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Residential Electricity Use Feedback: A Research Synthesis and Economic Framework

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PRODUCT DESCRIPTION

This report provides a synthesis of research relating to household electricity consumption feedback, both past and ongoing. The key findings of past summary studies are presented, and the areas that require further research are examined in detail. The report also proposes an economic framework that can provide the basis for further empirical research to comprehensively address various outstanding research gaps. Going forward, a research collaboration proposal is outlined that will allow for the characterization of the cost and benefits attributable to providing households with electricity consumption feedback information.

Results and Findings

Research findings suggest that residential electricity use feedback can be an effective tool in encouraging conservation. EPRI reviewed several past studies and found overall conservation effects that ranged from being negative (in one case, although on-peak reduction did occur) to 18%. This wide range suggests that there is more to be understood about feedback before its impacts are widely accepted. Research areas requiring additional focus relate to study participation levels, the persistence of feedback effects, the relative value of different types of feedback, dynamic pricing interactions, and distinguishing the effects of feedback among different demographic groups. Current utility research activity will address many of these areas, but it is difficult for any one utility to address all of them. A proposal is outlined to develop a widespread research collaborative to fully characterize how feedback affects residential electricity consumption.

Challenges and Objectives

This report moves the feedback debate along by helping readers to understand the concerns that utilities, regulators, and customers may have about feedback. This is important because regulators and utilities rely on cost-benefit analyses to direct their investments, which can be substantial and irreversible in the case of feedback. From a customer perspective, households should be provided with conservation tools that improve their ability to manage their resources; these tools should be suitable to a wide range of needs and circumstances, and their benefits should be equitably distributed.

This report will be of value to personnel at utilities and organizations poised to embark on new feedback-related research. By understanding key research areas that require resolution, and through the proposed collaborative research approach, research and investment dollars can be leveraged across multiple collaborators.

Applications, Value, and Use

Several feedback research initiatives are underway, others are being designed, and still others are being contemplated. Moreover, the rollout of advanced metering in some markets creates new opportunities to broaden the scale and scope of the research. Evaluated in isolation, they may contribute only marginally to the full and widely accepted characterization of feedback mechanisms and how these mechanisms affect household electricity consumption. Alternatively, if coordinated, they can provide the information needed for all parties to competently characterize the cost and benefits attributable to providing households with electricity consumption feedback information.

EPRI Perspective
Given its network of utility members and other key players in the utility industry, the Electric Power Research Institute (EPRI) is uniquely positioned both to stay current with ongoing feedback-related research activity and to coordinate the proposed collaborative research agenda.

Approach
The goal of this report was to document the existing state of feedback research and to develop a way to address outstanding research questions. This was accomplished by considering the issue of feedback from both behavior science and economic theoretical perspectives. Past empirical work (mostly from the behavior science literature) and current research activity were reviewed. An economic framework is detailed that can provide the basis for further research to comprehensively address various outstanding research gaps.

Keywords
Advanced metering infrastructure (AMI)
Behavior
Conservation
Feedback
Energy display device
Residential

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EXECUTIVE SUMMARY

Research findings suggest that residential electricity use feedback can be an effective tool in encouraging conservation. EPRI reviewed several past studies and found overall conservation effects that ranged from being negative (in one case, although on-peak reduction did occur) to 18%. This wide range suggests that there is more to be understood about feedback before its impacts are widely accepted. Research areas requiring additional focus relate to study participation levels, the persistence of feedback effects, the relative value of different types of feedback, dynamic pricing interactions, and distinguishing the effects of feedback among different demographic groups. Current utility research activity will address many of these areas, but it is difficult for any one utility to address all of them. A proposal is outlined to develop a widespread research collaborative to fully characterize how feedback affects residential electricity consumption.

Background

Many of today's pressing issues support the need for improved levels of efficiency and conservation, including climate change concerns and power generation and delivery constraints. Several studies have suggested that household-specific electricity consumption feedback information can be an effective tool in encouraging conservation. Considering as well the advent of new technologies that allow for greater ease of feedback provision, there are many compelling reasons that the topic of feedback is receiving much attention of late.

So why isn't everyone incorporating feedback into their efficiency programs? Although the answer to this question is multifaceted, EPRI wants to contribute to its resolution from the perspective of ongoing research requirements. Our intention is not to slow progress by calling for more research; rather, we want to move the feedback debate along by aiding in understanding the concerns that utilities, regulators, and customers may have about feedback. This is important because regulators and utilities rely on cost-benefit analyses to direct their investments, which can be substantial and irreversible in the case of feedback. From a customer perspective, households should be provided with conservation tools that improve their ability to manage their resources; these tools should be suitable to a wide range of needs and circumstances, and their benefits should be equitably distributed.

One definition for *feedback* is "the transmission of evaluative or corrective information about an action, event, or process to the original or controlling source" (Feedback 2009). This report, which focuses on the residential sector, further defines *feedback* as household-specific electricity consumption information.

Two Perspectives

This report considers the topic of feedback from two theoretical perspectives on how consumers make consumption decisions and the role of information in that decision process—one derived from behavioral sciences and the other from economics.

Each of these disciplines is multifaceted, containing many disparate branches. The behavior science and economic perspectives are fundamentally different ways of looking at the issue of feedback from a behavioral perspective. Both have much to offer in creating a foundation for a research agenda to resolve the questions and uncertainties surrounding the effects of how feedback influences household electricity consumption.

Feedback Categorization

Feedback can take several forms, ranging from the standard monthly electricity bill to real-time appliance-disaggregated consumption information presented through a user portal or interface. As a way to categorize feedback research, a feedback delivery mechanism spectrum was devised by EPRI (Figure ES-1). Its categories range from 1 to 6. The first four categories represent *indirect feedback*, or feedback that is provided sometime after consumption occurs. The last two represent *direct feedback*, or feedback that is provided real-time or near-real-time.

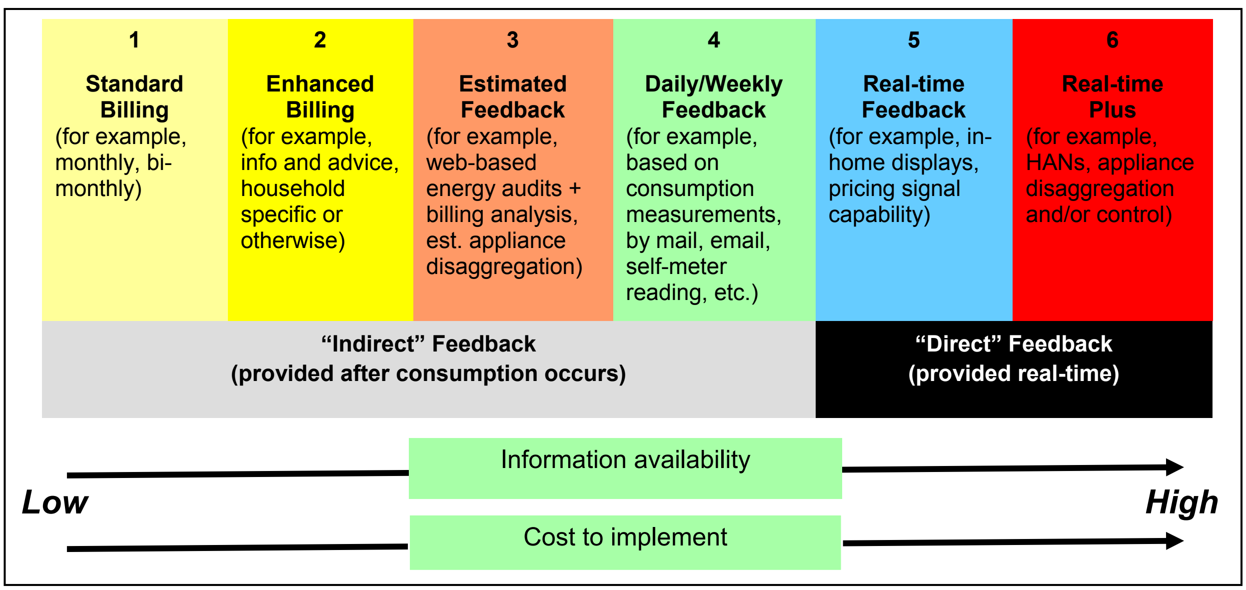

Figure ES-1
Feedback delivery mechanism spectrum

Past Feedback Research: Findings

A behavior science theoretical perspective shaped much of the early research on describing and measuring how feedback processes work and is the focus of considerable academic research.

Several overviews of the body of feedback research from the past 30 years have been recently performed, and most have supported the notion that feedback can be effective in encouraging electricity conservation. One often-cited summary study indicates that direct feedback consumption savings can be in the 5 to 15% range; indirect feedback studies showed consumption savings up to 10% (Darby 2006).

With regard to criteria for effective feedback, a number of themes emerge from these and other summary studies (Darby 2000, Fischer 2007, IPSOS Mori 2007, Abrahamse et al., 2005) on the factors that influence feedback impacts. Feedback is more effective in the following circumstances:

- It is provided frequently, as soon after the consumption behavior as possible.
- It is clearly and simply presented.
- It is customized to the household's specific circumstances.
- It is provided relative to a meaningful standard of comparison.
- It is provided over an extended period of time.
- It includes appliance-specific consumption breakdown (some studies).
- It is interactive (some studies).

Past Feedback Research: Gaps

Aided by the feedback delivery mechanism spectrum (shown in Figure ES-1) and other recent studies (Wood and Newborough 2007, Elburg 2008, Parker 2008), existing feedback research gaps were examined using the results of more than 30 pilot programs and research initiatives, both past and ongoing.

From 31 past research studies examined, the further study required can be categorized into five main areas:

- **Participation.** The studies have employed a large range of sample sizes. The largest have involved enhanced billing and energy display devices. A better understanding of the effects of feedback on specific demographic groups is required, which has sample design selection implications.
- **Feedback delivery mechanism distinction.** The most thorough analyses have involved enhanced billing and direct energy displays. However, more research is required to assess the relative effects between different feedback types, particularly across different demographic groups, as lower levels of feedback might be more cost effective.
- **Persistence.** Some of the studies provide indications that feedback persistence can occur. The best evidence comes from studies involving enhanced billing and energy display devices, although in the case of the former, results may not be generalizable to the North American context. In addition, study durations should be long enough to distinguish between persistence and seasonal effects. Finally, results from ongoing research that indicate that a large percentage of households stop using their display devices over time need to be reconciled against past study results that suggest conservation effect persistence.
- **Price.** Although relatively few in number, some studies support the notion that feedback provided in conjunction with dynamic pricing can have an incremental effect on peak

reduction in the 0–2% range. Preliminary results from ongoing research suggest that the percentage could be higher. More work is required to better assess the effects on overall consumption reduction, as at least one study provides evidence that feedback can increase overall consumption while reducing peak consumption. Related to this, a better understanding is required of the relationship between the types of information provided (for example, price signal provision versus energy consumption values) and the resulting effects.

- **Demographics.** Several studies have revealed insightful information about the effects of income, education levels, and household occupant age on the potential effectiveness of feedback. Some tenuous trends have emerged, but these need to be more thoroughly verified.

Ongoing Feedback Research

Several utilities and researchers (Table ES-1) are engaged in ongoing research to address some of the limitations of past research as well as issues that are specific to their jurisdictions. Many of the utility pilots will help to resolve some of these limitations identified, particularly regarding participation rates and the persistence question. However, fewer studies are assessing the areas of feedback comparisons, pricing and feedback interactions, and demographic associations; these areas require more work.

Table ES-1
Recent and ongoing pilot summaries

14 Ongoing Utility Pilots	
Baltimore Gas & Electric	NV Energy
Dominion Virginia Power	OFGEM (UK)
Duke Energy	Omaha Public Power District
Energy Trust of Oregon	SaskPower
Focus on Energy Wisconsin	Sacramento Municipal Utility District
Hydro One	TXU
National Grid, NSTAR, W. Mass. Electric	We Energies
Academic and Research Institutes	
Florida Solar Energy Center (FSEC)	Rutgers University
Georgia Institute of Technology	Stanford University
Massachusetts Institute of Technology	University of Waterloo

An Economic Model of Feedback Impacts

An economic model was constructed to characterize how feedback influences household expenditure decisions. It provides insight into how feedback impacts can be measured, as follows:

- In the absence of a good understanding of how electricity use translates to the services provided by household appliances and equipment, consumers are constantly spending more or less than they had planned. Unfulfilled expectations have adverse consequences for balancing overall expenditures on electricity and other household expenditure categories.
- Feedback helps consumers equate budgeted expenditures with actual bills. The nature of the adjustment depends on the uncertainty about when and how electric services are used. Feedback helps to resolve this uncertainty, and the result can be a decrease in overall electricity expenditures (that is, savings are reallocated to other goods and services), an increase in overall electricity expenditures (that is, more is spent on electricity at the expense of other goods and service), or a realignment of how electricity is used with no overall change in total usage (that is, greater satisfaction from the electricity expenditure). It is important that all of these possible responses be accounted for in pilots to ensure that the full and proper effects are measured.
- Initial (short-run) adjustments to information involve the more efficient use of existing appliance stock. This may somewhat limit the initial impact of feedback.
- In the longer run, capital expenditures on more efficient appliances may be accelerated (that is, undertaken sooner) or augmented (that is, appliances purchased have a higher efficiency than would otherwise have been the case) when feedback is provided to households. This is another reason to conduct extended pilots to ensure that the full impacts of an information treatment are captured.
- There may be other sources of information that could influence the nature of appliance capital expenditures (for example, Energy Star labeling and utility promotions). It is therefore critical to separate these influences from those associated with feedback so that conservation effects are not double counted.
- Causal associations may exist between households that respond to feedback and those that have undertaken conservation measures (for example, sealing doors and windows or installing more efficient florescent lights). Feedback may complement or supplement other conservation programs, or it may be a substitute for subsidizing energy efficiency measures.
- Price effects can and should be distinguished from feedback effects to ensure that policy actions produce predictable results.

These findings provide direction for the design and evaluation of pilots' impacts to ensure that feedback impacts are fully and separately measured.

Moving Forward: Design and Data Requirements

To fully characterize the effect of feedback on household electricity consumption, several pilot design and experimental recommendations can be made. Some of these include the following:

- To capture the *intra-household-inter-appliance* substitutions and cancellations, the experimental design must focus on individual households and appliance-specific and time-of-day usage.
- The pilot should be designed to affirm overall energy and demand effects in sufficient detail to comport with conventional program benefit measurement protocols, such as the cost-

effectiveness tests typically applied to energy efficiency measures and demand response programs.

- Fully disentangling the combined effects of price and feedback requires an experimental design that includes at least three groups: a control group—no time-differentiated prices and no feedback, a group with only time-differentiated prices, and one with both. If the decision is between implementing a new pricing regime and providing feedback, knowing the difference in the character and level of changes in usage is critical.
- Priority should be given to collecting demographic information on study participants, such as household size, ages of occupants, and education levels as well as some information on income, expenditures for energy and other major categories, and so on. It is also critical to obtain detailed information about the structure, such as size, age, type of construction, dwelling type (for example, single- or multi-family), heating fuel type, and recent investments in conservation measures.
- Pilots should be conducted for a sufficiently long period to establish persistence. Changes observed in a pilot of only one year may be associated in part with seasonal effects or other influences.
- Where possible, pilots should include different types of feedback delivery mechanisms so that the relative cost/benefit of both can be properly compared.
- Care must be taken to select control and treatment groups that are both representative of the customer population and sufficiently large for the empirical results to have statistical validity.

A Collaboration Proposal

It seems unlikely that any single utility can implement an experimental design to account for the interaction among all the factors described previously. However, a series of coordinated pilots can produce the full set of information required, going beyond what any individual pilot can accommodate.

A comprehensive resolution of all outstanding issues can be achieved through a cooperative and coordinated effort by many utilities across the country:

- Cooperation provides the means for sharing information quickly and effectively. Those with firsthand experience from pilots and other research initiatives can assist others who are at the discovery stage.
- Collaboration provides a way to share the field trials and costs of characterizing the many facets of how feedback information influences household electricity usage. Several individual pilots that are launched under the umbrella of a unified design approach will provide data that address different issues of local importance and will at the same time contribute to the overall understanding of how feedback mechanisms work over diverse customer, technology, and market circumstances. Each individual pilot investment will yield returns beyond what would have occurred had they been conducted in isolation.
- A collaborative and cooperative approach would provide a pool of data that will accelerate the full range of research needed to justify expenditures on technology, devices, and systems.

An effective consortium would be organized around three key functional services:

- A web site would serve as directory for finding information on research results and provide up-to-date information on ongoing and planned initiatives. Such an effort would complement existing repository web sites such as the behavioral research bibliographic database administered by Stanford University's Precourt Institute for Energy Efficiency.[1]
- Web casts, workshops, and forums would be sponsored to bring practitioners and researchers together to share experience and address topical issues.
- A research data repository would be developed to contain data from pilots and experiments. This would provide program designers with a way to evaluate how well the various mechanisms work under a variety of conditions.

The need for a consortium of utilities to address common issues relating to the value of feedback is pressing. Several pilots are now underway, others are being designed, and still others are being contemplated. Moreover, the rollout of advanced metering in some markets creates new opportunities to broaden the scale and scope of the research. Evaluated in isolation, they may contribute only marginally to the full and widely accepted characterization of feedback mechanisms and how these mechanisms affect household electricity consumption. Alternatively, if coordinated, they can provide the information needed for all parties to competently characterize the cost and benefits attributable to providing households with electricity consumption feedback information.

[1] This database can be found at http://piee.stanford.edu/cgi-bin/htm/Behavior/bibliographic_database.php?ref=nav4.

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1 INTRODUCTION

Many of today's pressing issues support the need for improved levels of efficiency and conservation, including climate change concerns and power generation and delivery constraints. Several studies have suggested that household-specific electricity consumption feedback information can be an effective tool in encouraging conservation. Considering as well the advent of new technologies that allow for greater ease of feedback provision, there are many compelling reasons that the topic of feedback is receiving much attention of late.

So why isn't everyone incorporating feedback into their efficiency programs? Although the answer to this question is multifaceted, EPRI wants to contribute to its resolution from the perspective of ongoing research requirements. Our intention is not to slow progress by calling for more research; rather, we want to move the feedback debate along by aiding in understanding the concerns that utilities, regulators, and customers may have about feedback. This is important because regulators and utilities rely on cost-benefit analyses to direct their investments, which can be substantial and irreversible in the case of feedback. From a customer perspective, householders should be provided with conservation tools that improve their ability to manage their resources; these tools should be suitable to a wide range of needs and circumstances, and their benefits should be equitably distributed.

To this end, EPRI is undertaking a wide range of research to advance the understanding of how feedback information—and the technology that delivers it—provides value to consumers, to the electric system that serves them, and to society.

Background

One definition for *feedback* is "the transmission of evaluative or corrective information about an action, event, or process to the original or controlling source" (Feedback 2009). This report, which focuses on the residential sector, further defines *feedback* as household-specific electricity consumption information. As will be explained next, it can take several forms, ranging from the standard monthly electricity bill to real-time appliance-disaggregated consumption information presented through a user portal or interface.

Characterizing the impact of feedback information on household electricity consumption is not a new field of research. Several initiatives were launched in the 1970s and 1980s to establish how the provision of more information about the timing and level of consumption would affect residential energy usage. The presumption was that the bills issued to consumers, which generally contained only cumulative energy usage and the total amount due, were of little help in making tradeoffs between electricity usage and cost. Lacking data to associate the value of the service electricity provides with the cost of that service, consumers were prone to wasting electricity—or so some proposed.

Early research (1970s and 1980s) focused on establishing what kinds of information would best capture consumers' attention and result in their taking remedial action, which was usually defined as reducing electricity usage. Some researchers explored using new information delivery channels, like personal coaching or creating community interest groups; other research was aimed at reconfiguring the electricity bill to provide routine and useful data. Still other efforts began to explore the concept of providing consumers with real-time consumption information in the form of energy display devices, although this technology was rudimentary and too costly for large-scale deployment at the time. The results of this research, along with consumer advocacy initiatives, led to the overhauling of electricity bills in most jurisdictions. Sometimes this transformation was helped along with prodding from regulators. However, during this period utilities generally were becoming proactive in anticipating and responding to consumer needs.

In the 1990s, a different sort of information delivery mechanism evolved. Motivated in part by the success of household audits in encouraging consumers to adopt energy efficiency measures, protocols and analytical processes were devised to collect and interpret detailed data about households' electricity consumption. This information was combined with predictive behavioral models that associated device usage with the demographics of the household to create a platform for characterizing in detail how a household uses electricity. These conditional demand models combined billing records (which contained only monthly cumulative kWh usage) with household-specific information to create a detailed and disaggregated portrayal of where electricity was used and the cost associated with that usage.

Initially, creating a complete household usage portrayal required that the consumer complete and return an audit form, which was then entered into the modeling system along with billing data. The results were then returned to the consumer, either accompanying a bill or separately. Internet-based systems developed in the past 7 to 10 years have streamlined the process and make the data more readily available to the household to process and use.

Tailored bill disaggregation systems were deployed successfully by some utilities, but they have not become ubiquitous for a number of reasons. The integration of the required data processing systems into utility billing processes proved challenging and impractical unless the utility had put in place new data management systems, which was often not the case. The impact of providing this information was therefore sufficiently characterized to the satisfaction of utilities and their regulators to warrant the expenditure. This technology became available at a time when many utilities were launching energy efficiency programs to promote measures with widely accepted net benefits, in effect draining off funds that might have been used to purchase such feedback systems.

The prospect of deregulation that most utilities faced in the late 1990s and early 2000s raised yet another barrier. Utilities were reluctant to make investments on customers that may not be theirs, because cost recovery was not ensured. Greater benefits seemed available by controlling consumer demand—not to reduce energy but to avoid investments in expensive and little-used generation and to supplement generation resources to improve reliability. Inadvertently, the promotion of the adoption of energy efficiency measures trumped investments in improved information.

The resurgence of interest in the value of information, or feedback,[2] can be attributed to the widely recognized need to reduce both consumer demand and overall consumption to aid in achieving greenhouse gas reduction targets. Those initiatives have benefited from the technology-driven revolution in how data can be collected, processed, and displayed. The advent of devices that can be attached to the meter to extract consumption data that are then conveyed to almost anywhere in the household opened up a new, direct feedback channel. Utilities are assessing the benefits of replacing conventional electric meters with advanced meters that can be read and programmed continuously by the utility. Moreover, they can be configured so that the electricity consumption data that are recorded are transferred directly to a display device in the home, to prompt actions, and stored in a PC or other computational device for later analysis. These direct feedback mechanisms inform consumption decision processes, which may lead to a conservation effect (that is, an overall reduction in household electricity consumption), and they can be adapted to work with control devices that execute consumer-specified operating profiles, potentially resulting in even greater savings.

In the past seven to eight years, several pilots have been launched to clarify, characterize, and quantify the impact of dynamic feedback on household energy consumption. Their findings contribute to the growing body of research that has advanced the understanding of feedback effects. But, many key aspects of how, and by how much, behaviors are influenced remain uncertain or are subject to a wide range of possible values—too wide to satisfy the requirements for making large utility investments.

Report Overview

To characterize how feedback affects electricity consumption, we employ two disciplines: behavioral sciences and economics. Those perspectives do not always converge. For example, a behavior science perspective may criticize an economic perspective that assumes the consumer to be a “rational-economic” being as insufficient to explain behavior. In response to this, the economist may retort that the behaviorist portrayal is difficult to verify empirically. It is not the intent of this report to attempt to resolve this perennial dispute; rather, the two perspectives, while different, each have something to offer. For this reason, they are both considered here.

This report begins by summarizing a behavior-based foundation that describes how consumers may process and act on information. This behavioral science perspective shaped much of the early research on describing and measuring how feedback processes work and is the focus of considerable ongoing academic research.

Next, a way to distinguish between the various types of feedback is presented, based on the delivery mechanism used and the level and frequency of information provided. A brief overview of the findings of the feedback literature from the past 30 years, aided by mapping each into the feedback characterization scheme, is then provided, using the results of a number of seminal summary studies. Aided by the feedback delivery mechanism type delineation, the research gaps cited by these and other studies are then used to closely examine the results of over 30 pilot programs and research initiatives, both past and ongoing.

[2] The terms *feedback*, *information*, and *feedback information* are used interchangeably in this report unless otherwise noted.

An economic framework is then constructed that describes how a household allocates its available income among goods and services. It is especially instructive in that it provides an explanation of why the allocation to electricity consumption may be less than optimal when consumers lack good information about when and how they consume electricity services. Moreover, the model establishes what constitutes observable or measurable evidence that an observed load change is attributable to an information mechanism. This characterization serves as the basis for specifying how to quantify the impacts of feedback treatments in pilot research and to sort feedback impacts from those attributed to pricing and other factors.

The report concludes by summarizing the behavior science and economic theoretical perspectives considered in the report. It emphasizes why measuring feedback impacts is a complex undertaking that is beyond the means of a single pilot. It also makes the case for a collaborative and cooperative research effort to produce the scale and scope of data—to an acceptable level of resolution—that consumers, utilities and their regulators, and equipment manufacturers need in order to make wise investment decisions.

2
BEHAVIORAL PROCESSES

This section provides an introduction to some of the behavior science theory that has motivated and directed several household feedback studies. It then describes a delivery mechanism-based framework that is used throughout the rest of this study to differentiate among the various mechanisms available to deliver feedback information about electricity usage to consumers.

Feedback and Behavior Literature

Energy behavior research has often been criticized for not being adequately rigorous with regard to the formation and testing of hypotheses about specific theories (Katzev and Johnson 1987; McCalley 2006). It is beyond the scope of this report to present a comprehensive review of the behavior science literature as it relates to feedback, but some introductory behavioral intervention definitions are provided here as well as one suggested behavioral science explanation of the feedback effect.

Energy Conservation and Behavior

It is often difficult to separate the impacts of behavior from those resulting from technological or economic stimuli because they often are interrelated. For example, behavior is involved when a consumer responds to a price signal by reducing her electricity consumption during high-priced on-peak hours and increasing the usage of other electric services during the lower priced hours. This involves a short-run reallocation of expenditures, using the stock of equipment that is available. Similarly, behavior is expressed when a consumer purchases a new technology such as an energy efficient refrigerator.

Behavior scientists have devised terminology to distinguish among these types of behavior. One-off actions, such as the purchase of new technologies, are often referred to as *purchase-oriented*, *non-repetitive*, *technology-related*, or *investment* behavior (Barr et al., 2005; Macey and Brown 1983; Stern 1992; and McKenzie-Mohr 1994, respectively).

Regarding reoccurring or frequent actions, the common terminology includes *habitual*, *repetitive*, and *daily* behavior (Barr et al., 2005; Macey and Brown 1983; and Stern 1992, respectively). Some researchers delineate even further: McKenzie-Mohr 1994 cites Kempton et al. (1984) and describes management behavior as adopting more efficient consumption practices with no perceived effect on comfort or lifestyle (for example, lowering the thermostat in the evenings). Alternatively, curtailment behavior connotes sacrifice, involving the restriction in lifestyle choices or a reduction in comfort (for example, lowering the thermostat while occupants are home or taking public transit instead of driving).

Strategies to influence behavior can be categorized in several ways, but a common delineation is between *antecedent* and *consequence* strategies. Antecedent strategies aim to influence behavior before it occurs. They are generally targeted to mass audiences and are usually not personalized. An example is a poster campaign aimed at encouraging building residents to turn off the lights when they leave a room, although such strategies can be much more comprehensive. Another example is the campaign in Texas to promote the proper disposal of trash, called *Don't Mess with Texas*. Both seek to alter the behavior of everyone indiscriminately.

Consequence strategies give customers information about their specific behavior to encourage behavior change. Such strategies can involve incentives (for example, rewards for pro-conservation behavior), disincentives (for example, high electricity prices during certain periods), commitment strategies (making a commitment to conserve a certain percentage of their use), and/or feedback strategies. Feedback strategies have gained prominence in part because of the array of new technologies that allow for the detailed provision of real-time consumption information to consumers.

A Possible Explanation of the Feedback Effect

Feedback is a consequence strategy by definition, although it also represents an opportunity to provide relevant but general energy conservation information (that is, antecedent information). Furthermore, as will be described next in more detail, although feedback may seem to primarily affect habitual behavior, it can influence purchase-oriented behavior as well. In other words, feedback may set off a range of behavioral actions. In order to observe and measure these effects, it is important to determine how each is manifested and then devise ways to empirically determine their impact on electricity consumption.

Interest in characterizing feedback impacts as it relates to energy conservation dates back to the 1970s and early 1980s, when it and other behavioral intervention research were spurred on in large part by the oil embargo. Research continued, although at a reduced rate, in the late 1980s and early 1990s. Recently, much attention has been directed at feedback and information associated with providing consumers with visual, real-time information using stand-alone devices or through elaborate advanced metering and communication systems.[3]

Much of the early feedback research sought to describe the mechanisms by which feedback works to encourage conservation behavior. One account explains that feedback works by "showing that actual conservation is below the level the person wants to achieve." (Seligman et al., 1981, p. 105). This implies that some sort of goal is required in order for feedback to be effective, and these authors did cite a study in which households that were given a difficult goal as well as feedback conserved more than those that received feedback alone or those that received feedback and an easier goal (Seligman et al., 1978).

Although this implies that an explicit goal is necessary, other research has suggested that "feedback has a motivational effect because it leads people implicitly or explicitly to set goals for themselves that they then try to achieve" (Seligman et al., 1981, p. 104). Because a goal could be implicit, it can be argued that in cases in which an individual may not explicitly set a

[3] For a discussion of the value of feedback attributable to advanced metering see EPRI 2008a or Neenan and Hemphill 2008.

goal, feedback may be framed relative to some meaningful but unarticulated (but effective) standard.

Another analysis suggests that feedback works through a three-step process: learning, habit formation, and internalization of behavior (van Raaij and Verhallen 1983). Although a very simplified view, Figure 2-1 illustrates this process as serial and compartmentalized.

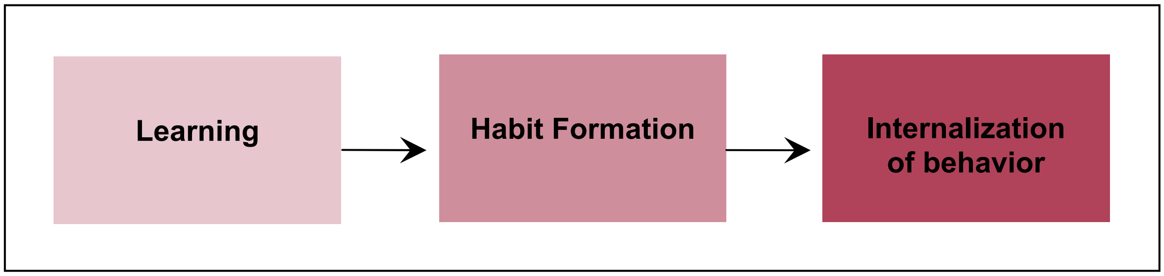

Figure 2-1
A suggested feedback process

In the learning phase, households observe or become aware of the specifics of their consumption patterns and, if the feedback is detailed and delivered quickly enough, they learn about how their specific actions affect their consumption levels. They respond by making small changes in their behavior, initially to view the effects on the feedback they receive and over time as a way to maintain a lower consumption level. These changes that persist may eventually become habits, so that, "without being energy-conscious all the time, people are behaving in an energy-conserving way. Habit formed with feedback should remain after withdrawal of the feedback" (van Houwelingen and van Raaij 1989).

Another study cites anecdotal experience that suggests that a behavior sustained for a period of three months will become habit, although the author believes that ongoing feedback is still necessary to keep householders informed as their circumstances change and as a perennial teaching aid (Darby 2006).

The third phase of the feedback process described above is the internalization of behavior. As energy-conserving behavior becomes habit, an individual's attitude will also change to reflect the adjustment in behavior. A number of behavioral theories provide a way to describe this phenomenon, including Bem's theory of self-perception[4] and one based on cognitive dissonance.[5]

Some theories suggest that other behavior change strategies (for example, strong economic incentives and highly persuasive messaging) do not persist once they are removed. They also suggest that individuals may attribute their behavior to the external circumstances, thus

[4] Bem's theory of self-perception suggests that experimental conditions can bring about new behavior and that attitudes will adjust accordingly and will persist after the experimental conditions are removed, which helps to sustain the behavior (van Raaij and Verhallen 1983).
[5] Cognitive dissonance suggests that when two beliefs held are inconsistent, there is a tendency of the individual to attempt to reduce this inconsistency (Kantola et al., 1984). Cognitive dissonance can also be applied to describe a tendency to reduce inconsistency when attitudes are not consistent with behavior and can occur through an attitude or a behavior change.

diminishing the potential for internalization so that the behavior does not persist once the incentives are removed (van Raaij and Verhallen 1983 and Katdev and Johnson 1987).

Although these theories suggest that the effects of feedback have the potential for persistence, as will be discussed in Section 3, this is not always borne out in practice. If feedback is not successful in habit formation, its impact on electricity usage is diminished or even abated completely. Persistence will profoundly influence whether and how utilities or others are willing to make the investments needed to provide more information to their customers.

This discussion began by tracing the evolution of mechanisms for the delivery of information about electricity consumption to households and examined a behavioral model that has been employed to characterize and quantify the effects. To facilitate a review of the studies and their findings, a framework for classifying and distinguishing between different feedback delivery mechanisms has been established and will be reviewed next.

A Categorization Methodology: The Feedback Delivery Mechanism Spectrum

There are several ways in which feedback research can be characterized, including by the type and frequency of information provided, by the type of delivery mechanism employed, by the character of the consumers involved, and by the prevailing electricity pricing environment. As a way to categorize feedback research, a feedback spectrum was devised by EPRI based on the feedback delivery mechanism (shown in Figure 2-2). It uses a portion of Darby's categorization that distinguishes between direct and indirect feedback (Darby 2000) and expands these two terms to provide greater resolution of the type and frequency of information provided. Figure 2-2 illustrates this spectrum, which is described in detail next.

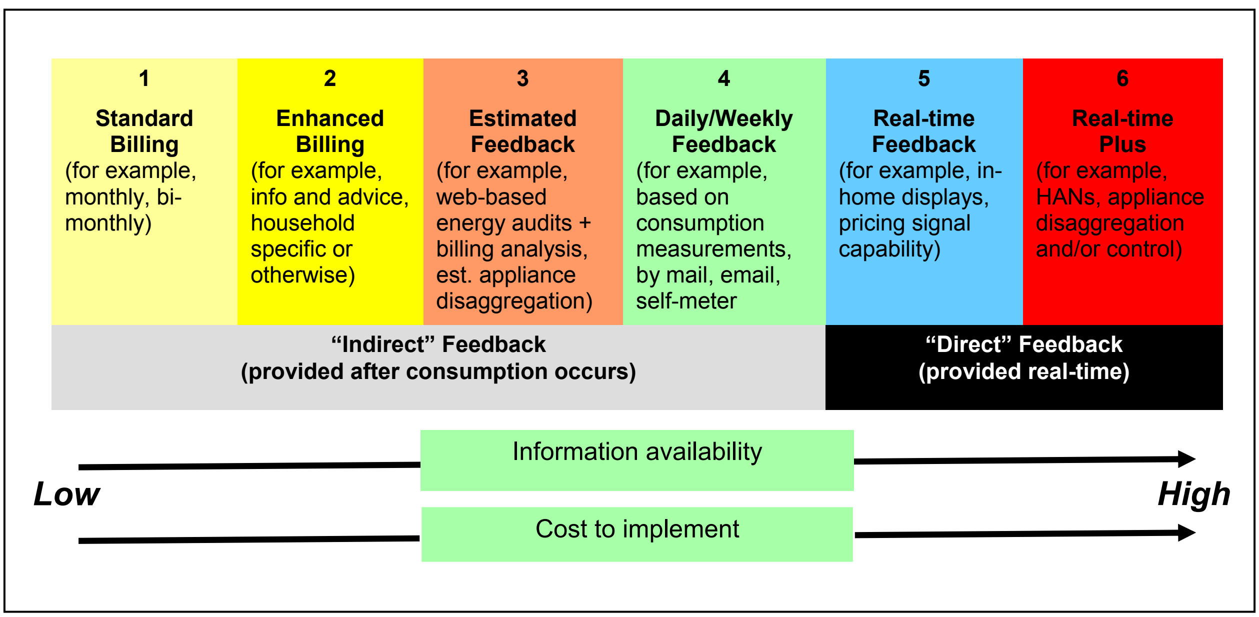

Figure 2-2
Feedback delivery mechanism spectrum

Indirect Feedback Mechanisms

Indirect feedback is defined as any type of consumption information that is provided some time after the consumption occurs. In the feedback spectrum shown in Figure 2-2, four types of indirect feedback are delineated: standard billing, enhanced billing, estimated feedback, and daily or weekly feedback.

Feedback Type #1: Standard Billing

This represents the traditional source of feedback that households receive. The bill displays the monthly kWh and rate ($/kWh), the corresponding cost, other charges, and the amount due. The information provided can be based on consumption estimates, although in North America, it is common that consumption values used for billing are actual meter readings. For some utilities, bills are provided even less frequently than monthly: bi-monthly and, in some Scandinavian cases, only four times a year. The basic usage and cost information provided is effectively an invoice because it usually lacks comparative statistics or any detailed information about the temporal aspects of consumption. Most utilities have moved beyond simple invoicing to bills, providing somewhat greater usage information content.

Feedback Type #2: Enhanced Billing

A step up from standard billing, enhanced billing provides more detailed information about a residence’s consumption pattern, including comparative statistics to help the household establish trends in usage and spot deviations from typical patterns. Typically, the current month’s expenditures and kWh consumption are compared to those of other months. In some cases, the cumulative and year-to-date statistics—as well as comparisons to similar homes—are provided as a form of benchmarking. For households on time-of-use rates, cost and usage are distinguished between the on-peak and off-peak periods. Some utilities provide other information to help the consumer, such as a depiction of the breakdown of energy consumption by end-use (for example, lighting, air conditioning, refrigeration, and washing machine and dryer). These are imputations based on average household patterns, not that premises’ actual device-specific usage.

Today, more attention is generally paid to ensuring that the bill is understandable, and it tends to be more visually pleasing than a standard bill. In effect, the bill has evolved into a monthly energy report for the home. However, that report is very elemental.

Feedback Type #3: Estimated Feedback

This category refers to the application of statistical techniques to disaggregate the total energy usage based on a customer’s household type, appliance information, and billing data. The result is a detailed account of electricity use by major appliances and devices. Today, these are commonly web-based “home energy audit” tools, which are offered by the utility to its customers. However, bill disaggregation services have been available for a long time, usually tied to a household audit that describes the appliances, the premises, and its occupants.

Households can often choose between a high-level or more detailed analysis, depending on the amount of time they wish to take inputting their appliance and billing detail. The output is an energy report that will estimate typical home usage, seasonally adjusted, as well as provide an estimate of disaggregated appliance consumption. Depending on the household's interest level, this sort of information can be provided as a one-off report or as an ongoing service.

Feedback Type #4: Daily or Weekly Feedback

Periodic reports are useful, but they rely on highly averaged data that mask changes in consumption that are due to temporal factors, such as a hot spell, or to changes in the character of the household (for example, the purchase of new devices or more efficient appliances) and its inhabitants (for example, a new baby or children leaving for college or moving in after graduation). In the past, this type of feedback was less common, largely limited to several small-scale research studies. The technology to deliver meter readings to households was too expensive or cumbersome to warrant its general availability. This category includes consumer self-read studies (in which individuals read their meter and recorded 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.

More recently, advanced metering infrastructure (AMI) and associated data management systems have enabled some utility customers to view their consumption data online one day after the fact.

Direct Feedback Mechanisms

Direct feedback refers to the provision of electricity consumption or price data in real-time (or near real-time), as it is occurring. The feedback delivery mechanism spectrum delineates direct feedback into two further feedback types: real-time and real-time plus.

Feedback Type #5: Real-Time Feedback

Perhaps the most common delivery mechanism for real-time feedback and the form that is currently receiving considerable attention by utilities and their regulators is the energy display device (also called the *in-home display*). Several devices are commercially available that extract energy usage data from the meter or electrical panel and display them on a device that can be located almost anywhere in the home. Some displays need to be installed by an electrician, but others can be installed by the homeowner. The display commonly delivers the home's overall consumption level, on a real-time or near-real-time basis, and the corresponding cost (the user enters the utility $/kWh rate). By providing a visual display of electricity consumption levels as they occur, residents can better relate their specific behavior with an electricity consumption impact. Many are sensitive enough to allow the consumers to determine device power requirements by recording the meter reading with the device off and with it on, which supports self-administered audits.

Another feedback mechanism within this category involves the display of electricity pricing information and is usually intended for consumers that participate in highly time-varying pricing plans such as real-time pricing and critical peak pricing. Although pricing display devices do not provide electricity consumption data, they do provide pricing information in real-time and have therefore been included in this category. Some pricing displays provide a visual display of the actual prices ($/kWh), while others provide visual cues when prices reach a specified level or indicate when the customer will be paid for curtailment by agreement.

Section 3 provides an overview of current pilot activity involving energy display devices as well as EPRI reports 1016972 (EPRI 2008b) and 1016088 (EPRI 2008c).

Feedback Type #6: Real-Time Plus

This category refers to systems that allow users to see not only their overall household consumption in real-time, but also the disaggregated consumption of individual appliances. This is distinct from the *estimated feedback* category (that is, type 3) in that the appliance level information is measured (or monitored) in real-time as opposed to estimated based on statistical analyses. Moreover, in many cases the technology that makes this possible also allows for the control of individual devices—in some cases according to predetermined algorithms.

This category includes systems that allow users to monitor consumption and/or control individual devices in their homes through home area networks (HANs). See EPRI report 1016113 (EPRI 2008d) for a discussion of HANs and their related communications protocols. Utility HAN demonstrations that interact with AMI are currently limited, although some early technology demonstrations are now being undertaken (see Section 3). From a feedback-provision perspective, the customer interface, or portal, of the HAN is the most useful system component. Depending on the end-use devices and the system, portals can display the following:

- Electricity consumption disaggregated by appliance type
- Consumption over historic periods according to the user's preference (for example, day, week, or month)
- Breakdown of usage by time of day
- Usage expressed in terms of a variety of metrics, including kWh, dollar value, and greenhouse gas emissions
- Preprogrammed "themes" that adjust specific appliance settings for different scenarios (for example, HVAC and appliance/lighting settings for when no one is home or during on-peak times)
- Pricing signals, alerts, or demand response events received from the utility

Most systems allow users to access and control their HAN through the Internet, allowing for remote access through PCs, laptops, and handheld devices as well as through a mobile phone.

This section introduced relevant terminology and suggested behavioral theories that describe the manner in which feedback is believed to work. It has also introduced a way to delineate between different types of feedback based on the information level it provides. The following section reviews the existing body of feedback-related research with the aid of this spectrum of feedback delivery mechanisms.

3 IMPACTS OF FEEDBACK

Several reviews of the body of feedback research have been performed in the past few years. Most have supported the notion that feedback can be effective in encouraging electricity conservation. In addition to reviewing and summarizing the findings of these reviews and additional recent research, this section also identifies areas in which further research is still required. Next, it provides an overview of ongoing feedback research activity at the utility level as well as at academic and research institutions. Finally, a synopsis of past and ongoing research is presented to provide a basis for establishing an effective research agenda going forward.

Past Feedback Studies

One comprehensive summary study of energy feedback research concluded that feedback, either alone or with other measures, produced energy savings of approximately 10%, although there were instances of higher results and cases in which no feedback effect was reported (Darby 2000). This study introduced the feedback distinctions *indirect* and *direct* and described the "invisibility" of energy consumption for the average consumer. Of the studies reviewed, the majority suggested that direct feedback—defined as real-time or near-real time consumption information, either alone or in collaboration with other measures—was the most effective. Indirect methods (for example, improved bill layouts) were not as influential in terms of conservation impacts, but they were effective in peaking interest and raising awareness and were popular with customers. The study also concludes that feedback alone can sometimes not be enough; the physical condition of the home and support from utilities, among other influences, can also be important.

In an updated version of the initial review (Darby 2006), a further delineation was made between the potential effectiveness of direct and indirect feedback: direct feedback is seen to be more valuable to making non-heating, day-to-day electricity consumption behavior changes because it makes their consequences more visible. Organized and categorized to align with this distinction, the body of studies indicates that direct feedback consumption savings are in the 5–15% range. Indirect feedback studies are potentially more valuable for making visible the value of technology change-outs, for example, the installation of more efficient heating systems or building envelope improvements. Studies that involved indirect feedback showed consumption savings up to 10%.

With regard to criteria for effective feedback, a number of themes emerge from these and other summary studies (Fischer 2007, IPSOS Mori 2007, Abrahamse et al., 2005) regarding the factors that influence feedback impacts. Feedback is more effective under the following circumstances:

- It is provided frequently, as soon after the consumption behavior as possible.

- It is clearly and simply presented.
- It is customized to the household's specific circumstances.
- It is provided relative to a meaningful standard of comparison.
- It is provided over an extended period of time.
- It includes appliance-specific consumption breakdown (some studies).
- It is interactive (some studies).

Similarly, past study limitations were identified and the need for further research in certain areas were proposed in these as well as in other more recent studies (Wood and Newborough 2007, Elburg 2008, Parker 2008). These include the following:

- Small sample sizes and the resulting statistical significance issues
- Persistence of effects that were not addressed because of the short study duration
- Insufficient treatments to sort out the effect of different and/or more detailed information on feedback impact
- Separating the effects of feedback from those attributable to price influences (which itself is a form of feedback), especially from dynamic pricing
- Distinguishing the effects of feedback among different demographic groups

The following explores the character and extent of these research gap areas using the results reported in 31 feedback studies. A list of the studies reviewed and a summary of their findings are provided in Appendix A.

Most of the studies reviewed were published in peer-reviewed journals or conference proceedings, although some are utility reports documenting the results of recent pilots. The majority of studies focus on the impact of feedback on the change in household electricity consumption levels (or the change in on-peak demand for studies involving a dynamic pricing element).

As with any study synthesis, there are limitations in the approach used to compare the studies reviewed; for example, only the average percentage change in household electricity usage is reported here, although some studies report a range of results. For most of these cases, the conservation value reported is that attributed to the feedback treatment, although there are some instances in which the feedback was mixed with other treatments. Lastly, although excluded for this review, there may be other valuable information to be gleaned from other types of feedback studies (for example, on natural gas or water consumption).

Study Participation

The level of variation in the number of participating households in the studies reviewed is illustrated in Figure 3-1. The horizontal axis indicates the study sample size (excluding control groups) and the vertical axis the percentage electricity consumption reduction, which was attributed to the feedback mechanism deployed. The majority of studies involved fewer than 200 participants, and some included only a handful. This suggests that comparisons of the reported conservation effect should be conditioned on the degree to which effects have been demonstrated to acceptable levels of statistical precision.

Participation is important because in the absence of strict statistical sampling protocols, small participation rates are more likely to provide less compelling evidence that the treatment did have an influence or result in misleading conclusions about the implications for the population as a whole. Some of the pilots were constructed so that the results would provide a more credible (statistically significant) result, at least with respect to the sampling frame—the specific population to which the study was directed and from which participants and controls were drawn. However, if the frame includes only part of the population, the results can be extrapolated reliably only to that part of the population of that utility.

As discussed next, one shortcoming of some past research is it does not impose sufficient structure on the initial sample design to test for differences in the feedback effect among customers with different housing, demographic, and electricity pricing circumstances.

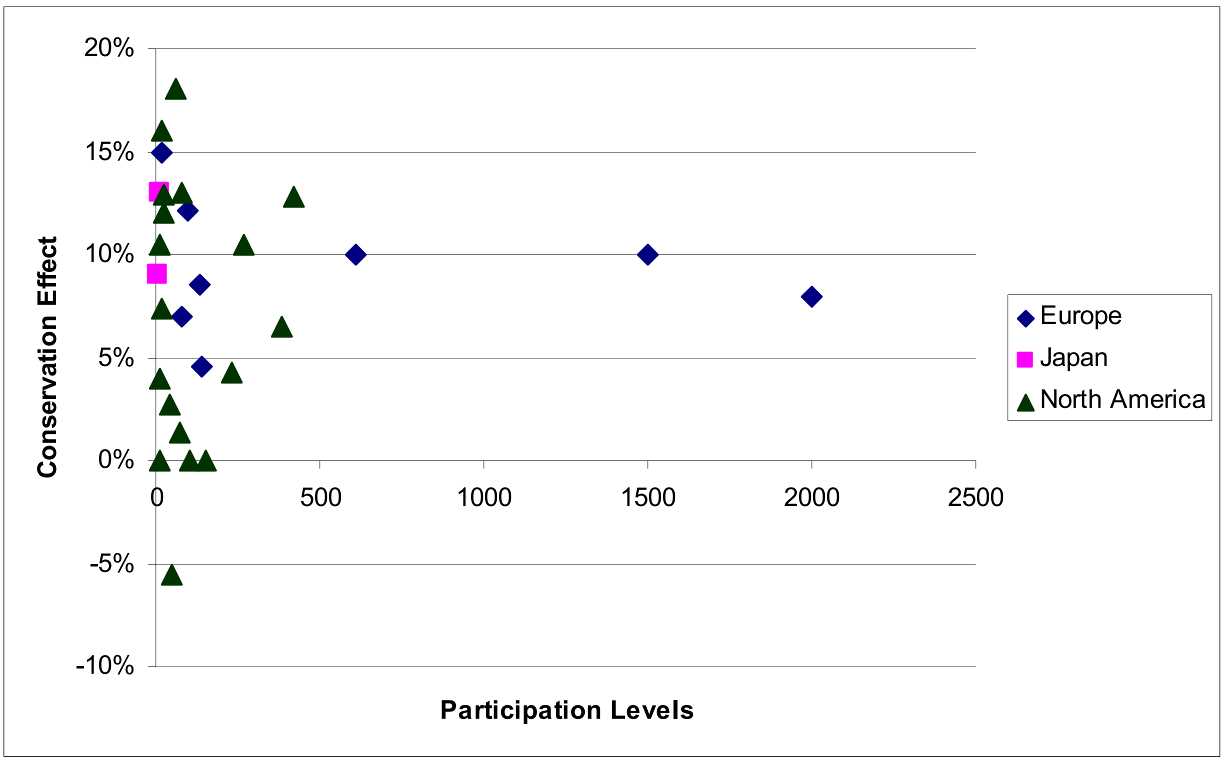

Figure 3-1
Range of study participation levels

Feedback Delivery Mechanism Impacts

The studies reviewed involved a range of different feedback types, study lengths, and contexts. Table 3-1 delineates the studies according to the feedback mechanism employed using the spectrum developed in Section 2. Recall that the first category, standard billing, serves as a reference point for comparing the impacts of more robust feedback delivery mechanisms.

Table 3-1
Feedback study sample sizes

Feedback type (according to Figure 2-2)	Direct or indirect	Number of studies	Sample size range	Average conservation effect
2 (Enhanced monthly billing)	Indirect	7	79–2,000	9%
3 (Estimated feedback)	Indirect	2	137–152	4%
4 (Daily/weekly feedback)	Indirect	5	15–267	8%
5 (Real-time feedback)	Direct	12	10–422	7%
6 (Real-time plus–HAN/appliance level information)	Direct	5	4–25	12%

The majority of the studies reviewed that assessed enhanced monthly billing (type 2) are from Scandinavian countries and were conducted in the 1980s and 1990s, when the standard bill was a low-information-content invoice that was provided as infrequently as four times a year. However, the average electricity consumption reduction of the studies reviewed is 9%, which is higher than all but one of the other mechanisms reported in Table 3-1. As will be reviewed next, the Sacramento Municipal Utility District (SMUD) is currently running a program in which several thousand customers receive monthly (and, in some cases, quarterly) customized energy reports in addition to their bills. Initial results indicate a savings attributable to this feedback of approximately 2% (Alexandra Crawford, personal communication, November 19, 2008).

Feedback type 3 (estimates of disaggregated usage) and type 4 (daily/weekly feedback) were reported to induce (on average) 4% and 8% reductions, respectively. Only two studies reviewed focused on the impacts of providing consumers with disaggregated billing information, each involving around 150 participants. More studies (five) were directed at establishing the impact of more frequent information on household electricity usage, ranging in number of participants from very small (15) to relatively large (267).

The results from some of the indirect feedback assessments (that is, types 2 through 4) are encouraging, despite results slightly lower on average than those from direct feedback studies (types 5 and 6, discussed further next). If an impact of up to 9% can be achieved by using established communication channels between consumers and their utility by augmenting billing information, substantial gains can potentially be realized without the need for costly meters and display devices. However, the current body of evidence would need to be fortified by more studies under diverse circumstances to warrant such a sweeping conclusion.

Real-time feedback (type 5), mainly in the form of energy display devices, is the feedback type assessed in 12 of the studies—most of them within the past five years. The largest study took place in 2003–2004 and was conducted by the Salt River Project (SRP). This involved a six-month summer-period assessment of 422 customers with prepaid energy displays as well as 202 different customers in the six-month winter period (Loren Kirkeide, Principal Analyst – SES, Salt River Project, personal communication, February 18, 2009).[6] Compared to typical display device programs, prepaid meter customers must think ahead to purchase credits on electronic cards that can be activated at kiosks throughout Phoenix, Arizona, in order to avoid service disconnections. Initially targeted for low-income groups, today there are more than 70,000 customers on this program. Although one motivation for such prepaid programs is to reduce instances of customer non-payment, this and other programs have indicated that prepaid metering can produce energy savings as well. Darby (2006) summarizes experience with prepaid displays in Northern Ireland and in Ontario, Canada, where savings of 3% and 20%, respectively, were reported. Another assessment of the Northern Ireland experience reports conservation of 11% with proper training and 4% without (Stein 2004). In both cases, approximately 25% of the utilities' residential customers were using the prepaid technology.

After the SRP study, the next largest study reviewed involved 382 participants. Many of the display device studies were relatively small—the median sample size of the studies reviewed is 55. The smallest participation rates are associated with assessments of real-time information disaggregated to the appliance level (type 6); these studies were mainly technology viability demonstrations. The average reported feedback effect (125) was the largest of all of the categories (although in one case [Wood and Newborough 2003], the study was concerned with feedback relating to one appliance—a stove—as opposed to multi-appliance disaggregated feedback).

Several studies combined feedback with other interventions (for example, general energy savings information provision or the provision of a goal to attain), but few were designed to compare the different types of feedback mechanisms as defined in Figure 2-2. The closest was one of the three studies by Seligman et al. (1978), which compared a blinking light indicating that outdoor temperatures were low enough to turn off the air conditioning (considered to be type 5 feedback) to consumption feedback that was provided to homeowners every two days (that is, type 4). In this particular case, the blinking light was shown to induce the main effect (a 15% reduction); the daily feedback was found to have little effect, although the authors attributed that to the unreliable nature of the data provided.

Although not comparing impacts across feedback mechanism types, a second study (Brandon and Lewis 1999) compared several variations of type 2 feedback (five variations of monthly feedback presentations provided via mail, plus through an interactive PC-based system). They found that the interactive PC-based feedback seemed to be most effective, although overall the feedback effect was only marginally significant.

In a third study, Martinez and Geltz (2005) provided both enhanced monthly information (type 2) as well as an energy pricing display (type 5), although the study was not designed specifically to test the relative effects of each (that is, all members of the treatment group received both types of feedback). In terms of current research, in addition to the monthly energy report program mentioned above, SMUD and We Energies are concurrently running an energy display program.

[6] SRP has also conducted other assessments of their prepaid meter program; the most recent study, in 2005/2006, included 272 summer-month and 191 winter-month customers with prepaid meters, and found an average decrease in annual electricity usage of 12.0%. (Loren Kirkeide, Principal Analyst – SES, Salt River Project, personal communication, January 29, 2009).

Although they are two separate programs, it may be insightful to compare differences between two feedback types implemented in the same jurisdiction.

Finally, although not reviewed in detail for this report, there is a growing body of research dedicated to understanding how feedback should be displayed within and across different feedback delivery mechanism types; that is, what design approach, layout, and/or metrics are most salient and most effective in encouraging conservation behavior, particularly across different demographic categories.

Studies have been undertaken to quantify the impact of each of the five feedback delivery mechanisms—although the research has not been uniform in terms of the relative number of studies focused on each—and their participation levels. As a result, it is difficult to draw definitive and actionable conclusions either about the level of reduction to expect from any of the feedback delivery mechanisms or about their relative effectiveness.

Feedback Persistence

Of the studies reviewed, approximately one third (that is, 12) included a check for whether the reported initial change in usage behavior persisted. The studies were relatively long (at least one year, which is considered long for these studies). One of two types of assessment took place: either the change in consumption was assessed throughout the study, or the effect was reassessed some time after the original study took place. The 12 studies are summarized in Appendix B. Excluded are two cases of self-reported persistence checks in which consumers were asked if they continued to take action.

There were seven instances in which there appeared to be no change in effect over the study duration. In one of these cases (Ueno et al., 2006a), persistence was measured not by a sustained change in electricity consumption, but by tracking the number of key strokes on the customer interface with a HAN-type system eight months after its installation. In the other six cases, two dealt with enhanced billing (type 2) and involved fairly large sample sizes and the longest study durations (Wilhite 1997 as cited in Darby 2006, and Nielsen 1993). The remaining four studies that indicated persistence involved energy display devices (type 5). Three of the last four studies (two from Mountain 2007 and Mountain 2006) were undertaken by the same researcher. A statistical model that incorporated a “time trend” indicated no change in conservation effect over the study periods (which were 18, 18, and 13 months, respectively).

The fourth study (McClelland and Cook 1979) reported that savings neither increased nor decreased over a period of 11 months but that the savings tended to be larger in lower consumption months. Because this study involved electrically heated homes equipped with air conditioning, *lower consumption months* translated to spring and fall. These results suggest that studies should be long enough to assess persistence over two or more years to ensure that potential seasonal effects are properly taken into account.

In 3 of the 11 cases, the savings were reported to increase over time. In one case (Wilhite and Ling 1995), enhanced billing was estimated to have resulted in electricity reductions of 8% and 10% at the end of the second and third years, respectively.

In the second case (Staats et al., 2004), which also involved enhanced billing in combination with other treatments, the conservation effect was approximately 5% at the end of the intervention period but was not statistically significant. On a follow-up check 26 months after the end of the intervention, the treatment group was reported to be conserving 8% relative to the initial baseline period, and the result was found to be statistically significant. However, because analogous results for the control group were not included for these consumption metrics, it is difficult to conclude that the sustained effects were a result of the treatments only. (The study does describe self-reported behaviors and demonstrates that many such behaviors did persist compared to the control group.)

In the third case, a follow-up period of three and one-half weeks after the daily feedback had been stopped revealed that the average conservation effect of one group of 15 households was approximately 10% (up from 4%) compared to a second group of 15 households (which itself began to receive feedback during the three and one-half week period); however, sample sizes were small, and no mention was made of the statistical significance of these effects.

In the remaining 2 of the 12 cases, when a check was performed some time after the initial intervention, the original effect was no longer significant. In one of these cases (Sexton et al., 1987), the lack of persistence of the initial on-peak consumption reduction may have been a seasonal effect because it was only a 10-month study. In the other case (Hutton et al., 1986), persistence was assessed by the frequency of display device use (measured by data logs of how often various types of information were accessed). Device use was shown to decrease substantially in the first few months of deployment. This phenomenon has also been demonstrated in ongoing display device pilots and will be discussed further below.

In summary, some of the studies provide an indication that the impacts of feedback can persist. Some evidence comes from studies involving enhanced billing (type 2), where the baseline billing method was infrequent to begin with. In the only HAN-type system reviewed (type 6) for which persistence was assessed, although consumption was not measured over time, it is at least encouraging that user interest (measured by number of keystrokes logged) seemed to persist for at least eight months. From three display device studies (type 5), there are indications that persistence can be expected, imputed from study lengths in the 1-year to 18-month range. In another display device study, electricity consumption declined substantially after the first few months, and similar results are being demonstrated with current research activity. Further research is needed to reconcile these findings against others that support the persistence of feedback effects.

Feedback and Pricing Effects

Price effects are measured as changes in consumption associated with changes in the price of the good. Unlike feedback, which can be categorized into a few different causal mechanisms, prices can change over a range of values either continuously and marginally or periodically by large amounts. Price elasticity serves as a conventional metric because it describes the change in consumption associated with a 1% change in price. Therefore, it can be applied to any specified price change, regardless of size.

Because electricity prices are subject to change in explicit and subtle ways and the impact is measured in the same manner as it is for feedback (that is, the change in electricity consumed), it is important in constructing feedback research to take into account price effects in order to isolate the feedback effect.

Of the 31 studies reviewed, 7 were performed in a dynamic pricing environment. Feedback studies that include price treatments are relatively recent, reflecting the ascendancy of interest in both feedback and dynamic pricing. The nature and results of these seven studies are reported in Appendix C.

The average incremental on-peak reduction effect of the feedback, over and above the effect attributed to dynamic pricing, ranges from 0 to 2%. Martinez and Geltz (2005) used enhanced billing (type 2) in combination with a pricing display device (type 5) that changes color based on a pre-specified price schedule. They found that the combination of treatments likely had some impact on shifting, although the results were not statistically significant—which they believed was likely the result of their small sample sizes. Sexton et al. (1987) found that the greatest incremental effect of their feedback (an energy display device, type 5) occurred with higher peak to off-peak price ratios. They also found a 5.5% increase in overall consumption attributable to the feedback (that is, a negative conservation effect), about which they state: "the incremental effect of monitoring in conjunction with time-of-use (TOU) pricing may be to (1) somewhat augment peak-period conservation, (2) induce significant increases in off-peak use, and, hence, (3) cause net consumption to increase" (p. 60). As will be discussed next, preliminary results from a dynamic pricing pilot run by Baltimore Gas and Electric, which used the same pricing display device as Martinez and Geltz (2005) for some customers, indicate that the device accounted for an incremental on-peak reduction effect of 6–7% over and above that attributed to price.

Although not conducted in a dynamic pricing environment, a study of the effects of an energy display device in British Columbia and Newfoundland, Canada, revealed a larger conservation effect in the latter province (Mountain 2007). The study's author suggested that some of the difference may be attributable to lower electricity prices in British Columbia, although he did not attempt to confirm that conjecture by pooling and comparing the pilot results after controlling for differences in design.

The reported feedback effect on overall conservation (as opposed to on-peak reduction) is smaller in pilots in which prices also vary (in the 0–4% range, although, as mentioned previously, in one case there was an overall increase in consumption of 5.5%). This might be because in agreeing to participate in a pricing pilot, the household occupants are predisposed to being aware of when and how they use electricity even without the specific information that feedback provides. More investigative research is required to assess this situation.

Feedback and Demographic Considerations

If some segments of the population benefit from feedback more than others, it is necessary to demonstrate the extent of the differences. To understand the costs and benefits of feedback associated with large deployments, the research findings must be generalizable to the broader population consisting of diverse demographic groups based on income, education levels, and other factors. The premises' structural factors such as dwelling type and size, and heating fuel also need to be considered because they condition—and may limit—the extent to which household occupants can reduce electricity consumption while maintaining comfort levels.

Stratifying the population according to such factors and employing a corresponding sampling design are useful because they allow for direct testing of whether there are strata differences using the pilot data. The alternative is to segment the data afterwards and use statistical or other empirical associative methods to determine whether differences are evident according to demographic or other distinguishing household characteristics. Stratification provides a much stronger determination of association, but it requires having sufficiently detailed household-level data up front—before treatment and control groups are assigned. Detailed information about each member of the sampling frame (that is, the population of customers to which the pilot is targeted) is usually not known at this stage because utility records generally contain little distinguishing information about households beyond usage history and dwelling type (for example, single- or multi-family).

In the absence of data to use for stratification, correlations are called upon to impose associative segmentation. Household consumption levels have been used as a proxy for demographic traits such as household income, although this correlation is not often clear.

Although the way in which study results varied according to the demographic distinctions was not always clear, Appendix D summarizes the 15 studies that reported at least some demographic characteristics of their population frame, the majority of which involved single-family dwellings.

In one case, a study of northern Ontario homes used housing and demographic features collected from participants in a behavioral model and reported that the conservation effect of a display device (type 5) was not dependent on factors such as age, income, or education (Mountain 2006). In similar studies in Newfoundland and British Columbia that used the same display device and statistical model, some demographic-dependent variations of the conservation effect were found (Mountain 2007). In Newfoundland, households that more likely to respond to the display (that is, households that were more likely to conserve) were more highly educated and had more pro-conservation attitudes, lower incomes, smaller family sizes, and fewer senior citizen–age occupants. Conversely, in the case of the British Columbia study, the only demographic effect that was positively associated with the level of response to the displayed information was household education level. An ongoing assessment of a 30,000 display device program by Hydro One in northern Ontario may provide a better characterization of the influence of demographic factors on feedback effects. (More information on this study is presented next.)

A study of 98 households in the United Kingdom (UK) looked at the effects of different types of enhanced billing (type 2). It found that demographic factors did not appear to influence the savings from the feedback provided (Brandon and Lewis 1999). However, it did appear that relative household consumption level (that is, distinguishing low kWh users from higher kWh users) was positively associated with savings from the feedback. Environmental beliefs, predicted personal behavior (that is, the inclination to behave in a more pro-conservation manner), and the number of household occupants were also found to be positively and significantly associated with feedback-related savings.

The SRP prepaid meter assessments found no statistically significant differences in effect (percentage change differences) among three electricity consumption strata (Loren Kirkeide, Principal Analyst – SES, Salt River Project, personal communication, February 18, 2009).

An early 1990s study compared the effects of more frequent billing (monthly versus quarterly) as well as providing comparative usage statistics (for example, consumption with respect to historic usage or benchmarked against other consumers) over a three-year period for approximately 600 homes in Norway. Younger households and those with higher education and income levels were found to be more likely to reduce their consumption as a result of the feedback (Wilhite and Ling 1995).

Other studies listed in Appendix D indicated demographic- or consumption-related variations. Considering the categories of age, income, education, and historic consumption levels, these studies suggest that there is at least some evidence to support the following:

- **Age.** There is some indication that feedback-related electricity savings may be greater in younger households. At least two studies indicated this association; others found no association with age.
- **Income.** No generally applicable associations were found. However, at least one study found that lower income households saved more; at least one found the opposite, and others found no association of feedback impact and income.
- **Education.** Feedback-related electricity conservation may be greater in more highly educated households. At least four studies found this association; others found no association of feedback impact and education.
- **Level of electricity consumption.** Feedback-related savings may be greater with higher consumers than with lower consumers. At least three studies indicated this association, although at least one found no association.

In summary, demographic assessments are important in establishing the distributional impacts of feedback. Several studies have revealed insightful information about the potential effects of income, education level, and household occupant age on feedback effectiveness. 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.

Summary

A review of the literature suggests that further study is required in relation to five main areas:

- **Participation.** The studies employed a range of sample sizes. The largest have involved enhanced billing and energy display devices. A better understanding of the effects of feedback on specific demographic groups is required, which has sample design selection implications.
- **Feedback delivery mechanism distinction.** The most thorough analyses have involved enhanced billing and direct energy displays. More research is required to assess the relative effects of different feedback types, particularly across different demographic groups, as lower levels of feedback might be more cost effective.

- **Persistence.** Some of the studies provide indications that feedback persistence can occur. The best evidence comes from studies involving enhanced billing and energy display devices, although in the case of the former, results may not be generalizable throughout North America. In addition, study durations should be long enough to distinguish between persistence and potential seasonal effects. Finally, results from ongoing research that indicate that a large percentage of households stop using their display devices over time need to be reconciled against past study results that suggest that conservation effect persists.
- **Price.** Although relatively few in number, some studies support the notion that feedback provided in conjunction with dynamic pricing can have an incremental effect on peak reduction in the 0–2% range. More work is required to better assess the effects on overall consumption reduction—at least one study provides evidence that feedback can increase overall consumption while reducing peak consumption. To this end, a better understanding of the relationship between the types of information provided (for example, price signal provision versus energy consumption values) and the resulting effects is required.
- **Demographics.** Several studies have revealed insightful information about the effects of income, education level, and household occupant age on the potential effectiveness of feedback. Some tenuous trends have emerged, but these need to be more thoroughly verified.

The studies reviewed assess these issues to various degrees, but none covers all of them comprehensively. This is not a critique of the studies; each was designed with specific circumstances in mind and, in most cases, it would not make sense or be feasible for the researchers to assess all of the issues presented here. However, the lack of uniformity in study design makes it difficult to compare results to produce a definitive and holistic characterization of feedback effects. But, as will be discussed further next, this synthesis of the body of existing research does indicate where and how additional research will be most fruitful. First, it is instructive to review ongoing research initiatives to see how they might contribute to resolving cause-and-effect ambiguities.

Ongoing Research Activity

Many utilities and researchers are engaged in ongoing research to address some of the limitations of past research as well as issues specific to their jurisdictions. The following two sections provide a snapshot of some of these activities as of December 2008.

Utility Pilot Initiatives

Several utility pilots are currently ongoing. Two recent EPRI technical briefs have highlighted some of this pilot activity, and this report includes a summary of ten more (Table 3-2). The details of these latter 10 pilots can be found in Appendix E. It should be noted that Table 3-2 is not an exhaustive summary of pilot activity and that other pilots are ongoing as well. For example, other utilities that are currently considering or beginning pilots or programs include the following:

- BC Hydro is considering an energy display device pilot (type 5).

- Puget Sound Energy will be initiating a program using Positive Energy's Home Energy Reports (type 2).
- Reliant Energy began installing Tendil's Insight energy display device in homes in November 2008 (type 5).
- Xcel Energy, as part of its SmartGridCity initiative, is equipping tens of thousands of homes with broadband over power lines (BPL), AMI, and HAN equipment, including a web-based portal and specific end-use load controllers (type 6).

Table 3-2
Recent and ongoing pilot summaries

EPRI Document	Date	Utility Pilots Summarized
1016972	June 2008	• Hydro One • Nevada Power & Sierra Pacific Power (now NV Energy) • NSTAR • TXU Energy
1016088	October 2008	• Dominion Virginia Power • Energy Center of Wisconsin/Focus on Energy • Energy Trust of Oregon • Nevada Power & Sierra Pacific Power (now NV Energy) • Omaha Public Power District • Sacramento Municipal Utility District (display device program, type 5)
1016844 (the current report)	December 2008	• Baltimore Gas and Electric • Duke Energy • Energy Trust of Oregon (updated) • Hydro One (updated) • National Grid/NSTAR/W. Mass Electric (updated) • NV Energy (updated) • OFGEM (UK) • Sacramento Municipal Utility District (Energy Report program, type 2; no update for type 5) • SaskPower • We Energies • No updates for Dominion Virginia Power, Focus on Energy (Wisconsin), Omaha Public Power District, or TXU

Table 3-3 summarizes the utility pilots identified in Table 3-2 according to the contribution each may make to resolve the five research gap areas highlighted previously.

Table 3-3
Ongoing pilot activity and research areas

Ongoing Utility Pilot	Participation	Feedback Mechanism	Study Duration	Price Versus Feedback	Demographic Distribution
Baltimore Gas and Electric	625 (part of larger dynamic pricing pilot)	5 (Ambient Orb)	13 months	Yes	Effects on demographic groups will be assessed
Dominion Virginia Power	1,000	5 (Blue Line PowerCost Monitor)	12 months	No	
Duke Energy	~100	6 (various HAN-related technologies)			
Energy Trust of Oregon	370	5 (Blue Line PowerCost Monitor)	13 months	No	
Focus on Energy Wisconsin	150	5 (Blue Line PowerCost Monitor)	~12 months	No	No
Hydro One	~30,000	5 (Blue Line PowerCost Monitor)	12 months	No	Effects on demographic groups will be assessed
National Grid, NSTAR, W. Mass. Electric	3,512	5 (Blue Line PowerCost Monitor)	15 months	No	
NV Energy	93	5 (five different display devices)	6 months	No	No
OFGEM (UK)	Tens of thousands	2, 5 (various feedback types within each mechanism)	~24 months	Yes	Effects on demographic groups will be assessed

Ongoing Utility Pilot	Participation	Feedback Mechanism	Study Duration	Price Versus Feedback	Demographic Distribution
Omaha Public Power District	150	5 (Aztech In-Home Display; Blue Line PowerCost Monitor)	~5 months	No	
SaskPower	100	5 (Blue Line PowerCost Monitor)	12 months	No	No
Sacramento Municipality Utility District	35,000 (type 2) 10,000 (type 5; billing analysis/assessment will involve fewer participants)	2, 5 (Positive Energy Billing Reports; Blue Line PowerCost Monitor)	~48 months (type 2) 12 months for assessment (type 5)	No	Effects on demographic groups can be assessed (type 2)
TXU	400	5 (Energy Inc. TED – The Energy Detective)		No	
We Energies	50,000 (type 2) 12,000 (type 5)	2, 5 (monthly billing reports, vendor TBD; Aztech In-Home Display)	~36 months for each program	Yes	Effects on demographic groups can be assessed

Comparing disparate studies is fraught with difficulty because many are intended to accomplish different goals. For example, although the NV Energy sample size is relatively small, one of its intentions is to assess customer preference of various display device features—not the display devices themselves. Similarly, the main purpose of the SaskPower pilot is not to quantitatively assess the conservation effects (although it is doing this anyway), but to assess customer opinions about the displays. Other utilities have diverse objectives in mind as well. However, keeping in mind these comparison limitations, some trends emerge.

With regard to participation rates, although difficult to draw conclusions about the appropriateness of the sample size selection without knowing specific design details, about half of the sample sizes are over 500. This is an encouraging trend compared to past feedback studies in which only 4 of the 31 studies reviewed had sample sizes above 500.

With regard to feedback mechanisms, three large programs (OFGEM, SMUD, and We Energies) are assessing and comparing different types of feedback delivery mechanisms (although in the cases of SMUD and We Energies, they are two separate studies). In the OFGEM program, within each mechanism type (specifically, types 2 and 5), different feedback instruments are also being assessed. This applies to the ongoing display device studies by both NV Energy and OPPD. Although these trends are encouraging, more studies are required to assess the relative effectiveness of the different feedback mechanism types as well as the different instruments and displays within each type (including how the information is displayed). In addition, pilots representing feedback types 3 and 4 are noticeably missing from Table 3-3. The evaluation of the effectiveness of these sorts of feedback provision tools should be considered because some AMI systems allow customers to view their consumption information online after a one-day delay (type 4, with applications for type 3 as well).

Almost all studies are now at least one year in length to assess persistence. However, as outlined previously, longer study periods would be preferred to properly assess potential seasonal effects and to form a more robust persistence assessment in general. OFGEM, SMUD (with its type 2 assessment), and We Energies are doing this; Baltimore Gas and Electric's dynamic pricing pilot feature pricing display devices will be reassessed in 2009 for a second summer season. Similarly, other utilities may be able to perform ongoing assessments in cases in which display devices are retained by the households.

Few pilots are looking at pricing and feedback interaction effects (exceptions are Baltimore Gas and Electric, OFGEM, and We Energies), and relatively few will be able to assess demographic trends of any potential feedback effects (exceptions are Baltimore Gas and Electric, Hydro One, OFGEM, and We Energies). More work is still required in these areas.

The results of ongoing research activity will make an important contribution to the body of feedback research by addressing gaps such as the persistence question and improved participation levels. However, these areas—in particular, feedback delivery mechanism comparisons, pricing and feedback interactions, and demographic assessments—require more work.

Academic and Research Institutes

Several universities and research organizations are actively involved in feedback-related research. A summary of the following six institutes' activities can be found in Appendix F.

- Florida Solar Energy Center (FSEC)
- Georgia Institute of Technology
- Massachusetts Institute of Technology
- Rutgers University
- Stanford University
- University of Waterloo

This section has provided an overview of past feedback studies, including those that highlight key areas that require further investigation. These issue areas were then presented in more detail to thoroughly assess the degree to which research gaps exist. The latter half of this section was devoted to describing ongoing research, much of which has been designed to address some of these key gap areas. The following section will introduce an economic framework that can provide the basis for further empirical research to comprehensively address these issue areas.

4
AN ECONOMIC FRAMEWORK FOR ELECTRICITY DEMAND AND THE VALUE OF FEEDBACK INFORMATION

The report has provided a high-level overview of some behavioral science definitions and theories and examined the literature, much of which stems from the behavioral science realm, to elaborate on the feedback research gaps that still exist.

This section offer a different perspective on behavior informed by economic theory, which characterizes the value of information through an examination of how consumers allocate income to expenditures and the role information plays in that process.

The Need for a More Robust Characterization of Feedback Impacts

Information provides value to consumers through the identification and characterization of the choices available. Those choices involve making marginal valuation tradeoffs because the income available is limited. Through information that distinguishes the major differences in the attributes of available alternatives, consumers are better able to understand the tradeoffs implicit in their choices. As discussed previously, the results of many experiments and pilots suggest that the provision of information to consumers about when and how they use electricity as well as the associated cost results in a reduction in the level of electricity consumed. This appears to be the case for a range of feedback delivery mechanisms, although the level and persistence of the reported impacts vary widely.

Many of the more recent pilots involve providing consumers with information in the form of direct feedback. The levels of household electricity usage and cost are displayed electronically and prominently. The impact is commonly measured by comparing household electricity consumption after the treatment with that of a control. The control is composed of households with similar attributes that do not receive the information treatment or the treatment consumer's historical usage provides the basis for comparison (or both). If electricity usage of the treatment participants is lower than that of the control participants, that result is attributed to the feedback treatment.

A statistical test is used to determine if the measured difference is significant (meaning that there is a relatively low probability that the difference would arise by chance alone). This analytical approach establishes association but not necessarily causation. Moreover, it does not provide a detailed characterization of the process by which the result was accomplished by consumers. Finally, this framework-free analysis limits the extent to which the results can be extended to other circumstances—to customers of different demographics living in difference premises and paying different prices. As noted in the previous section, one researcher suggested that the large difference among three pilots using the same feedback technology was due in part to price differences but was not able to provide confirming support for that contention.

Many behavioral models offer a description of the process by which information alters behaviors. However, these conceptual characterizations are often difficult to confirm empirically in a way that allows them to be extended beyond the narrow circumstances of the pilot. This may explain why so many pilots have been commissioned, despite a growing body of pilot estimates of feedback impacts. Stakeholders are still trying to understand how and why information, apart from the influences of price changes, affects consumer electricity usage.

To value various feedback delivery mechanisms, it is necessary to develop a credible explanation of the behavioral processes that lead to this outcome and identify a method to measure the relative size of these influences, both initially and over time. One approach is to characterize consumer demand for electricity by explaining why and how consumers allocate expenditures to electricity and other goods and services in the absence of any price change. Through a detailed and rational explanation of this budget reallocation that occurs, it is possible to develop a framework for empirically establishing the extent to which observed changes in usage by consumers exposed to information treatments are indeed attributable to that treatment. In turn, this framework will guide the design and evaluation of pilots to resolve what so far have been ambiguities about what transpires. Moreover, if such a specification is extensible—that is, it incorporates and accounts for consumer characteristics and circumstances—pilot results can be used to estimate the impacts in other market, customer, and information treatment circumstances.

EPRI developed an electricity demand model that accounts for and rationalizes why more detailed information about the costs of electricity consumption influences household electricity expenditures. The foundation for this model comes from the economic theory of demand that characterizes price and other influences within the context of rational behavior. *Rationality* in this context means that consumers consistently and persistently seek to acquire the maximum satisfaction from the income available and products and services they can buy.

Such a model provides a theoretical framework for designing pilots and tests specifically to verify feedback impacts. This framework will help utilities and others design and carry out rigorously constructed pilots to understand the nature of the impact of information feedback. Based on the data generated during such pilots, the framework is a way to quantify those impacts empirically, both in the context of the pilot and more generally.

An Economic Framework for How Information Influences Electricity Consumption

A traditional conceptual model of overall consumer or household demand focuses on residential electricity demand and on consumers' response to price, keeping other factors constant. However, these other factors are not always constant, and changes in them can be the primary influence on consumption, particularly when prices are relatively stable. Factors such as weather, changes in the daily routines of inhabitants, and episodic changes (such as additions to or reductions in the number of household inhabitants) influence electricity consumption.

Potentially, feedback designed specifically to affect electricity consumption does so as well. It is therefore important that a behavioral model account for all influences and provide a way to describe the extent to which these behaviors comport with observable and rational consumer behavior. Moreover, the framework must distinguish between short-run adjustments and long-run changes in consumption—an important distinction in other behavioral models, as discussed in Section 2.

To understand how these factors interact to affect electricity consumption, the economic model must account explicitly for the fact that consumers derive their demand for electricity primarily and indirectly through their demands for the services of electrical appliances (Sexton and Sexton 1987 and Reiss and White 2005). Changes in electricity consumption in the very short run are conditioned on (that is, limited by) the available and fixed stock of electrical appliances. Those devices define the physical nature of what service can be provided by a specified level of energy; examples include the following:

- The amount of hot water or cool air provided by a kWh
- The amount to time a television or PC can run on a kWh
- The energy required to power the household lighting needs

However, electricity demand in the medium or long term is jointly determined along with the demand for the stock of electrical appliances (Dubin and McFadden 1984). As a way to obtain the highest possible value from their electricity expenditures, consumers who are not satisfied with a particular device can elect to buy a new one with different operating characteristics, including one that uses electricity more efficiently. The result is that they now have new choice opportunities because these devices provide equivalent services with lower energy consumption.

To identify the value of feedback, the demand model is constructed conceptually to characterize two conditions, as follows:

1. The case in which information is provided under current rates and billing systems whereby electricity consumers make decisions on electricity use based primarily on information from a prior month's bill. The bill may provide no information or some comparative information, such as last month's usage compared to that of the previous month or to the same month a year earlier (type 1 as presented Section 2, Figure 2-2). However, the consumer receives no information about energy usage rates for individual appliances or devices or the corresponding costs of such usage.
2. The case in which substantially more information feedback is provided to consumers, corresponding to types 2 through 6.

This dichotomy is sufficient to construct a characterization of electricity demand that would distinguish differences among all six categories. Through these comparisons, this model of electricity demand provides the framework needed to understand the relative influences of price and other financial inducements and measures that complement or substitute for information to affect a consumer's demand for electricity.

To identify the effects of information on electricity use and its value to consumers and the utility, the model contains a starting, or reference, point from which the change associated with information, and other influences, can be measured. This reference point is represented in the model by the case in which information results in no change in electricity use. As the following exposition reveals, this case is important because feedback treatments in pilots may be inducing effects that are being overlooked because the analytical protocols applied are not sufficiently detailed. When this reference case is understood, two additional cases are introduced in which information causes electricity consumption to increase and decrease. Together, these cases cover all possible outcomes from the imposition of information treatments. Collectively, they constitute a framework for design in pilots to ensure that all possible effects can be observed, isolated, and measured.

The basic elements of this electricity demand model are described in the sections that follow. A full description of the model is provided in a separate technical brief (Boisvert 2008).

Maximization of Consumer Utility and the Demand for Electricity

The electricity demand model adopted for this study is conceptually similar to the consumer demand model discussed by Braithwait (2000) to explain response to a time-of-use rate structure. In that paper, Braithwait (as in an early paper by Caves et al., 1984) derives the electricity demand function from the consumer maximization of a three-level indirect utility function, which is assumed separable in electricity consumption and other major groups of consumption items. *Separability* implies that consumers sort goods and service into bundles and sequentially allocate the available budget first to goods within each bundle and then among the bundles.

This step-wise process of allocating an available budget to consumption involves a relative valuation process. At each level of budget allocation, the decision on what to spend depends on the value the consumer places on each bundle of goods and services, in effect describing a hierarchical and conditioned behavioral process. When a decision is made at each level, it can be revisited at subsequent budget allocation stages.

In the case of electricity, *separability* implies that consumers assign different values to electricity consumption based on 1) the time of day and the time of year the electricity is consumed and 2) how the electric device provides services. This results in a series of electricity service bundles to which the budget can be allocated. At the first level, the consumer determines overall electricity expenditures as a proportion of overall spending, reflecting the relative prices and demand for electricity in relation to the prices and demand for other consumer goods. At the second level, the consumer allocates monthly usage between weekdays and weekends. Finally, weekday electricity usage is allocated by a consumer between time periods in which electricity prices may or may not differ substantially, for example mid-day and all other hours.

This demand model is best understood within the broader context of a general model of consumer demand and spending on major categories of consumer goods. It is not necessary in this larger model to assume that the consumer's utility function is also separable in the other major categories of consumer goods, but in so doing, we are able to simplify the discussion and make more transparent the way in which information can affect the demand for electricity.

By invoking the assumption of separability across all major groups of expenditures, a consumer's entire utility function can be conveniently represented as a tree whose branches indicate the sequence of decisions involved in budget allocation (Pollak 1971). Such a characterization is depicted in Figure 4-1. It has considerable intuitive appeal in thinking about consumer demand because within this structure, each branch of the tree corresponds to a subset of commodities, such as food, housing, electricity, and other energy.[7]

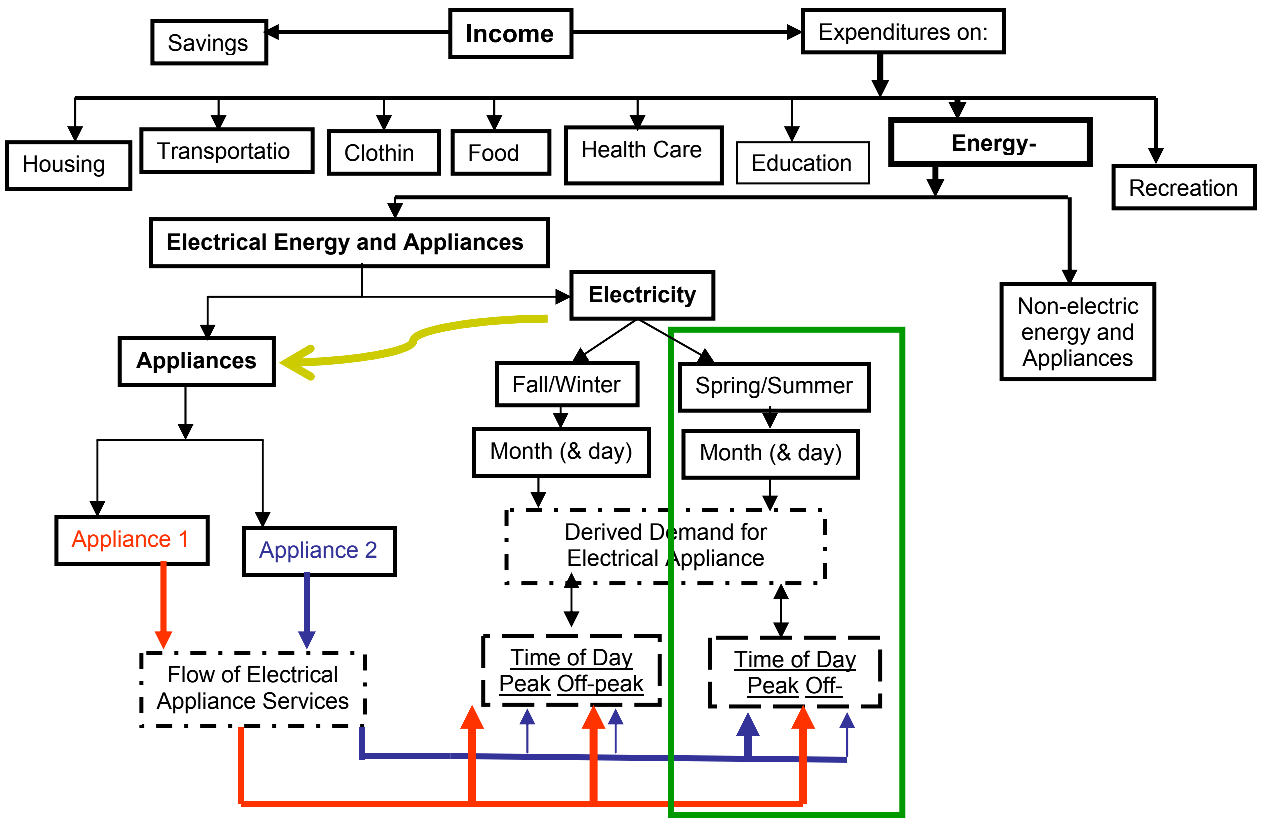

Figure 4-1
Consumer expenditures and demand

It is instructive to examine Figure 4-1 in greater detail. At the top of the figure, consumer income (which is assumed to be fixed for the budget period) is initially allocated between savings and expenditures. Expenditures are then allocated to the eight major expenditure categories listed at the next level of the tree, one of which is energy, which is defined to include purchases of electrical and non-electrical energy as well as the electrical and non-electrical appliances that provide services to customers.

[7] From a strict theoretical perspective, the critical assumption in this separable characterization of demand is that an individual's preference between two collections of goods that differ only in the components of one subset are independent of the identical other components in the two consumption baskets. In addition to its intuitive appeal, this assumption of separability allows for the identification of *conditional* demand functions for goods on any branch of the tree. These conditional demand functions can be defined for when one or more goods are pre-allocated. In general, a conditional demand function for a good in the remaining subset that is not pre-allocated expresses the demand for that good available, as a function of (1) the prices of all goods in the subset of goods not pre-allocated; (2) total expenditures on the subset of goods; and (3) the quantities of pre-allocated goods (for example, Pollak 1971, p. 424).

Within each of the major categories of expenditure, the tree could be expanded to reveal other smaller branches that reflect how these expenditures are allocated among the subcomponents of each category. For example, it would describe the allocations among meat, vegetables, grains, and so on in the food category; among dental care, medical care, and so on in the health care category; and among movies, concerts, traveling, and so on in the recreation category). Likewise, electricity is further delineated into distinct services such as lighting, HVAC, electronic devices, ovens, and refrigerators, which are embodied in the derived demand for electric appliances services.

To characterize the effects of information about electricity costs, it is necessary only to delineate the additional branches of the utility tree that depict how total expenditures for household-related energy are allocated. From this point, the branch corresponding to household energy-related expenditures divides into three smaller branches: 1) expenditures on electrical energy, 2) expenditures on electric appliances, and 3) expenditures on non-electric energy and appliances. The branch for electrical energy and appliances divides further into 1) spending on electricity and 2) spending on electrical appliances.

This latter division suggests that consumers make conscious decisions on how to divide electricity-related spending between purchases of electricity and appliances that can affect the amount of electricity consumed in deriving utility from the services provided by their stock of appliances. In contrast to routine expenditures to pay the electricity bill, electrical appliances are durable goods that are purchased infrequently. From the terminology coined by behavioral scientists (described in Section 2), these are purchase-oriented or investment-related behaviors. To characterize the decisions about budget allocations on these durable goods relative to consumer spending for electricity, we can treat appliance purchases as a stream of payments, as if they were financed, or equivalently annualize the appliance cost if it were purchased outright. This makes the purchase of an appliance comparable with the electricity payment; therefore, expenditures over any period of time (for example, a month) can be allocated between these two expenditure categories.

In Figure 4-1, we can also trace the two branches that further allocate the spending on electricity. For illustration, it is convenient to distinguish between purchases by major season (fall/winter) and (spring/summer) to reflect, for example, that heating and cooling are distinct services. By continuing down these branches, we can further distinguish between monthly and daily expenditures and finally to electricity use by time of day. The models of electricity demand used by Braithwait (2000) and others correspond to either of these two smaller branches of the tree.

To illustrate how this budget process works, it is convenient to begin at the bottom of the tree.[8] This is where weekday electricity usage is being allocated by a consumer between time periods, for example, by separating the afternoon and early evening hours form all other hours of the day. That allocation will be different because of how electric services deliver value, even if prices are uniform (that is, do not vary over the day). At the next level, monthly usage is allocated between weekdays and weekends, while at one level above, overall electricity expenditures as a proportion of household energy-related spending are determined—and so on back up to the trunk

[8] *Separability* refers to a hierarchical structure of choosing among products and services that can work in either direction; starting with individual goods and services and working upward, or by first allocating the budget among aggregations and then making allocations with each.

of the tree. At each successive branch, these allocations of expenditures are based on the relative prices and demand for electricity in relation to the prices and demand for other consumer goods.

Figure 4-1 makes explicit the interrelationships among the existing stock of electrical appliances, the flow of services that can come from these appliances, and the fact that it is the derived demand for these services that determines the demand for electricity by time of day. The level of appliance services demanded is reflected by the width of the arrows.

The results based on separability of expenditure decisions mean that demand for electricity for any day of the month or any hour of the day can be expressed as a function of electricity prices that may differ across hours of the day, between seasons or among months, and due to the total monthly expenditures on electricity. The latter effect leads to one obstacle in the empirical specification of electricity demand. Separability implies that income and the prices of goods other than electricity enter the demand function for electricity only through their effects on total expenditures for electricity (Silverberg and Suen 2000, p. 297). Therefore, changes in prices of other goods and income would act as shifters in the demand functions for electricity.

The validity of this separability hypothesis is an empirical question: do consumers actually use this hierarchical process? However, it has rarely been tested in a formal statistical sense. The data available for the estimation of electricity demand rarely contain information about income and prices of other goods for residential electricity consumers. Conditional demand functions allow the estimation of electricity demand using only electricity prices. They provide a reasonable approximation of electricity demand, particularly for commodities such as electricity, whose demands in the short run are constrained by the performance characteristics of the household's stock of electrical appliances.

A Model of Conditional Demand for Electricity

This section describes the derivation of conditional demand specifications that are consistent with the notion of rational consumer utility maximization. Those willing to accept that such a formation can be constructed may refer to "The Effects of Information on Electricity Consumer Behavior" (later in this section), where its implications are discussed.

To derive the conditional demands for electricity, it is important to recognize that under the assumption of separability the consumer's preferences for electricity can be characterized by an indirect sub-utility function (Cornes 1992, p. 152). Adopting the notation by Sexton and Sexton (1987), this sub-utility function is constructed to reflect the fact that the demand for electricity is derived from the services (for example, heating, cooling, personal computing and TV viewing, hot water heating, and washing clothes) provided through the operation of electrical appliances (as shown in Figure 4-1). Therefore, the demands for both appliances and electricity are derived from these demands for appliance services.

The Consumer's Sub-Utility Function for Electricity

Based on these assumptions, the sub-utility function for electricity (from which the conditional demand function is derived) can be expressed in terms of the fixed stock of appliances the consumer owns and an aggregate index that represents the level of all other goods and services. This index accounts for the position of the conditional demand for electricity in price/quantity space (where the demand curve crosses the price and quantity axis) and is established by the prices for other goods and the level of available income. Assume that there are j = 1,…,N appliances. Each appliance is denoted A_j, and X represents the prices of other goods and income as an index). The consumer chooses the rate of utilization for each appliance, R_j. A consumer's direct sub-utility for electricity can be expressed as:

$$U = U(R_1, ..., R_N, X) \qquad \textbf{Equation 4-1}$$

The consumer's utility or satisfaction (U) is derived by using the appliances that are available (R_n). The consumer maximizes satisfaction by choosing the rate at which each appliance is used.

Define the price of electricity as m (in dollars per kWh) and the kWh requirement per unit of service for appliance *j* as K_j. Accordingly, the cost, or price, of a unit of service from the use of an individual appliance is:

$$P_j = mK_j, \; j=1,...,N \qquad \textbf{Equation 4-2}$$

This "price" (P_j) is the appliance's kWh requirement per service unit multiplied by the cost per kWh.

Based on the separability assumption, the consumer can maximize the utility derived from the use of electrical appliances (using Equation 4-1) by choosing the N appliance utilization rates subject to a constraint on total spending for electricity. This constraint is designated by B, for a specified time period (for example, a month), as follows:

$$B = \sum_{j=1}^{N} [R_j] P_j \qquad \textbf{Equation 4-3}$$

Equation 4-3 expresses the budget as the sum of the products of the selected appliance usage rates (R_j) and the respective appliance prices (P_j).

For a well-behaved utility function, the simultaneous solution of the first-order conditions for utility maximization yields demands for N optimal appliance utilization rates for a given expenditure on electricity as follows (see Boisvert 2008 for details): [9]

$$R_j^*(P_1, ..., P_N, B, X), \; j=1,...,N \qquad \textbf{Equation 4-4}$$

[9] These utility maximizing demand functions are consistent with the sub-indirect utility function: $U^* = U^*(R_j^*(P_1, ..., P_N, B, X), ..., R_j^*(P_1, ..., P_N, B, X))$. A demand curve for an appliance utilization rate is derived as the negative of the ratio of the partial derivative of indirect utility with respect to the appliance price and the partial derivative of indirect utility with respect to the electricity expenditure constraint (Silberberg and Suen 2001, pp. 261–272).

These utility maximizing utilization rates depend on the N appliance prices (P_j), total electricity budget (B), and the other prices and income (X) that shift the demands for these appliance services.

Even though such detail is not incorporated specifically into the algebraic model, it is easy to visualize that even under a fixed utility rate of "m" per kWh, the demand for electricity may still differ by season, weekday, and weekend or by time of day, depending on the efficiency (for example, price or cost of utilization) of the fixed appliance stock and differences in the times at which the services from a particular appliance are demanded. In such a specification, weather plays an important role for some services (such as heating and cooling), and household demographics and circumstances play an important role for others (such as hot water usage and television and electronic device operation).

In a more general formulation, such as is depicted in Figure 4-1, each appliance might be labeled with a second index for the season, day of the week, or time of day that the appliance is most frequently being used. For the purposes of this report, the impacts of feedback can be traced using the simpler, fixed electricity-level formulation.

The Role of Information Within This Framework for Electricity Demand

Despite the lack of specific information about electricity prices and appliance efficiency, consumers today do make electricity consumption decisions daily. The total expenditure for electricity becomes evident typically only at the end of the month or at the end of some other billing period when payment is required. In this situation, Sexton and Sexton (1987) argue that consumers must view individual appliance-service prices and the monthly bill as jointly determined random variables. In other words, their monthly bills are subject to fluctuations that are externally generated and beyond the consumer's control. Further, if consumers are risk neutral (that is, they express neither an aversion to nor a preference for risk), they base their electricity consumption decisions on subjective expectations about these appliance-service prices and the corresponding electricity bill.

Formally, risk-neutral consumers base electricity consumption decisions on expected appliance service prices—denoted by $\{(\hat{P}_1,...,\hat{P}_N)\},\ j=1,...,N$ — that are selectively determined (that is, the decision includes their view of the sources and influences of the random factors). The budgeting process now includes an element of uncertainty because selecting the service rate of appliances up front (at the beginning of the month, for example) involves speculation on what those service costs will be.

The individual appliance service demand functions are functions of these expected prices. In contrast to Equation 4-4, the appliance demands for pre-determined electricity expenditures and so on are:

$$R_j = R_j(\hat{P}_1,...,\hat{P}_N),\ j=1,...,N \qquad \textbf{Equation 4-5}$$

These decisions on the rates of appliance utilization must satisfy the requirement that the expected monthly bill, $\hat{B}$, must equal the sum of the expected appliance-service prices multiplied by the appliance utilization rates:

$$\hat{B} = \sum_{j=1}^{N} R_j(\hat{P}_1, ..., \hat{P}_N)\hat{P}_j$$ **Equation 4-6**

Because the only information made available to consumers is the actual monthly bill, B*, they are afforded the opportunity to verify the accuracy of their price and expenditure expectations only periodically (for example, each month). Denoting the actual appliance-service prices as P_j*, this would imply the following:

$$B^* = \sum_{j=1}^{N} R_j(\hat{P}_1, ..., \hat{P}_N)P_j^*$$ **Equation 4-7**

How are these expectations formed? The monthly bill typically contains limited information—the amount of energy used and perhaps some comparison of the current and a recent month's usage. This limited information is useful only to the extent that such detail enlightens the consumer's expectations for the coming month. Consumers can employ an iterative process in which their observations of successive bills may lead to adjustments in electricity consumption over time. They would form expectations each month and compare the actual bill to what they expected. Then, based on any differences, they would revise their expectations for the next month, seeking to improve the forecast so that what they actually pay approaches what they expected (and desired) to spend. The outcome of this learning process depends on the nature of the uncertainties.

If such a process is typical of consumer behavior, a consumer's electricity consumption behavior would converge to what Sexton and Sexton (1987) call a *minimum-information equilibrium* in which the expected budget for electricity approximates the actual budget. However, what if more and useful information were available to assist the customer in this process of adaptive learning? More detailed or frequent information about how well actual consumption and expenditures are tracking what was budgeted may hasten the process of resolving the adverse effects of uncertainty, in effect reducing or even eliminating it.

The value of this additional information to consumers would depend in part (but only in part) on how successful this information is in helping them converge to this equilibrium. Therefore, information may have value—but not necessarily so. Moreover, the way in which the benefit is manifested depends on how the information affects the consumer's budget allocation process.

Three cases characterize the outcomes of providing more information to consumers about their electricity usage level and pattern:

- Case A: The expected bill converges to the actual bill.
- Case B: The expected bill consistently underestimates the actual bill.
- Case C: The expected bill consistently overestimates the actual bill.

To understand how this decision outcome framework helps place a value on information, it is instructive to consider first the case in which the expected bill converges to the actual, Case A. This provides a basis for deriving the implications from the other cases (B and C), thereby offering insights into the design of programs that generate useful information about electricity consumption.

In Case A, the expected bill is approximately equal to the actual bill. In order for the consumer's expected total electricity bill to converge to the actual bill, each expected appliance service price must converge to its actual price. In the strictest sense, uncertainties about every aspect of appliance service are removed. This latter condition is sufficient to achieve this minimum-information equilibrium, but it is not necessary. The expected bill also converges to the actual bill, even for consumers who continue to make errors in forming appliance service-price expectations, as long as the sum of positive errors cancels the sum of negative errors. Whether these errors cancel for any specific consumer (or segment of consumers) is an empirical question.

The Effects of Information on Electricity Consumer Behavior

As discussed previously, feedback measures can range from enhanced billing (type 2) to advanced technology, such as smart meter-derived real-time consumption through energy display devices (type 5) or HANs (type 6). However, to be of value to consumers, that information must provide a means by which consumers can alter expected electricity expenditures and/or expected per-unit appliance service prices. It would do so by affecting the perceptions about electricity price, m, or the relative efficiency of appliances, k_i. The effects of this information are illustrated through a two-appliance example.

Case A. Assume that the expected bill approximates the actual bill at the minimum-information equilibrium. For the (simplifying) two-appliance example, suppose that access to information leads to a change (increase) in the expected service price of appliance 1. It follows that there is a corresponding change (decrease) in appliance 2's expected service price. Otherwise, equilibrium conditions are violated.

To illustrate, assume that appliance 1 is a major electricity-using appliance, such as central air conditioning, and appliance 2 is a composite of all other electric appliances. Further, suppose that through systematic experimentation with a display device that lowers the temperature by one degree, the consumer realizes that the contrail air service cost is greater than she originally anticipated. There must be a complementary downward adjustment in other electricity usage so that the minimum-information equilibrium, consistent with holding to the budget allocation for electricity constant, is restored.

Based on our theory of electricity demand, appliance utilization rates vary inversely with expected service prices, so that these revised service price expectations would lead to a decrease in electricity use for cooling and an increase in electricity use for other appliance services.[10]

[10] Sexton and Sexton (1987) derive these relationships formally.

To summarize, if we make the assumption that consumers use the information/feedback, we gain important insights into the value of information even from this very stylized model. If consumers have converged to this minimum-information equilibrium prior to receiving the new information, one would expect no change in electricity usage. For this reason, it may be tempting to argue that while there is a benefit to consumers from being provided with useful information, there is no direct benefit to the utility or to the electricity system. One reason for arriving at this conclusion is that this stylized demand model does not specify how the change in demand for the services of certain appliances alters electricity by season or by time of day. For example, under these conditions, the energy reductions may be coincident with peak demand, and thus, lead also to demand (kW) savings. However, the model as specified does not reveal if that is indeed the case, although the model could be expanded to do so.

An important aspect of convergence is that if, by chance (and without receiving the additional information), a consumer's subjective expected price for each appliance converges to the actual service prices, or nearly so, there would be no change in total spending on electricity, nor would spending be reallocated among appliance services. Under these assumptions (as unlikely as they may be), information would be of no value either to the consumer or to the utility, because it does not influence the level or pattern of electricity consumption. Although an unlikely scenario, unless our model embodies this scenario as a limiting, extreme case, the model cannot reveal the value on information/feedback when it is manifested. Therefore, this limiting case provides a baseline against which the changes in electricity consumption due to information/feedback can be compared. This is best seen through a consideration of the other two cases mentioned previously.

Case B. In this case, the consumer's subjective estimate of the bill consistently underestimates the actual bill. As a result, the consumer's expenditures exceed the budgeted amount. In this case, the effect of information (unless it is completely ineffectual) almost certainly results in lower electricity consumption as a first step in adjusting to the new information. However, this frees up budget that now can be spent elsewhere, some of which may be spent on electricity, offsetting somewhat the initial impact of information.

The consumer's overall level of utility will increase because, by spending less on electricity, the consumer can now reallocate that surplus to other goods—to other major expenditure categories such as food and clothing as depicted in the utility tree shown in Figure 4-1. Thus, there is now an equal or more than compensating increase in the level of utility or satisfaction due to the additional spending on other goods; otherwise, the consumer would not have reallocated expenditures.

This second step in the adjustment, which leads to a reallocation of some spending on electricity to other goods and services, will occur only if the information helps the consumer to formulate better appliance service-price expectations. The end result is that electricity consumption falls and there is no additional change in total electricity consumption as the result of the reallocation of the electricity budget surplus generated by the first step in the adjustment.

Case C. In this case, the consumer's subjective expectations lead to consistently overestimating the bill. This case is treated last because, given the increased cost of energy and especially electricity in many markets in recent years, this situation may be less relevant than either of the other two cases—but that can be settled only through careful research.

As in Case B, the consumer's adjustment to new information about the bill is portrayed as involving two steps. After the consumer receives the information and realizes that he/she was overestimating electricity costs, the level of spending on electricity will now increase. By bringing spending in line with expectations, the consumer's utility has increased because the consumer now spends a larger part of the pre-determined budget for electricity. In doing so, there is an overall increase in the consumer's satisfaction.

As a result, there is a reduction in spending on other goods and services and a corresponding loss in utility. But overall there will be a net increase in the consumer's satisfaction because the marginal gain in satisfaction from extra spending on electricity exceeds the loss in satisfaction from lower expenditures on other goods and services. Otherwise, the consumer would not make the reallocation. However, in this case, the impact of information is to increase electricity usage.

The analysis of these three cases is instructive. It demonstrates that if consumers incorporate information/feedback into their decision process, effects of information on changes in behavior can be characterized both in terms of total electricity use (for example, a conservation effect) and in a reallocation between different appliance services that may or may not have implications for changes in electricity usage by season or by time of day. The model as formulated indicates what to look for (and measure) to determine whether an information treatment results in the reduction of electricity usage.

An important implication for pilots that seek to measure feedback impacts is that participants may fall into one of three categories:

A. Those who benefit from the information by reallocation of the electricity sub-budget, which results in no change in electricity usage

B. Those who benefit by reducing electricity usage because they were unintentionally spending more than they were receiving in value

C. Those who increase total expenditure on electricity because they unintentionally under-valued electricity services

If the study measures the impact of information only by the extent to which household electric energy (kWh) is reduced, it will underestimate the actual benefit of the extent to which participants fall into category A or C.

Although these results are significant, this stylized model reveals nothing explicitly about the impact on the load profile (timing of consumption) or about the reallocation of electricity use. However, the model could be expanded to include such detail (for example, the time-of-use detail for the fall/winter season in the green box in Figure 4-1). Because of peak load concerns, this additional detail could reveal the value of any overall electricity conservation both to consumers and to the market if the information leads to a reallocation away from the system peaks. The value of this load shifting could be determined *ex post* by attributing a monetary value to improved reliability (in the short term) or through the avoided costs associated with the reduction in the generation investment requirements (in the long term).

An Extension to Purchases of More Efficient Appliances

As a result of uncertainty about prices, consumers maximize welfare using price forecasts. These predictions are based on the assumptions that the expected spending on electricity is pre-determined and that expenditures are conditioned on an existing stock of electrical appliances. However, the magnitude of these changes could be affected by the type of information or feedback deployed. Furthermore, although not transparent from the basic model, other types of changes in behavior may also be reasonable to expect in response to improved information. For example, when price expectations are improved, a reallocation of expenditures among appliance services may also be accompanied by an *ex post* adjustment in total spending—even if the consumer is able to accurately predict the total bill.

In an expanded discussion of this model, Boisvert (2008) demonstrates how changes in both expected electricity spending and in investments in new appliances affect the demand for electricity. If the information or feedback leads a consumer to the conclusion that the cost of the service for a particular appliance is much higher than was expected, the purchase of a more efficient appliance could result.

However, it is likely that the purchase of the new appliance was, in part, based on the expectation of a reasonably short payback period. Therefore, in the intermediate term, this purchase may be paid for by a shift of some portion of the combined budget for electricity and electrical appliances away from the purchase of electricity necessitated by the increased annualized cost of electrical appliances resulting from the purchase of the new appliance. This shift from spending on electricity to the annualized cost of appliances due to the purchase of the new, more efficient appliance is depicted in Figure 4-1 by the arrow connecting the associated branches of the utility tree. As one might expect, an investment in more efficient equipment, spurred by information, would lead to lower electricity consumption. Utility programs designed to inform consumers about the potential savings from the purchase of more efficient appliances intend to achieve just such an expenditure reallocation.

Furthermore, these effects of information on electricity usage in both the short and intermediate terms are unlikely to happen in isolation. These effects may also have to be disentangled from the effects of higher electricity rates or new rate designs on overall electricity consumption and its time of use. The addition of such intervening influences would add to the complexity of any experimental design that is focused on measuring the impact of information. The analysis of these complexities may well be facilitated through the coordination of experimental designs across utilities.

Implications for the Experimental Design to Estimate the Value of Information

The conceptual model introduced in this report offers a framework around which to structure an experimental design to quantify the value of information to consumers, to the utility, and to the electricity system. We do so by first understanding how rather simple experimental designs can be constructed to be consistent with the predictions from this model. We can relax a number of the model's assumptions and determine how these can be accommodated through a more complex experimental design.

Prior to the time when Sexton and Sexton published their paper, this simple model of electricity demand under budget and price uncertainty appeared consistent with their interpretation of the collective research on the effects of information; information treatments did not affect electricity use. This conclusion stems largely from experimental designs that were constructed to facilitate statistical inferences regarding differences in mean electricity consumption across treatment groups based on fixed effects models of analysis of variance (ANOVA).[11]

For example, this often involved a comparison of the mean electricity usage of consumers who received an information treatment with that of a control group. The statistical test indicated whether any differences were statistically significant. However, these statistical models cannot reveal any inter-household reallocation of expenditures that may have been undertaken. Moreover, if consumers have had the time to converge to a minimum-information equilibrium, there would be no reason to expect any differences in total electricity consumption. In situations in which some consumers were not in this equilibrium position, the authors argue that this same result might also be obtained as long as there were equal numbers of consumers, or nearly so, who over- and under-estimated total expenditures on electricity.

Whether these situations were true—either then or now—is of course an empirical question. However, these conclusions would seem at odds with a number of more recent studies described previously that report significant annual reductions in household kWh due to information availability.

Current billing practices followed by many utilities are not particularly conducive to encouraging adaptive behaviors by consumers such as those described by the information impact model discussed earlier. Many households receive bimonthly billing; this frustrates attempts to compare expectations with actual usage. The use of fuel adjustment clauses that are neither announced nor communicated in advance of their applicability makes such comparisons even more difficult. The difficulties can only be exacerbated for bills that arrive during transitions between seasons. Finally, the information provided on bills is generally limited to gross comparisons of expenditures and kWh between the current and the previous month or to the same month a year earlier and are of limited use in promoting constructive adaptive behaviors. Unless the consumer keeps individual records, including detailed information about individual appliance usage, there would be little basis on which to formulate and revise subjective expectations based only on measured usage.

Although these recent empirical results and other observations are sufficient to question the validity of either of the two assumptions on which Sexton and Sexton draw their conclusions, the annual reductions in most of these recent studies are extrapolated from the results of pilots or studies that in some cases ran for less than a year. Moreover, few of them appear to have attempted to characterize the point at which these reductions occurred or extrapolate the energy

[11] A simple ANOVA model with fixed effects could be given as:

$$\text{kWh}_{ij} = \beta_i + e_{ij}, i = 1,...,I;\ j = 1,...,n_i, \{e_{ij}\} \sim \text{NID}(0,\sigma^2)$$

where KWh_{ij} is electricity consumption for household j in treatment group i, and β_i is the population mean electricity consumption for treatment group i. The hypothesis tests associated with this model generally involve the equality of all or some of the β_i's.

savings to the implied demand (kW) savings, although current pilot designs are attempting to investigate this. Only a portion took measures to determine whether these reductions would persist. Finally, generalizations are particularly difficult because of the pronounced differences in the information treatments provided.

The Experimental Design of Information Impact Pilots

This discussion illustrates the influence of information on consumer electricity consumption behavior in both the short term (budget reallocation among non-durables) and in the long term (the capital investments in devices). Effort to verify and quantify these behavioral changes clearly requires a disciplined and concerted approach. The critical aspect of information impact field research, pilots, experiments, and other consumer interactions is the development of an experimental design that will properly and precisely identify the magnitude of the information effects and distinguish them from other influences. Although somewhat naïve in light of current data management and computational capacity, the theoretical model by Sexton and Sexton highlights several of the critical effects of information on electricity use.[12] The authors also offer some initial advice on the kinds of analyses that are needed to estimate the effects empirically.

For example, some of the difficulties in deriving the effects of information on electricity usage can be overcome through disaggregate models of analysis of covariance (ANCOVA), as used by Sexton et al., 1987. Even these models underscore the need to treat households or firms as individual observations. However, if these more disaggregate models focus on total electricity usage, they still capture only the *inter-household* effects that may tend to cancel out in the more aggregate models. They do not capture the *intra-household-inter-appliance* substitutions and cancellations that are critical to an understanding of whether and how information affects electricity consumption. For this reason, it is no surprise that Sexton and Sexton suggest that the ideal strategy would be to measure household electricity usage by appliance. Lacking the data to do so, they recommend that the focus be on usage during important times of the day. This data shortcoming can be corrected in a well-designed pilot.

Although these sentiments may have been less well known when Sexton and Sexton published their paper, there are few, if any, current practitioners of electricity demand who have not echoed these sentiments at almost all stages of their empirical work. In a recent study of household electricity demand, Reiss and White (2005), for example, claim to address several of the interrelated difficulties posed by nonlinear pricing—in particular, heterogeneity in consumer price sensitivity and consumption aggregation over appliances and time. Because of data limitations, they were also unable to apply their model directly at the appliance level.

This latter difficulty can, to some extent, be overcome by models that account explicitly for electricity usage at times of the day when certain appliances are in heavy use. However, the implications of implementing such a strategy in a study to investigate the effects of information on electricity use, but one in which prices do not differ, are significant. That is, unless prices differ, the models will fall under the heading of conditional demand models that also date to the

[12] Despite its simplicity (even in light of the elaborations), the theoretical model originally developed by Sexton and Sexton highlights the important ways in which information could affect electricity usage. One could add complexity to the model (for example, more appliances, risk averse behavior, and complementary appliance services), but the major results would remain largely unchanged.

1970s (EPRI 1984). The major difference is that separate models could be estimated for different times of day. Regardless, any experimental design must document the existing appliance stock (including age and efficiency) for both control and treatment groups. Ideally, the experiments should be in the field for a sufficient time to allow new information to affect the purchase of new appliances.

Despite the limitations of these conditional demand models for the estimation of conventional demand functions for electricity, the inclusion of price differences in the experimental design of a study to investigate the effects of information on electricity use has its own set of problems. That is, suppose one of the information treatment groups is faced with time-differentiated prices along with new information. Further, suppose that we observe a shift in demand away from the high-priced period. According to the theory, the shift could entirely be the result of the higher price, or it could be a combination of the response to the higher price and improved information about estimated appliance prices for those used heavily during that high-priced period. It would be difficult to disentangle the information and price effects.

To manage combined price and information treatments, we would need an experimental design with three groups: a control group (no time-differentiated prices and no information), a group with only time-differentiated prices, and a group with both. As we have seen, some studies have made such efforts, the most recent being the assessment of time-of-use pricing and energy display devices (Hydro One 2008). Similarly, ongoing work at BGE is assessing the interactions between dynamic pricing schemes and pricing display devices (as well as other enabling technology) (Case et al., 2008).

Regardless of these and similar difficulties, it is important to recognize them at the outset—at the experimental design stage. It is more critical if the success of the effort depends on pooling data and, in so doing, leverage investments in these studies. Data remain a limitation, and a priority should be given to gaining from each household, treatment, and control some information on income and expenditures for energy and other major categories if only to organize consumers into groups (such as low, medium, and high income or energy intensive). Moreover, capital expenditures on more efficient appliances must be tracked to identify a reallocation of electricity payments in a way that signals that the conservation effect is permanent. We should have some success in this regard if utilities adopt a common experimental design.

In their design of the information/feedback system, utilities must make sure that the consumers' transaction costs involved in the use of the information technology are not too high. Otherwise, effective use of the technology may be limited at the outset to a small fraction of consumers. At a minimum, we need sufficient socioeconomic and demographic factors to capture these differential effects. If the data are available, these effects might be captured by the creative construction of interaction terms between these factors and the indicator variables for the various control and treatment groups. These factors can shift the response up or down, but these same factors—through the introduction of the interaction effects—may also affect response at the margin.

Where possible, this information should be common to all designs of participant utilities. If experiments were of sufficient duration to allow for appliance purchases, there could even be some chance to model electricity use and appliance purchases jointly. The wide range of contradictory results from information pilots is largely the result of the difficulty associated with the comparison of discretely designed or implemented studies. Past experience with demand response modeling only reinforces the critical need for a common design based on detailed data. The experimental design must also be able to capture the differential nature of a potential for changing behavior embodied in the information technology.

5
HARNESSING THE POTENTIAL OF FEEDBACK

This report synthesizes the results of pilots and experiments involving feedback mechanisms. It does so relying on two theoretical perspectives on the way in which consumers make consumption decisions and the role of information in that decision process—one derived from behavioral sciences and another from economics. Each of these disciplines is multifaceted, containing many disparate branches. However, the perspective of each can be summarized generally as shown in Table 5-1.

Table 5-1
Theoretical perspectives on feedback

	A Behavioral Science Perspective	An Economic Perspective
Behavioral characterization	People respond to their environment (which includes technologies) influenced by individual context and perspective	People maximize satisfaction from fixed budgets
Role of feedback	Fosters learning and implicit goal setting; increases sense of control	Reduces uncertainty and budget allocation volatility
Process	Learning Habit formation Behavior internalization	Allocate budget with reduced uncertainty Modify allocations within electricity uses Modify expenditure allocations among goods
Manifestation	Persistent energy consumption reduction (behavior change) Potentially consider more efficient appliances	Short term: better use of appliance stock Long term: consider more efficient appliances

The term *behavior science* encompasses many disciplines but, at a high level, its behavioral characterization seeks to explain how individuals interact with their environment. One perspective suggests that feedback helps individuals learn from the consequences of their consumption behavior as well as any behavior adjustments they may make as a result of learning. Over time, new habits may form. Eventually, behavior internalization may occur as attitudes adjust corresponding to the new energy-conserving behavior, further contributing to making the behavior permanent.

From an economic perspective, consumers strive to maximize the satisfaction (that is, utility) they realize from expending available, and limited, income. They make tradeoffs among expenditures on available goods and services until no further trades improve satisfaction, resulting in what amounts to a budget for each. Maximizing satisfaction is hindered when consumers lack sufficient information about when and how they use electricity, resulting in electricity expenditures that do not match what was allocated or budgeted. Feedback is a corrective tonic: it reduces uncertainties and results in budget reallocations that can result in more, less, or the same amount of expenditures on electricity. Short-term adjustments, limited because of the stock of appliances and their inherent efficiency, may be expanded as new, more efficient appliances are purchased, which is the outcome of trading ongoing expenditures on electricity for new equipment purchases.

The behavior science and economic perspectives are fundamentally different ways of looking at the issue of feedback from a behavioral perspective. Both have much to offer in creating a foundation for a research agenda to resolve the questions and uncertainties surrounding the effects of feedback on household electricity consumption. The resolution of these issues is essential to inform decisions by utilities and regulators related to the investment and implementation of feedback technologies and AMI. It will also be valuable to technology manufacturers in establish technical requirements and ultimately to consumers who will make more informed consumption decisions.

What We Know from Past and Ongoing Research Initiatives

The review of feedback research reveals several unresolved issues related to the influence of information on household electricity consumption:

- The studies reviewed represent a wide range of conservation effect results; one study reported a negative conservation effect (that is, consumption increased when feedback was provided), while another reported an 18% average conservation effect. The wide variation in reported results is an indication that there is more to be learned before actionable impacts are widely accepted.
- Although past research suggests that direct feedback on average produced a higher reduction in electricity usage than indirect feedback (Darby 2006), to our knowledge there has been no rigorous dual-treatment pilot undertaken specifically to verify or clarify the source of these differences. Given that the associated costs of feedback delivery may increase as one moves from indirect to direct feedback, it is essential to establish the nominal and relative impacts of the different feedback types so that credible cost-benefit analyses can be conducted.
- Within and across different feedback delivery mechanism types, more research on the way in which feedback should be displayed is needed; that is, what design approach, layout, and/or metrics are most salient and most effective in encouraging conservation behavior, particularly across different demographic categories.
- The differences associated with feedback impacts vary considerably even for pilots that used similar feedback delivery mechanisms. For example, thorough pilots in Ontario, Newfoundland, and British Columbia, Canada, used the same energy display device under similar sampling protocols and population frames. However, they reported strikingly

different levels of average reductions in electricity: 7% in Ontario, 18% in Newfoundland, and 3% in British Columbia.

- Pilots that involve prepaid displays, which provide consumers with account balance information only, report energy reductions between 3% and 20%. Because it serves two purposes—mitigating non-payment and reducing household energy usage—and because it can be implemented selectively, this specific delivery mechanism deserves further evaluation.
- The degree to which an initial conservation response persists, which is the primary purpose of providing feedback, has not been adequately established for either direct or indirect feedback mechanisms. Given the size of the investment required, the persistence of the reduction in electricity use will greatly influence the cost-benefit ratio. Resolving the long-term expectation should be part of all newly implemented pilots, and most ongoing pilots appear to be heading in this direction.
- The distributional aspects of feedback across diverse household demographic characteristics have not been fully established. There is some evidence to support the notion that feedback impacts vary with demographics such as household age, but the links are tenuous. These issues need resolution because uneven impacts over the population of households can lead to cross-subsidization. Related to this, a better understanding of variations in feedback delivery mechanism type and presentation preferences across different demographic groups is required.
- There is some evidence that the feedback effect can vary with household electricity consumption level, suggesting that higher electricity consumers may save more. If this is indeed the case, there may be merit to focusing first on higher electricity consumers, especially when the cost of delivering the feedback is invariant to the premise size. This approach, however, may result in cross-subsidization if the feedback effects disproportionately benefit higher consumers; this would need to be reconciled in any program design.
- Few of the studies considered the temporal nature of the reduction in electricity usage or the extent to which the reduction was coincident with system peak demand. These are conventional measures of conservation effects essential to calculating net benefits and cost-effectiveness.
- Most of the studies reviewed involved single-family residences. The effects of feedback in multi-family premises require more attention, especially in areas in which residences include a high proportion of apartment buildings and condominiums.
- Pilots have not provided sufficient insight into how long it takes feedback to produce persistent results. This knowledge is critical for the many markets faced with the need for near-term reductions in electricity usage in order to forestall the need for large, long-term investments in generation resources. It can also inform decisions about whether advanced meters should be configured to support display devices upon installation or be configured in a simpler fashion because the additional costs are not justified by the expectations of benefits. The UK is currently grappling with somewhat similar policy considerations in that there is debate about whether feedback devices should be provided in advance of or in conjunction with AMI deployments (for a review, see Darby 2008).

An economic model was constructed to characterize how feedback influences household expenditure decisions. It provides insight into how feedback impacts can be measured, as follows:

- In the absence of a good understanding of how electricity use translates to the services provided by household appliances and equipment, consumers are constantly spending more or less than they had planned. Unfulfilled expectations have adverse consequences for balancing overall expenditures on electricity and other household expenditure categories.
- Feedback helps consumers equate budgeted expenditures with actual bills. The nature of the adjustment depends on the uncertainty about when and how electric services are used. Feedback helps to resolve this uncertainty, and the result can be a decrease in overall electricity expenditures (that is, savings are reallocated to other goods and services), an increase in overall electricity expenditures (that is, more is spent on electricity at the expense of other goods and services), or a realignment of how electricity is used with no overall change in total usage (that is, greater satisfaction from the electricity expenditure). It is important that all of these possible responses be accounted for in pilots to ensure that the full and proper effects are measured.
- Initial (short-run) adjustments to information involve the more efficient use of existing appliance stock. This may somewhat limit the initial impact of feedback.
- In the longer run, capital expenditures on more efficient appliances may be accelerated (that is, undertaken sooner) or augmented (that is, appliances purchased have a higher efficiency than would otherwise have been the case) when feedback is provided to households. This is another reason to conduct extended pilots to ensure that the full impacts of an information treatment are captured.
- Other sources of information could influence the nature of appliance capital expenditures (for example, Energy Star labeling or utility promotions). It is therefore critical to separate these influences from those associated with feedback so that conservation effects are not double-counted.
- Causal associations may exist between households that respond to feedback and those that have undertaken conservation measures (for example, sealing doors and windows or installing more efficient florescent lights). Feedback may complement or supplement other conservation programs, or it may be a substitute for subsidizing energy efficiency measures.
- Price effects can and should be distinguished from feedback effects to ensure that policy actions produce predictable results.

Collectively, the results of pilots and insights from behavioral models provide a way to establish what needs to be done to fully characterize the feedback effects associated with the range of delivery mechanisms available. Doing so is imperative because regulators and utilities rely on cost-benefit analyses to direct investments. In the case of feedback, the investment can be substantial and irreversible and involve specific delivery mechanisms if feedback delivery is embodied in advanced metering technology. Technology manufacturers also need better estimates of the impact in order to gauge the market for devices that extract and display meter readings or to design and build systems that integrate usage displays with utility metering functions.

Verifying Feedback Impact on Household Electricity Consumption

Recommendations for fully characterizing the effect of feedback on household electricity consumption fall into two separate but related categories. The first relates primarily to the design of pilots and experiments; the second relates to the need for pilot design coordination across many utilities representing a variety of customer and market circumstances.

Design and Data Requirements

- To capture the **intra-household-inter-appliance** substitutions and cancellations, the experimental design must focus on individual households and appliance-specific and time-of-day usage. It should measure the diurnal nature of the change in usage because consumers may respond to feedback by adjusting when electricity is used. If these shifts are coincident with system peaks, the implications for demand (kW) savings can also be significant. Individual household effects must be accounted for to distinguish among the different ways that feedback can influence the budget reallocation process.
- The pilot should be designed to affirm both overall energy and demand effects in sufficient detail to comport with conventional program benefit measurement protocols, such as the cost-effectiveness tests typically applied to energy efficiency measures and demand response programs.
- The experimental design should be sufficiently robust to disentangle a change or shift in usage attributed to the feedback treatment from one that is the result of a change in rates, particularly in dynamic pricing environments.
- Fully disentangling the combined effects of price and feedback requires an experimental design that includes at least three groups: a control group (no time-differentiated prices and no feedback), a group with only time-differentiated prices, and a group with both. If the decision is between implementing a new pricing regime or providing feedback, knowing the difference in the character and level of changes in usage is critical.
- Just because there was no base rate change does not mean that usage prices did not vary. It is important to account for factors that cause routine and unannounced (prior to their applicability) rate variations associated with fuel adjustments. Price changes are becoming more commonplace with the near universal use of fuel adjustment clauses in states with vertically integrated utilities and the increased reliance on periodic outsourcing of energy procurement in customer choice states.
- Priority should be given to collecting from each household, for both treatment and control groups, demographic information such as household size, ages of occupants, and education levels as well as some information on income, expenditures for energy and other major categories, and so on. These data serve as conditioning variables that are essential for sorting the impacts of several potentially confounding influences and provide a way to distinguish important trends and distributional differences.
- To control for other important characteristics that vary among households, it is critical to obtain detailed information about the structure, such as size, age, type of construction, dwelling type (single- or multi-family), heating fuel type, and recent investments in conservation measures. This information is similar to that which might be collected during an

energy audit. Moreover, any changes that occur throughout the pilot period must be recorded so that potential impacts can be properly taken into account.

- Pilots should be conducted for a sufficiently long period to establish persistence. Changes observed in a pilot of only one year may be associated in part with seasonal effects or other transitory influences.
- Where possible, pilots should include different types of feedback delivery mechanisms so that the relative cost/benefit of both can be properly compared. Where this is not feasible, studies should be designed such that the results can be combined with and therefore reliably compared to results in other jurisdictions.
- Care must be taken to select control and treatment groups that are representative of the customer population and are sufficiently large for the empirical results to have statistical validity. All participants should be randomly recruited from the population frame; those who agree to participate should then be randomly assigned to treatment and control groups. When feasible, as a further test, an additional control group that has no knowledge of the study should be employed. Furthermore, it may be beneficial to bolster the sample size of specific population segments to properly assess any variation of effects with specific demographic information.

Taken together, these recommendations underscore the inherent difficulties in disentangling the effects of feedback on electricity consumption from other effects such as price, feedback type, and a host of other factors.

Coordination

It seems unlikely that any single utility can implement an experimental design to account for the interaction among all of the factors described previously. However, a series of coordinated pilots can produce the full set of information required, going beyond what any individual pilot can accommodate.

Additionally, it is unlikely that a single utility's household population is representative of that of all other utilities and markets. Even a comprehensive and locally representative sample will not be fully applicable elsewhere because of differences in the housing stock, household appliances, consumer demographics, and other factors.

A comprehensive resolution of all outstanding issues can be achieved through a cooperative and coordinated effort by many utilities across the country. Such an approach is currently being employed, at least to some degree, in the UK feedback trials described earlier. Similarly, the U.S. Department of Energy has recently launched an initiative to coordinate utility research and field trials to promote the development of smart grid technology. In addition, EPRI recently launched demonstration projects to accelerate the rate at which technical and behavioral issues associated with advanced energy efficiency and smart grid technologies are identified and resolved. Several states are considering coordinated advanced metering pilots involving several utilities. This spirit of cooperative and coordinated research needs to be extended to the study of household feedback impacts as well.

The proposed coordination would effectively leverage the efforts of many individual research initiatives. In order to facilitate such a coordinated effort, the following should be kept in mind:

- It is critical to develop a common and/or complementary set of feedback mechanisms to evaluate, define appropriate control and treatment groups, and identify a common format for sample selection.
- There must be substantial agreement on the amount and extent of the data to be collected and common instruments developed to collect the data. There must also be agreement on how certain variables and other data items are defined; where this is not possible, a general strategy must be developed for qualitatively and consistently ranking or categorizing the data.

A Proposal for a Coordinated Research Effort

Cooperation and collaboration are required for several reasons. Cooperation provides a way to share information quickly and effectively. Those with firsthand experience from pilots and other research initiatives can assist others who are at the discovery stage. In return, they benefit from research initiatives that are directed at resolving outstanding issues, instead of ones that contribute only marginally to the measurement of aspects that are already relatively well understood or produce results that are so circumscribed that they are not generalizable to other circumstances.

Collaboration provides a way to share the field trials and costs of characterizing the many facets of how feedback information influences household electricity usage. Several individual pilots that are launched under the umbrella of a unified design approach will provide data that address different issues of local importance and will at the same time contribute to the overall understanding of how feedback mechanisms work over diverse customer, technology, and market circumstances. Each individual pilot investment will yield returns beyond what would have occurred had it been conducted in isolation.

Lastly, a collaborative and cooperative approach would provide a pool of data that will accelerate the full range of research needed to justify expenditures on technology, devices, and systems. Pooling pilot data will lead to more robust behavioral models that associate consumer response with the full array of feedback delivery mechanisms as well as account for other influences such as the following:

- Pricing (the nominal level and price changes)
- Technology (for example, what type of feedback is provided, what information is displayed, how often, and in what visual manner)
- Household demographics (for example, household age, education, and income)
- Premise characteristics (for example, single- versus multi-family households and appliance and electric device stock and efficiency ratings)

This pooling of data can be accomplished by the formation of a consortium composed of utilities and other stakeholders. Its express purpose would be to resolve uncertainties and subjectivities regarding the impact of feedback on household electricity consumption. An effective consortium would be organized around three key functional services, as follows:

- A web site would serve as directory for finding information about research results and provide up-to-date information about ongoing and planned initiatives. Such an effort would complement existing repository web sites such as the behavioral research bibliographic database administered by Stanford University's Precourt Institute for Energy Efficiency.[13]
- Web casts, workshops, and forums would be sponsored to bring practitioners and researchers together to share experience and address topical issues.
- A research data repository would be developed to contain data from pilots and experiments. This would provide program designers with a way to evaluate how well the various mechanisms work under a variety of conditions. Behavioral models would have the diverse and detailed data required to construct comprehensive models to estimate the expected impact of feedback mechanism under a variety of market and customer circumstances.

This consortium would offer research coordination services to assist utilities considering implementing a pilot or experiment. Each entity would develop its research objectives and establish budgets and other guidelines. These would define the principles under which they would design the pilot independently.

The consortium would then assist in the development of a design that takes into account past, ongoing, and contemplated research activities and propose a research design that fulfills the base objectives and contributes substantially to resolving other outstanding and important issues. When a final design has been formulated, each utility would undertake its implementation following the design protocols. Arrangements would be made to collect data from each pilot, incorporate them into the research data repository, and provide assistance to the utility in evaluating those data and extracting insights and actionable results.

The consortium could also provide implementation services to its members, such as the preparation and administration of requests for proposals and other procurement vehicles; the provision of implementation activities including participant recruitment and selection, evaluation protocol design, and general program oversight; and the performance of other project-related services.

The need for a consortium of utilities to address common issues relating to the value of feedback is pressing, and several pilots are now underway. Others are being designed, and still others are being contemplated. Moreover, the rollout of advanced metering in some markets creates new opportunities to broaden the scale and scope of the research. Evaluated in isolation, they may contribute only marginally to the full and widely accepted characterization of feedback mechanisms and the way in which they affect household electricity consumption. Alternatively, if coordinated, they can provide the information needed for all parties to competently characterize the cost and benefits attributable to providing households with electricity consumption feedback information.

[13] This database can be found at http://piee.stanford.edu/cgi-bin/htm/Behavior/bibliographic_database.php?ref=nav4

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A
PAST STUDIES REVIEWED

Table A-1
Past study summaries

Reference	Location	Duration (months)	Sample Size	Feedback Type	Conservation Effect	Persistence Check?	Incremental Effect of Feedback Over Dynamic Rate Effect	Effect Variation Tested with Customer Type?
Allen and Janda 2006	OH, USA	3	10	5	0%	No.	NA	Surveyed 30 in low-income and 30 in high-income neighborhoods; 4 displays to low-income, 6 displays to high-income; Sample size too small to draw conclusions.
Benders et al., 2006	Nether-lands	5	137	3	8.5%	No. Authors explicitly state this; more research is required.	NA	Not tested; authors believe that it is mainly energy-savvy individuals who participated.
Bittle et al., 1979–80	IL, USA	0.3	267	4	10.5%	No.	NA	Rural. Found that higher electricity consumers saved more; low and medium consumers used more; authors believed that this was exacerbated in higher temperatures.

Reference	Location	Duration (months)	Sample Size	Feedback Type	Conservation Effect	Persistence Check?	Incremental Effect of Feedback Over Dynamic Rate Effect	Effect Variation Tested with Customer Type?
Bittle et al., 1979	IL, USA	1.4	15	4	4%	A 3.5 week monitoring period after feedback stopped for first group; found first group used 10% less than the second group during this time even though second group was now receiving the feedback.	NA	Rural, middle class.
Brandon and Lewis 1999	UK	9	98	4	4%	No.	NA	Results from the model indicated correlation between savings from feedback and environmental beliefs, self-predicted personal behavior (or intention to behave environmentally), usage level of the home, and number of occupants.
Dobson and Griffin 1992	ON, Canada	2	25	6	13%	No.	NA	Sample chosen from a larger sample that was randomly selected.
Elliott et al., 2006	CA, USA	4	152	3	0%	No.	0%	Stratification based on climate zone, housing type, and electricity consumption.
Haakana et al., 1997 (electricity)	Finland	7	79	4	7%	Self-reported behavior about 2.5 years after gas portion had started.	NA	All groups had similar household sizes, attitude categories, and appliances.

Reference	Location	Duration (months)	Sample Size	Feedback Type	Conservation Effect	Persistence Check?	Incremental Effect of Feedback Over Dynamic Rate Effect	Effect Variation Tested with Customer Type?
Horst 2006	MI, USA	12	4	6	Quantification of incremental feedback effect on overall conservation not performed	Not clear.	Quantification of incremental feedback effect on overall shifting not performed "Data provided by the monitoring system gave reasonable physical evidence of the success of the DSM appliance experiment"	Not tested.
Hutton et al., 1986	BC & QC, Canada; CA, USA	12	75	5	1%	Yes. A drop-off in ECI use in 3 locations was recorded after first few months.	NA	Representative sample with some screening, 3 cities (1 with electrically heated homes and cold winters, 2 with non-electrically heating mild winters), 4 electricity strata. Assumed that one stratum was weighted heavily with middle class, more highly educated, more price responsive; hypothesized that effects would be greater here, but saw this in only 1 of the 3 cases and for gas and total consumption (not electricity only).
Hydro One 2008	ON, Canada	5	234	5	4%	No.	Incremental effect of 1.8% over TOU rates	Class type (high and low density residential, farm, general service <50 kW), geographic; results not reported by class type.
IBM 2007	ON, Canada	6	373	2	Quantification of incremental feedback effect on overall conservation not performed	No.	Quantification of incremental feedback effect on overall shifting not performed	Not reported. Sample had higher education and income compared to Ottawa, but similar to Ontario demographic statistics.

Reference	Location	Duration (months)	Sample Size	Feedback Type	Conservation Effect	Persistence Check?	Incremental Effect of Feedback Over Dynamic Rate Effect	Effect Variation Tested with Customer Type?
Martinez and Geltz 2005	CA, USA	2	61	5	Quantification of incremental feedback effect on overall conservation not performed	No.	0%	Sample weighted toward high consumption users; 87% were detached single-family dwellings; most were occupant-owned.
McClelland and Cook 1979	NC, USA	11	25	5	12%	Yes; a check over a period of 11 months found values to "neither increase [n]or decrease over time."	NA	Not mentioned; regressed usage on family and house size; occupants of new, moderately priced homes.
Mountain 2006	ON, Canada	13	382	5	6.5%	Yes. Included a "time trend" in the model; no reduction in conservation effect observed over 13 months.	NA	Results from the model indicate that conservation did not depend on socio-economic factors.
Mountain 2007	NF, Canada	18	58	5	18%	Yes. Included a "time trend" in the model; no reduction in conservation effect observed over duration.	NA	Results from the model indicate that "heating configuration, the presence of electric heating, the size of the dwelling, the number of residents, their income, their levels of education, the number of senior citizens, attitudes toward conservation and seasonality all play a role in affecting the impact" (p. 34).
Mountain 2007	BC, Canada	18	43	5	3%	Yes. Included a "time trend" in the model; no reduction in conservation effect observed over duration.	NA	Results from the model indicate that the "determinant of the responsiveness is the level of education of household members over 14 years of age. As well, seasonality plays a role" (p. 34).

Reference	Location	Duration (months)	Sample Size	Feedback Type	Conservation Effect	Persistence Check?	Incremental Effect of Feedback Over Dynamic Rate Effect	Effect Variation Tested with Customer Type?
Nielsen 1993	Denmark	36	1500	2	10%	Yes, because it was a long experiment. Appeared fairly constant over 3 years, although there was a slight tendency toward increased savings at the start.	For houses, those without higher tariffs saved 3% less than those with; flats consumed 2% more—this is **not** incremental to the feedback effect alone, which was not assessed	Assessed effects in different neighborhood composed of houses and apartments as well as blue and white collar areas; appear to have controlled for income; deem results for entire country, although not obvious how they did this.
Parker et al., 2008	FL, USA	12	17	5	7%	No.	NA	Found that largest consumers had largest savings.
Loren Kirkeide, Principal Analyst –SES, Salt River Project, personal communication, February 18, 2009	AZ, USA	6 (each)	2005/2006 Study: 272 (summer) 191 (winter) 2003/2004 Study: 422 (summer) 202 (winter)	5	2005/2006 Study: 12% 2003/2004 Study: 13%	No	NA	Stratified by season and energy consumption; included various dwelling types and geographic locations. Found no statistical difference between seasons. Found no statistical difference between energy consumption strata.
Robinson 2007	ON, Canada	3	106	4	0%	No.	0%	No. Higher income, higher education in sample; did not control for this in analysis.
Seligman et al., 1978	NJ, USA	1	20	5	16%	No.	NA	Not mentioned.
Seligman et al., 1978	NJ, USA	0.75	15	4	11%	No.	NA	Identical houses; other than this, not mentioned.
Seligman et al., 1978	NJ, USA	1	80	4	13%	No.	NA	Identical houses; other than this, not mentioned.

Reference	Location	Duration (months)	Sample Size	Feedback Type	Conservation Effect	Persistence Check?	Incremental Effect of Feedback Over Dynamic Rate Effect	Effect Variation Tested with Customer Type?
Sexton et al., 1987	CA, USA	10	51	5	-5.50%	Yes. Found that effects were no longer significant in the last 3 months (for peak and total), although this was likely a seasonal effect.	Incremental effect of 1.2% over TOU rates	Homes with displays were selected randomly from the 3 (of 5) largest consumption classes, across 3 temperature zones and 4 peak/off-peak rate structures.
Staats et al., 2004 (electricity)	Nether-lands	7	140	2	5%	Yes. Electricity savings over intervention period were 4.6%; 26 months later (with no intervention in between), they were 8% (compared to initial baseline).	NA	Participants were mostly women, higher income, and highly educated.
Ueno et al., 2006b	Japan	2	8	6	9%	No.	NA	Households included married couples with 1–3 children.
Ueno et al., 2006a	Japan	1.4	10	6	13%	Yes. Tracked number of "button presses" up to 241 days after installation; no obvious downward trend.	NA	Households included married couples with 1–3 children; 1 house included an elderly woman; average floor space 141 m2 (or 1,518 ft2) and 139 m2 (or 1,496 m2); information on age, education, income.
Wilhite and Ling 1995	Norway	36	611	2	10%	Yes, because it was a long study. Savings at end of second and third year were 7.6% and 10%, respectively, so there was an increased savings with time.	NA	Younger, with higher income and more education were more likely to reduce; 25% all electric heating and 50% some electric heating.
Wilhite 1997 from Darby 2006	Norway	21	2000	2	8%	Yes. Evaluation was 16 months after the test period.	NA	Study included a representative sample of households; 25% all electric heating and 50% with some electric heating.

Reference	Location	Duration (months)	Sample Size	Feedback Type	Conservation Effect	Persistence Check?	Incremental Effect of Feedback Over Dynamic Rate Effect	Effect Variation Tested with Customer Type?
Wood and Newborough 2003	UK	2	20	5–6	15%	No.	NA	Not mentioned.

B

FEEDBACK STUDIES AND PERSISTENCE

Table B-1
Feedback study overview: persistence of effects

Reference	Study Duration (months)	Sample Size	Feedback Type	Conservation Effect of Feedback	Persistence Check	Persisted?
Bittle et al., 1979	1.4	15	4	4%	A 3.5 week monitoring period after feedback stopped for first group; found first group used 10% less than the second group during this time even though second group was now receiving the feedback.	Yes, increased
Hutton et al., 1986	12	75	5	1%	Yes, a drop-off in monitor use in all 3 locations was recorded after the first few months.	No
McClelland and Cook 1979	11	25	5	12%	Yes, a check over a period of 11 months found values to "neither increase [n]or decrease over time."	Yes
Mountain 2007 (British Columbia)	18	43	5	3%	Yes, included a "time trend" in the model; no reduction in conservation effect was observed over the duration.	Yes
Mountain 2007 (Newfoundland)	18	58	5	18%	Yes, included a "time trend" in the model; no reduction in conservation effect was observed over the duration.	Yes

Reference	Study Duration (months)	Sample Size	Feedback Type	Conservation Effect of Feedback	Persistence Check	Persisted?
Mountain 2006	13	382	5	6.5%	Yes, included a "time trend" in the model; no reduction in conservation effect was observed over 13 months.	Yes
Nielsen 1993	36	1,500	2	10%	Yes, because it was a long experiment. Appeared fairly constant over 3 years, although there was a slight tendency toward increased savings at the start.	Yes
Sexton et al., 1987	10	51	5	-5.50%	Yes, found that effects were no longer significant in the last 3 months (for peak and total), although this was likely a seasonal effect.	No
Staats et al., 2004 (electricity)	7	140	2	5%	Yes, electricity savings over the intervention period were 4.6%, although not statistically significant; 26 months later (with no intervention in between), they were 8% (compared to initial baseline) and significant. However, analogous changes with the control group are not reported.	Yes, increased
Ueno et al., 2006a	1.4	10	6	13%	Yes, tracked the number of "button presses" up to 241 days after installation; no obvious downward trend.	Yes
Wilhite 1997 as cited in Darby 2006	21	2,000	2	8%	Yes, evaluation was 16 months after the test period.	Yes
Wilhite and Ling 1995	36	611	2	10%	Yes, because it was a long study. Savings at the end of the second and third year were 7.6% and 10%, respectively, so there was an increased savings with time.	Yes, increased

C

FEEDBACK STUDIES AND PRICING EFFECTS

Table C-1
Feedback study overview: studies in dynamic pricing environments

Reference	Study Duration (months)	Sample Size	Feedback Type	Conservation Effect of Feedback	Incremental Effect of Feedback Over Dynamic Rate Effect
Elliott et al., 2006	4	152	3	0%	0%
Horst 2006	12	4	6	Quantification of incremental feedback effect on overall conservation not performed	Quantification of incremental feedback effect on overall shifting not performed. "Data provided by the monitoring system gave reasonable physical evidence of the success of the DSM appliance experiment."
Hydro One 2008	5	411	5	4%	1.8%
IBM 2007	6	373	2	Quantification of incremental feedback effect on overall conservation not performed	Quantification of incremental feedback effect on overall shifting not performed.
Martinez and Geltz 2005	2	61	5	Quantification of incremental feedback effect on overall conservation not performed	0%
Robinson 2007	3	106	4	0%	0%
Sexton et al., 1987	10	51	5	-5.5% (increase)	1.2%

D

FEEDBACK STUDIES AND DEMOGRAPHIC CONSIDERATIONS

Table D-1
Feedback study overview: demographic considerations

Reference	Study Duration (months)	Sample Size	Feedback Type	Conservation Effect of Feedback	Effect Variation Tested with Demographics?
Bittle et al., 1979-80	0.3	267	4	10.5%	Rural. Found higher electricity consumers saved more; low and medium consumers used more; authors believed this was exacerbated in higher temperatures.
Wilhite 1997 as cited in Darby 2006	21	2,000	2	8%	Study included a representative sample of households; 25% all electric heating and 50% with some electric heating.
Hutton et al., 1986	12	75	5	1%	Representative sample with some screening, 3 cities (1 with electrically heated homes and cold winters, 2 with non-electrically heating mild winters), 4 electricity strata. Assumed that one stratum was weighted heavily with middle class, more highly educated, more price responsive; hypothesized that effects would be greater here, but saw this in only 1 of the 3 cases and for gas and total consumption (not electricity only).
Allen and Janda 2006	3	10	5	0%	Surveyed 30 in low-income and 30 in high-income neighborhood; 4 displays to low-income, 6 displays to high-income; too small sample size to draw statistical conclusions.

Reference	Study Duration (months)	Sample Size	Feedback Type	Conservation Effect of Feedback	Effect Variation Tested with Demographics?
Elliott et al., 2006	4	152	3	0%	Stratification based on climate zone, housing type, and electricity consumption.
Hydro One 2008	5	234	5	4%	Class type (high- and low-density residential, farm, general service <50 kW), geographic; results not reported by class type.
Mountain 2007 (Newfoundland)	18	58	5	18%	Results from the model indicate that "heating configuration, the presence of electric heating, the size of the dwelling, the number of residents, their income, their levels of education, the number of senior citizens, attitudes toward conservation, and seasonality all play a role in affecting the impact" (p. 34).
Mountain 2007 (British Columbia)	18	43	5	3%	Results from the model indicate that the "determinant of the responsiveness is the level of education of household members over 14 years of age. As well, seasonality plays a role" (p. 34).
Parker et al., 2008	12	17	5	7%	Found that highest electricity consumers had largest savings.
Brandon and Lewis 1999	9	98	4	4%	Results from the model indicate correlation between savings from feedback and environmental beliefs, self-predicted personal behavior (or intention to behave environmentally), usage level of the home (high and medium electricity consumers more likely to reduce consumption compared to low consumers), and number of occupants.
Mountain 2006	13	382	5	6.5%	Results from the model indicate that conservation did not depend on socio-economic factors.
Nielsen 1993	36	1,500	2	10% (houses; feedback plus other interventions; effect of feedback alone not assessed)	Assessed effects in different neighborhoods composed of houses and apartments as well as blue and white collar areas; appear to have controlled for income; deem results for entire country, although not obvious how they did this.

Reference	Study Duration (months)	Sample Size	Feedback Type	Conservation Effect of Feedback	Effect Variation Tested with Demographics?
Sexton et al., 1987	10	51	5	-5.50%	Homes with displays were selected randomly from the 3 (of 5) largest consumption classes, across 3 temperature zones and 4 peak/off-peak rate structures. ANCOVA performed; model controlled for demographics, housing, and weather. Sample weighted toward high consumption users; 87% were detached single-family dwellings; most were occupant-owned.
Wilhite and Ling 1995	36	611	2	10%	Younger, with higher income and more education were more likely to reduce; 25% all electric heating and 50% some electric heating.
Loren Kirkeide, Principal Analyst –SES, Salt River Project, personal communication, February 18, 2009	6 (each)	2005/2006 Study: 272 (summer) 191 (winter) 2003/2004 Study: 422 (summer) 202 (winter)	5	2005/2006 Study: 12% 2003/2004 Study: 13%	Stratified by season and energy consumption; included various dwelling types and geographic locations. Found no statistical difference between seasons. Found no statistical difference between energy consumption strata.

E

ONGOING UTILITY PILOT ACTIVITY

<table>
<tr><th colspan="2">Baltimore Gas & Electric</th></tr>
<tr><td>Objectives</td><td>Assess effects of Dynamic Peak Pricing (DPP, a type of critical peak pricing), Peak Time Rebates (PTR), Smart AC Switch, and Energy Orb

Assess various aspects of AMI deployment

Estimate demand elasticities

Assess customer interest and willingness to participate, extent to which they would participate with rebates and DPP</td></tr>
<tr><td>Feedback/ Technology Demonstration Details</td><td>Feedback Type: 5

Price Display Device: Energy Orb (Ambient Technologies); other enabling technologies as well

Number of Orbs: 625 units (A sub-set of a 1,300-customer AMI pilot with dynamic pricing)
125 with low Peak Time Rebate
125 with high Peak Time Rebate
125 with low Peak Time Rebate and AC switch
125 with high Peak Time Rebate and AC switch
125 with Dynamic Peak Pricing and AC switch
Duration: February 2008–March 2009 (~13 months for billing analysis)</td></tr>
<tr><td>Status</td><td>Preliminary results:

Average peak reduction over 5-hour period for first 7 of 12 events:
DPP only: 19%
DPP + Orb + AC switch: 33%

PTR (low): 17%
PTR (low) + Orb: 23%
PTR (low) + Orb + AC switch: 29%

PTR (high): 20%
PTR (high) + Orb: 27%
PTR (high) + Orb + AC switch: 33%
Incremental amount of peak reduction attributable to Orb: 6–7%

Final report: ~December 2008</td></tr>
<tr><td>References</td><td>Cheryl Hindes, personal communication, October 31, 2008

Case, et al., 2008</td></tr>
</table>

Baltimore Gas & Electric	
Contact	Cheryl Hindes, Director, Customer Load & Settlement Baltimore Gas & Electric Baltimore, Maryland

Duke Energy	
Objectives	Assess how Duke can position itself to promote the next generation of tools and assess benefits to the customer and the company To gain early experience regarding new HAN technologies, both from a technical and a customer-experience perspective
Feedback/ Technology Demonstration Details	Feedback Type: 6 Two ongoing small-scale assessments of Home Area Network technology, in conjunction with energy efficiency and Smart Grid assessment goals: 1. McAlpine Microgrid project, Charlotte, NC - evaluation 2 or 3 HAN portal vendors, potentially including Lixar, Autuni, Sequentric - still in vendor selection stage - will likely involve 30-50 homes - will also link to solar PV and battery storage at the local substation 2. Conserve and Save project, Cincinnati, OH - involves 35-40 homes (about half are employees) - sending pricing signals to these customers and learning how they respond - various technologies: some solar pv, battery storage, and one plug-in hybrid electric vehicle A third small-scale assessment from a customer perspective (versus a technology assessment): 3. Residential One Month Off (ROMO), Charlotte, NC - approximately 6-8 households, mainly employees - using Lixar web-based portal, household setting “themes” like “Home” and “Away” - enabling technologies: mainly programmable communicating thermostats, likely control over 1 or 2 pool pumps, some electric water heaters, lamps, etc. - goal is to assess customer opinions of technology/ interface, as well as impacts on behavior
Status	Early stages for all; to date, the focus is more on learning around installation and technology challenges
References	Michelle Davis, personal communication, November 4, 2008 Neeta Patel, personal communication, November 24, 2008
Contact	Neeta Patel Director, Technical Assessments and Applications Duke Energy

Energy Trust of Oregon	
Objectives	Assess effect of feedback devices on energy consumption Gain knowledge about how people use the display Identify areas of difficulty
Feedback/ Pilot Design Details	Feedback Type: 5 Energy Display Device Pilot, PowerCost Monitor (Blue Line Innovations) Number of units: 370 units 200 free to recipients of Home Energy Review (HER), technician-installed 170 for $29.99 to those “Early Adopters” (EA) who ordered them online and self-installed Duration: Feb 2008 – Mar 2009 (~13 months for billing analysis)
Status	Six-month survey results for HER/EA: 64%/66% still using display 27%/20% said display is no longer functional Of those still using it, most (55%/51%) look at display 1-2 times per day Overall (65%/73%) believe the displays have changed the way they use energy (main uses identified: lighting, computers, AC, dryer) Billing analysis results: due in March (to incorporate one heating season)
References	Scott 2008 Kate Scott, personal communication, November 24, 2008
Contacts	Kate Scott, Residential Sector Program Initiatives Energy Trust of Oregon, Inc. Portland, OR Phil Degens, Evaluation Manager Energy Trust of Oregon, Inc. Portland, OR

Hydro One	
Objectives	Assess effectiveness on large scale Assess persistence over 1 year's time
Feedback/ Pilot Design Details	Feedback Type: 5 Energy Display Device Pilot, PowerCost Monitor (Blue Line Innovations) Number of units: 30,000 units Duration: 1 year's time
Status	Results: analysis is on-going, should be some results relatively soon Next step: May do doing another feedback program, but this depends on regulator ruling; issue for them is cost recovery; going forward, regulator is less willing to support another initiative
Reference	David Curtis, personal communication, November 9, 2008
Contact	David Curtis, Director, Business Transformation Hydro One Toronto, ON

National Grid, NSTAR, Western Massachusetts Electric – Mass	
Objectives	Assess different display device marketing strategies Assess customer response to different display device costs Assess customer perceptions of value/usefulness of device compared to other potential energy efficiency services Assess short-term and long-term behavior changes and energy savings attributable to the pilot programs
Feedback/ Pilot Design Details	Feedback Type: 5 Energy Display Device Pilot, PowerCost Monitor (Blue Line Innovations) Number of units: 3,512 units across three utilities Duration: May 2007 – July 2008
Status	Survey results: For mail-outs (self-installations): 29% did not set up the display For all display recipients: 27% did not set up the unit Of those that set up the display: 96% used it after initial set-up For those that set up the display: 49% indicate that they were still using the display after 2-6 months and 35% after 8-12 months Reasons others stopped using: display did not work well, the battery died, the unit broke, don't need it anymore now that they know how much they use Of those that installed and used the display 63% indicate they have made changes to their electricity using behavior as a result of the PCM Initial billing analysis results: final report due December 2008; initial results reveal an average annual savings of 2.9% for those people who installed and used the unit
References	Laura McNaughton, personal communication, November 11, 2008 Bill Blake, personal communication, November 25, 2008 MacLellan 2008
Contacts	National Grid: Laura McNaughton NSTAR: Charlie Olsson, David MacLellan Western Massachusetts Electric: John Walsh

NV Energy	
Objectives	Expand on conservation programs, and identify the role of display devices in these programs Gain insight into the effectiveness of different device design features Learn about the economics of a device deployment Obtain customer opinions about the technology
Feedback/ Pilot Design Details	Feedback Type: 5 Various Energy Display Devices Number of units: 93 Duration: Feb-July 2008
Status	Results: Billing analysis: average savings of 5.22%; greater in southern Nevada than in north; summer savings greater than winter AC) Device feature preference analysis: Most preferred feature: accurate display of energy use; cost and kWh used “right now,” in last 24 hours, and for billing cycle, for whole home and appliance-level; that it be a dedicated device Least preferred: utility alerts; that is should be wireless, portable, or require no battery, “looks good” Next step: complete analyses of survey and in-home interview data; compare low and high saving households; analysis of changes in attitude, behavior and consumption with time
Reference	Holmes 2008
Contact	Larry Holmes, Manager, Customer Strategy and Programs NV Energy Las Vegas, NV

OFGEM Energy Demand Reduction Pilot (UK)	
Objectives	Undertake and evaluate a series of trials designed to reduce demand and encourage conservation on an enduring basis, with a focus on feedback mechanisms that increase information to (primarily) residential customers
Feedback/ Technology Demonstration Details	Feedback Types: 2–5 Details: A wide range of information and feedback provision media being assessed, including those that need and do not need an AMI element; AMI is being trialed as well Number of customers: tens of thousands; EDF Energy, E.ON UK, Scottish and Southern Energy, and Scottish Power each performing a number of trials; multiple trial locations throughout England, Scotland, and Wales Duration: varies; requires data from at least two winters and two summers; completed by February 2009
Status	Ongoing trial status being kept confidential; more details on the request for proposal can be found in the Invitation to Bid (OFGEM 2006). Early information as of June 2008 (from OFGEM 2008): There is no statistical significance between treatment and control groups for the billing and display device trials Various surveys suggests up to half of display device recipients are not using the device, with up to half of these because the battery was not changed when required Some device installation problems (clip-on device) One survey suggests that a high percentage of people who installed their device changed their habits (self-reported). Overall results: due late 2010/early 2011
References	OFGEM 2006 OFGEM 2008 Sarah Darby, Research Councils' Energy Programme Research Fellow, University of Oxford, personal communication, November 13, 2008 SSE 2008

SaskPower	
Objectives	Obtain opinions on how customers like the display Believe there is enough evidence to support that real-time feedback will reduce consumption; thus main objective is not detailed quantitative analysis, although they are doing this as well
Feedback/ Pilot Design Details	Feedback Type: 5 Energy Display Device Pilot, PowerCost Monitor (Blue Line Innovations) Number of units: 100 Duration: June 2008–June 2009
Status	Results: expected summer 2009 Next step: May do a larger roll-out before results depending on provincial government mandates; units would be offered at discounted rate for larger roll-out
Reference	Barbara Gilbey, personal communication, October 29, 2008
Contact	Barbara Gilbey, DSM Program Leader, Business Development, Customer Services SaskPower Regina, SK

Sacramento Municipal Utility District	
Objectives	Assess effects of providing a more detailed electricity consumption report on a large scale, either as an energy efficiency tool, a marketing tool, or both Assess effect's persistence over several years
Feedback/ Pilot Design Details	Feedback Type: 2 Monthly and quarterly billing reports provided by Positive Energy Number of customers: 35,000 reports (25,000 monthly; 10,000 quarterly) Duration: 2008–2012 (4 years' time, although numbers/focus may change)
Status	Preliminary results: after approximately 6 months (equivalent to 5 monthly reports, 1–2 quarterly reports), data indicate a 2% savings compared to control group (50,000); based on this decided to extend the program for another 3 years, with customer numbers contingent on results Next step: continue and assess energy savings, customer opinions, and program costs on on-going basis; perhaps change up some delivery options (for example, Use online reports? Target specific customers? Specific message testing?)
Reference	Ali Crawford, personal communication, November 19, 2008
Contact/ Personal Communication Reference	Ali Crawford, Project Manager SMUD Sacramento, CA

We Energies	
Objectives	Assess the effects of benchmarking report (Type 2) and information displays (Type 5) on household conservation; assess over a large sample population, including single and multi-family dwellings; assess persistence over multi-year period; in the case of Type 5, assess interaction of pricing and feedback, and effect on peak reduction.
Feedback/ Pilot Design Details	Feedback Type: 2 Monthly billing reports (vendor TBD) Number of customer: 50,000 reports Duration: 2009–2011 (~3 years' time) Feedback Type: 5 Energy Display Device Pilot, In-Home Display (Aztech Associates Inc.) Number of customer: 12,000 Duration: 2009–2011 (~3 years' time)
Status	Both programs are just getting started; deployment in mid 2009.
Reference	We Energies 2008
Contacts	David Ciepluch (Type2) and Bob Reagan (Type 5), Advocacy & Energy Options We Energies Milwaukee, WI

F
RESEARCH INSTITUTE ACTIVITY

Florida Solar Energy Center (FSEC)

Danny Parker, Principal Research Scientist in Buildings Research at the Florida Solar Energy Center (FSEC), which is part of the University of Central Florida (UCF), says that FSEC became involved with feedback-related research as part of its work with the Buildings America program for Zero-Energy Homes through the U.S. Department of Energy. It is recognized that achieving zero-energy homes will require efforts on multiple fronts; efficient appliance technology is key, but potential conservation gains through other means are also of interest. Given the encouraging results of various feedback studies, these types of technologies are also being considered.

FSEC was involved in initial work to assess the use of energy display devices as educational tools with which homeowners could assess their appliance end usage (Parker et al., 2006). This led to more recent research in which 22 homes were provided with The Energy Detective (TED) by Energy Inc. for a period of one year. Findings indicated an average savings of approximately 7% (weather adjusted), although there was significant variation across the test group (Parker et al., 2008).

Future work may involve the assessment of appropriate feedback display designs and interfaces. This may leverage the work of UCF's Department of Psychology and its Applied Experimental and Human Factors program, which has explored similar applications involving jet fighter controls. FSEC may also potentially participate in pilot assessments of enabling technologies that would allow residents to more easily reduce their electricity consumption. As a possible example, Parker cites the GreenSwitch technology, which allows users to reduce consumption levels of various household appliances to pre-set levels with one flick of a switch.[14]

In addition to the effectiveness of different display designs in visually communicating information, Parker believes that other research areas that require more emphasis include the longitudinal evaluation of the persistence of feedback effects, the interaction between pricing and feedback effects, and the potential effect of feedback devices on peak load reduction. Furthermore, as with its 22-home study, Parker believes that many feedback studies have involved relatively small samples sizes, limiting their potential statistical significance and generalizability.

[14] http://www.greenswitch.tv/

Contact Information:
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http://www.fsec.ucf.edu/

Georgia Institute of Technology: Aware Home Research Initiative

The Aware Home Research Initiative (AHRI) at the Georgia Institute of Technology aims to explore and understand emerging residential technologies and services. A multidisciplinary effort, research applications include health care and "aging in place," entertainment, and domestic resource management. At the center of the research activity is the "Aware Home" itself, a 5,300 square foot home that contains two apartments with identical floor plans. Although the original intention was to have residents live in one of the apartments in order to have a live test environment for emerging domestic technologies, the apartments are now used for various research projects, primarily those that cannot be performed in a typical laboratory setting. Another use of the home is for usability or psychology studies in which people are invited into the home to use and assess technologies in a home environment. In addition, researchers can stay for extended periods, inviting friends and family to test various technologies in a controlled environment. Generally, the facility acts as a sort of stepping stone between an artificial laboratory environment and an actual residence and serves as a showcase of current and past research for groups touring the facility.

In one student research project through the AHRI, a qualitative assessment was performed on the ways in which residents take conservation and efficiency actions, including how they manage their electricity consumption. One finding was that many householders did not have a good idea of their homes' electricity consumption patterns (Chetty et al., 2008). This in part led to a second project that attempted to make electricity consumption more visible through the provision of feedback. Both stationary and portable feedback devices were developed and distributed to eight homes in the community for a three-week period. They found that initially householders used the devices to determine which appliances used the most electricity, and some were surprised by the findings. A consumption analysis revealed an average savings of 11% and that households with the highest savings appeared to have had lower initial awareness levels about energy consumption (Yun et al., 2008).

Other feedback-related research includes the development of power line event detection technology, which enables detection of the "on" or "off" status of various household loads. Although still in early stages, applications could include the provision of appliance-level detail regarding household electricity consumption.

The group is looking to potentially partner on research using technology from vendors including Comverge for its smart thermostat and energy display device and Landis and Gyr for intelligent metering.

Contact Information:
Brian Jones
Director, Aware Home Research Initiative, Georgia Institute of Technology
Atlanta, Georgia
http://awarehome.imtc.gatech.edu/

Massachusetts Institute of Technology

Researchers at the Massachusetts Institute of Technology (MIT) have been working for several years in the area of behavior change. The House_n Research Consortium of the MIT Department of Architecture includes students from the MIT Media Lab. Collaborators include the Boston Medical Center, Stanford Medical, the University of North Carolina School of Public Health, and other partners such as Intel Research, Bensonwood Homes, and the Center for Integration of Medical and Innovative Technology (CIMIT).

Research spans several disciplines, but the main focus areas have been health care (for example, healthy behavior, wellness, and aging) and energy conservation. Within this latter area, the two main thrusts are the development of scalable strategies for net-zero energy housing and behavior change to encourage conservation.

The systems developed and prototyped for the behavior change research combine four key elements: just-in-time information, some automation, persuasive techniques or messaging, and elements of user control. Given its high market penetration and frequent daily use by consumers, much of their research uses mobile phones as a medium for combining these factors. For example, one system that has been prototyped involves communication by mobile phone with a GPS-enabled thermostat; the system calculates a user's location and travel time to return home and can adjust to the appropriate setting just as the user returns home. With regard to the message persuasiveness, content is important—it should stay positive and be targeted to specific people. This is currently the topic of some of MIT's health-related research.

Part of the research facilities include the "PlaceLab," a highly instrumented apartment-sized research facility in which technologies can be assessed in the context of a "real" living environment. Electricity consumption information as well as very detailed behavioral data such as occupant location and related activities can be tracked so that behavior and consumption can be directly correlated. In one study, a couple lived in the lab, and—acknowledging the existence of the Hawthorne effect[15]—researchers were able to use the data gathered to calculate the couple's conservation potential, which was approximately 40%. Although these pilot-level results cannot be directly extrapolated to larger samples, they are useful in designing scaled-up studies to assess overall savings potentials. The group has also recently developed portable PlaceLab technology so that any home can be instrumented.

Other research activities include the disambiguation of the panel-level consumption load data so that individual appliance consumption signatures can be detected. This may represent a relatively low-cost way of providing real-time, appliance-specific consumption information to consumers, although currently systems would require significant "training" or calibration for each household. Researchers can also use a wireless setup to assess appliance-level information as necessary. Another demonstration tool used a system developed by IBM to project on the wall the real-time cost of an appliance (for example, over the plug or near the appliance). Although the system had significant visual appeal for demonstration purposes, the projector idea has limitations with regard to the electricity it consumes, and the effects of this type of feedback were not investigated in detail. A more scalable variation to investigate might involve the use of mobile phones.

[15] The Hawthorne effect describes the notion that people will not behave as they normally would if they know they are being studied.

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http://architecture.mit.edu/house_n/

Rutgers University

The Rutgers Initiative on Climate and Social Policy is a multidisciplinary program aimed at addressing the challenges of climate change. One of the initiative's four key research areas explores the role of attitudes and beliefs with regard to personal consumption behavior, government policy, and other issue areas and will involve the development of near-real-time behavior program evaluation methodologies that can be used for relatively quick program assessments. Other research involves a partnership with New Jersey's Public Service Enterprise Group (PSEG) to engage in feedback program design and assessment—a move that is motivated by New Jersey's energy plan, which calls for a 20% reduction in peak demand through behavior change alone.

Although the research partnership is still in the early stages, it is intended that various types of feedback will be assessed through PSEG's customer base, with the goal of addressing several research questions: understanding the optimal medium for data presentation (that is, the type of feedback), the metrics, the correct message, the persistence of any effects, and so on. Also of interest is the way in which different people receive and process different types of information; for example, are some segments of the population ready to conserve and just need information, while others still require additional motivation?

The partnership will include Dan Ariely, a Professor of Behavioral Economics at Duke University, whose group is developing various energy display devices for assessment.

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Stanford University

The Precourt Institute for Energy Efficiency (PIEE) at Stanford University intends to promote energy efficiency, understand the various barriers to economically efficient energy reductions, and inform relevant policymaking. Within PIEE's "Behavior and Energy" cluster, one group is involved in behavioral research relating to feedback. Group members hail from disciplines spanning engineering, building science, behavior science, human/computer interaction, and a joint program in design covering fine arts and mechanical engineering. A common goal of this group is to better understand what feedback technologies and systems elicit the largest behavioral impacts and are suitable for mass-market scalability.

The group is involved in various research endeavors, including working with display technology providers to help incorporate behavior science knowledge into interface design and understanding the potential impacts of reporting consumption using different metrics. The group is performing experiments in collaboration with technology vendors, including Greenbox, a developer of web-based energy consumption visualization software. The group's other research areas include understanding how to cost-effectively include appliance-level information and investigating the incremental gains to be had by this additional information.

In September 2008, the Behavior & Energy Cluster—led by Dr. Carrie Armel, a Research Associate with PIEE—convened a workshop on End-Use Energy Reductions through Monitoring, Feedback, and Behavior Modification.[16] Topics included interface design, information types, behavior change strategies from various fields, advanced metering and home area network technology and the resulting detailed information enabled along with discussions on requirements for the mass-diffusion of behavior-changing technologies. Related to this, the group is developing a white paper summarizing feedback technologies with a high potential for mass-market diffusion and attempting to better understand customer segmentation as it relates to energy use in order to better understand who to target.

In addition, along with the California Institute for Energy and Environment at the University of California and the American Council for an Energy Efficiency Economy, PIEE also co-organizes the annual Behavior, Energy, and Climate Change Conference.[17]

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http://piee.stanford.edu/cgi-bin/htm/index.php?ref=home

[16] http://piee.stanford.edu/cgi-bin/htm/Behavior/2008_energy_and_feedback_workshop.php
[17] http://piee.stanford.edu/cgi-bin/htm/Behavior/becc_conference.php

University of Waterloo

Research into electricity use feedback at the University of Waterloo began in 2005, in partnership with the Milton Hydro Distribution Incorporated, a local distribution company. At the time, Milton Hydro had the largest deployment of advanced meters in the province of Ontario, Canada, and was the first to charge time-of-use rates.

Initial research involved the provision of weekly feedback information by mail and e-mail to 106 households that were on time-of-use rates. The feedback included average weekly consumption levels for the previous week, a graph of each day's electricity consumption patterns, consumption reported in terms of various metrics (for example, total and on-peak kilowatt-hours, dollar values, and greenhouse gas and air pollution emissions), household-specific appliance consumption information, and overall energy-saving tips. The findings revealed that the feedback had little incremental effect on shifting or overall conservation (Robinson 2007).

Other recent research involved collaboration with Milton Hydro as well as with Direct Energy and Bell Enterprises in the assessment of the Smart Home Energy Conservation Program. Through this study, 108 homes were equipped with enabling technology including programmable communicating thermostats and air conditioning controls. Through a web-based system, participants were able to monitor their electricity consumption and set control levels for their air conditioning, all in a time-of-use price environment. An overall electricity savings of 2.9% and a 13.2% savings in on-peak consumption were found (Schembri 2008).

Current research involves the development and implementation of the Energy Hub Management System along with utility partners Milton Hydro, Hydro One Incorporated, and technology partner Energent Incorporated. The Hub will allow for two-way control of key energy producing and consuming devices within the network and will take factors such as electricity prices and market conditions and weather conditions into account. Based on this, decision rules will be developed to help energy managers understand appropriate actions to best manage their energy demand. Hub applications will be at the residential, commercial, farm, and industrial levels.

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http://www.environment.uwaterloo.ca/research/greenpower/projects/index.html

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