter Level)	not measured		United States (MI)	Whirlpool Woodridge Study	2006	unclear	Horst 2006	Real Time Plus Feedback (Appliance or Sub Meter Level)
Hydro One Networks Inc 2008	Real Time Feedback (Aggregated)	3.3% with TOU rates (7.6% with in-home devices and TOU), 6.7% for HHs with display but not TOU	0.067	Canada (Ontario)	Hydro One	May-Sept 2007	3.7% for TOU group, 5.5% with in-home device + TOU (8.5% on a hot summer day)	Hydro One Networks Inc 2008	Real Time Feedback (Aggregated)
IBM 2007	Enhanced Billing	6% overall savings (conservation by group = 6% for TOU, 4.7% for CPP, 7.4% for critical peak rebate)	0.06	Canada (Ontario)	Ontario Energy Board Smart Price Pilot	Aug 2006 - Feb 2007	10-28% summer peak load savings but savings for TOU group were not significant.	IBM 2007	Enhanced Billing

Author, Year	Feedback Type(s)	Overall Savings	OES	Region	Utility	Vintage of Study	Peak Savings	Sample Size (N)	Duration (months)
Kasulis et al. 1981	Enhanced Billing	not specified .		United States (Oklahoma)	Edmond Municipal Electric Company	1977-1978	not specified.	Kasulis et al. 1981	Enhanced Billing
Martinez & Geltz 2005	Real Time Feedback (Aggregated)	Not specified		United States (CA)	SCE, SDG&E and PG&E; Information Display Pilot	Aug - Oct 2004	Savings above and beyond price structure were reported but not found to be statistically significant	Martinez & Geltz 2005	Real Time Feedback (Aggregated)
Robinson 2007	Daily/Weekly Feedback	0% saving associated with feedback—measured after TOU pricing was already in effect. i.e., no net impact of feedback	0	Canada (Ontario)	Milton Hydro	July-Oct 2006	not reported	Robinson 2007	Daily/Weekly Feedback
Sexton et al. 1987	Real Time Feedback (Aggregated)	electricity demand increased 5.5% overall and 12% in off-peak periods. Demand declined 1.2% during peak periods.	-0.055	United States (CA)	Southern California Edison	May 1979 - March 1981	0.012	Sexton et al. 1987	Real Time Feedback (Aggregated)
Sulyma et al. 2008	Real Time Feedback (Aggregated)	0.086	0.086	Canada (British Columbia)	BC Hydro Power Smart Program	2006-07	0.096	Sulyma et al. 2008	Real Time Feedback (Aggregated)