The Economy-Wide Impact of Feedback-Induced Behaviors that Drive Residential Electricity Savings

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EXECUTIVE SUMMARY

Advanced utility meters (so-called "smart meters") coupled with in-home displays or feedback devices provide the means by which residential energy consumers can become more knowledgeable about their energy consumption practices. Such devices, in effect, enable consumers to become active managers of their own energy resource use, or in this case their home electricity usage patterns. Indeed, one extensive ACEEE meta-review of 57 different feedback programs indicates a 4 to 12 percent range of residential electricity savings on average across an international sample—depending on the technologies employed, the characteristics of the program, and other relevant factors (Ehrhardt-Martinez, Donnelly and Laitner 2010).

At the same time, however, few studies have explored the scale of investment or larger impacts that might accompany the growth and successful implementation of feedback programs. Nor have they examined the economy-wide benefits that might accrue from the systematic integration of feedback-induced energy savings over time. This report provides some initial estimates of the larger macroeconomic outcomes of feedback programs**.** In effect, it asks the question: what might the success of these programs imply for the larger economy as a whole?

Depending on the range of assumptions about program effectiveness within individual households, and the overall participation of households across the entire U.S. economy, the assessment here finds feedback programs to be highly cost-effective. Moreover, the analysis suggests a small but net positive benefit to the nation's employment levels. From a benefit-cost perspective, the analysis suggests a net savings of $1.60 to $7.70 for every dollar invested in feedback program expenditures and associated technology investments.[1] The likely range is a net savings of $2-3 over the period 2012 through 2030. When the variety of program expenditures and efficiency investments are evaluated, together with their net energy bill savings, it appears that feedback programs might provide an average gain of 6,000 to 56,000 net jobs per year over that same period of analysis.

One final question that might yet be explored is to ask how important are the estimated two to ten percent residential sector savings from feedback programs, especially as they might compare to other recent estimates of national electricity savings potential from all sectors at some point in the future. One recent ACEEE study, for example, found a cost-effective electricity savings potential as high as 40 to 50 percent by the year 2050 (Laitner et al. 2012). Based on this simple comparison, we might conclude that it might make sense to move directly to a technology-based policy perspective since it is likely to achieve a multiple from 5 to 25 greater impacts. Alternatively, as suggested by McKenzie-Mohr (2010), expanding feedback programs could catalyze a social and cultural shift that can result in even greater efficiency gains that complement other policy mechanisms—should we choose to explore that possibility.

[1] The technology cost estimates do not include the cost of establishing a "smart grid" but instead cover in-home costs of monitors and displays, with or without a smart grid.

ACKNOWLEDGMENTS

This report has emerged from a growing body of interest in the social and behavioral dimensions of energy consumption and energy efficiency. It is the product of ACEEE's own emerging interest in the topic and the organization's effort to expand its focus beyond technological considerations. The Google Foundation was similarly encouraged by the potential energy savings associated with residential feedback technologies, and with encouragement from Michael Terrell, took the initiative to fund this important piece of research.

While funding is certainly a critical aspect of any successful research effort, our work would be wholly incomplete without the benefit of the many pioneering efforts undertaken by the individuals who engaged in the primary research associated with the many feedback studies that underpin this report. In that regard I greatly value the contributions of Karen-Ehrhardt-Martinez whose work with the author over the past 6 years has shaped many of the emerging insights found in this study. I also acknowledge a number of key ACEEE staff who contributed to this report in a variety of ways. They include Steven Nadel (Executive Director), Susan Mazur-Stommen (Director of the Behavior and Human Dimensions Program), Ben Foster whose insights gave rise to the idea of the critical role of tacit knowledge in shaping a potentially larger feedback response, and Renee Nida who is editor of ACEEE's many publications. At the same time, I acknowledge the many valuable comments and insights received from Kat Donnelly, Rebecca Ford, Cindy Frantz, Beth Karlin, Sea Rotman, Janet Stephenson, Michael Terrell, and Ed Vine. I offer all of you my heartfelt thanks. While I benefited hugely from our many conversations and from all of their comments, I did not always accept their suggestions. To that extent, any errors or mistakes remain my responsibility. But rest assured that all comments, both those accepted and deferred, continue to inform my thinking and will undoubtedly find their way into future behavioral assessments.

INTRODUCTION

Advanced metering devices and new feedback programs and technologies are opening up a wide range of new opportunities to make energy consumption more visible to residential consumers and to engage individuals and households in more thoughtful and deliberate energy use practices. Data from several recent studies suggest that feedback-induced energy savings can be significant (Darby 2006a; 2006b; EPRI 2009; Faruqui, Sergici, and Sharif 2009). Indeed, one extensive ACEEE meta-review of 57 different feedback programs indicates a 4 to 12 percent range of residential electricity savings on average across an international sample—depending on the technologies employed, the characteristics of the program, and other relevant factors (Ehrhardt-Martinez, Donnelly and Laitner 2010). In the United States, past programs ranged from 2 to 11 percent (ibid). A recent supplemental ACEEE review of nine additional programs shows feedback savings that range from zero to 19.5 percent, with an average savings of 5.5 percent among all nine programs (Foster and Mazur-Stommen 2012). Although not reported, this last study also suggested an average 15 percent savings based on weighted sample size. The reason for the large difference in weighted average savings is that one very large program in Northern Ireland, representing 74 percent of the total sample population, showed that the high end of a 19.5 percent savings would increase the average reported savings. A more extensive review of more than 100 feedback projects and assessments by Karlin and Zinger (2012) suggests an average savings of 10 percent among participating households.

At the same time, however, few studies have explored the scale of investment or larger impacts that might accompany the growth and successful implementation of feedback programs. Nor have they examined the economy-wide benefits that might accrue from the systematic integration of feedback-induced energy savings over time. This report provides some initial estimates of the larger macroeconomic outcomes of feedback programs in four ways. First, it explores the link between feedback programs as they might induce a different pattern of conservation and energy efficiency behaviors. More specifically, it examines the range of economy-wide electricity bill savings should residential feedback program be as successful as the various studies now suggest. Second, it examines how those changed behaviors might drive greater levels of investments in more energy-efficient technologies in the nation's homes. Third, it evaluates the impact of those changed behaviors and investment patterns as they might expand electricity bill savings beyond the immediate feedback responses. That is, the assessment examines the scale of additional savings that might be induced should experience increase greater awareness and action after the initial exposure to feedback programs. Finally, it assesses the net benefits to the larger economy as the result of those expanded investments. This last category includes a working estimate of net employment impacts that result from the movement to a more energy-efficient economy.

In many ways this narrative and analytical exercise provides an alternative way to look at the potential of feedback programs by using exploratory economic models to examine large policy questions. Instead of evaluating individual electricity savings among those households that might participate in feedback programs, this study examines scenarios of potential electricity savings at the economy-wide level. In this way, it follows previous assessments that provide a range of plausible outcomes that might inform policymakers about larger economic possibilities rather than necessarily providing a single prediction or a specific program evaluation (Bankes 1993; Lempert et al. 2003; Laitner et al. 2006). In short, this study does not attempt to verify or explain electricity savings from past programs; rather, it asks the question: what might the success of these programs imply for the larger economy as a whole? To that extent, it characterizes the different studies only to explain the boundaries or assumptions used in the different scenarios rather than validate any individual finding within those studies.

BACKGROUND

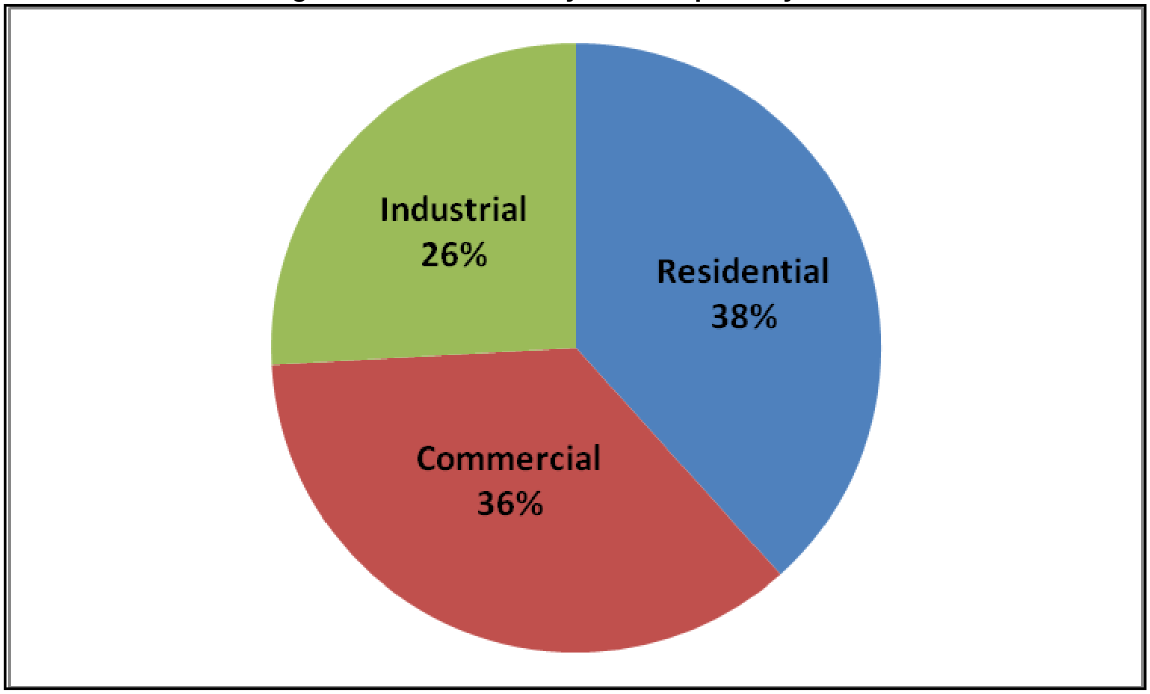
In its *Annual Energy Outlook 2012*, the Energy Information Administration (EIA) projects that electricity use will increase by about 18 percent over the period 2012 through by 2035 (EIA 2011). In particular, EIA estimates that electricity use in our nation's buildings will increase by 25 percent over this same period. A variety of demographic and economic factors will drive this trend, especially as they influence residential air conditioning, cooking, and the use of consumer electronics and appliances, which EIA suggests will grow 10, 38, and 48 percent, respectively. Interestingly, these particular end uses are also among those that are likely to be influenced in response to the effective introduction of new feedback programs and technologies.

As shown in Figure 1 below, EIA estimates for 2012 show that the residential sector is already the largest consumer of electricity in our nation's economy. It now accounts for 38 percent of total electricity consumption in the U.S.

While the relative importance of electricity consumption in the residential sector has continued to grow, so too has the level of interest in engaging energy users in new ways. This renewed attention to the human dimensions of energy consumption has enabled a fresh look at how a more informed understanding and increased levels of awareness and engagement might reshape energy use practices in a positive and cost-effective manner. As explained by Mahone and Haley (2011), behavior-based strategies use non-economic incentives to change how people perceive their energy use and in this way they are able to reshape energy use patterns resulting in an overall electricity or energy savings. Building on this perspective, there is also now a shift toward a more "people-centered" approach to generating greater levels of energy productivity rather than emphasizing a primarily technology-based approach. As Ehrhardt-Martinez and Laitner (2010) suggested, "The adoption, use, and innovation of technology are firmly rooted in human behavior.[2] Therefore, it is difficult to fully distinguish where behavior ends and technology begins, or to determine how best to attribute energy savings whether as a function of technology or behavior. In fact, most energy savings that are achieved through the application of new technologies also rely, to varying degrees, on changes in behavior."

[2] In fact, some researchers such as Laitner (2010) specifically characterize technology within its human cultural dimensions. Laitner's definition of technology is intentionally broad and includes "the cumulative knowledge embodied in our artifacts, equipment, and structures—all with an effort or desire to achieve a given social objective; and the norms and rules by which we choose to deploy that knowledge." In many ways, this is consistent with Lewis Binford's (1962) classic paper on the various forms of material culture and their impact on consumption.

Figure 1. 2012 Electricity Consumption by Sector



Source: EIA (2011)

Notwithstanding the growing body of evidence suggesting that behavior-based strategies could result in sizable amounts of energy savings, the assumption that such initiatives are best thought of as 'boutique' or 'niche' strategies continues to be pervasive. Such traditional, technology-rooted perspectives of building engineers and economists typically assume that behavior approaches are best employed as a means of supplementing the energy-saving approaches associated with large technology investments (Laitner and Ehrhardt-Martinez 2010). In fact, evidence from past experiments and programs shows that the potential savings from people-oriented strategies may be larger than otherwise anticipated. For example, Dietz et al. (2009) suggest that 17 different household actions—ranging from the use of low-flow showerheads and changing furnace and air-conditioning filters to driving more carefully and carpooling—might provide a behavior-based wedge that reduces energy-related carbon dioxide emissions in the residential sector by 20 percent or more. Similarly, in an exploration of a more extensive list of 120 household actions, Laitner and Ehrhardt-Martinez (2010) found that changes in household behaviors could result in a 22 percent reduction in household and personal transportation energy use over a five- to eight-year period. Finally, Meier (2010) suggests that energy crises can also serve as an indicator of how dramatically and quickly energy use practices can change. According to Meier's assessment, changes in energy practices have resulted in immediate, community-wide electricity savings of 30 percent and post-crises savings of eight to ten percent.

With a behavioral wedge that might approach 20 percent savings or more, one might easily ask the question: why is it that policy analysts and program managers still view people-centered initiatives as small-scale, niche strategies? Two explanations come to mind. The first is that most programs implemented to date have remained largely in the pilot or experimental phase. In other words, the idea of a behavioral wedge is still under review. In other cases, they are seen merely as a follow-on strategy or a means to enhance existing technology-based efficiency programs. Ehrhardt-Martinez (2011) reminds us that a few programs have already achieved a 15-20 percent savings, and she believes that well-designed programs—ones that build on key insights from the social sciences—could approach a savings of 20 to 30 percent.[3] However, as she also suggests

[3] As an example of how we might learn to build on the behavioral resource, Oncor, CenterPoint Energy, IBM, Landis+Gyr, Itron, GE, San Diego Gas & Electric, and Tendril are founding partners of what has been

more recently, the programs must be designed to actually achieve that magnitude of energy conservation and efficiency gains. C3 Energy's Andy Frank (2012) agrees, saying: "We're only scratching the surface in terms of the innovation potential from customer engagement program approaches." He notes: "C3 Energy has seen savings in excess of 6% for households by helping them set energy-saving goals and reward them for meeting these goals, but we are learning more and more each day. Because there are few barriers-to-entry for the consumer, we are able to innovate much more rapidly than traditional technology installation programs."

A second reason for imagining only a small-scale savings—one that forms the basis of the analysis that follows—is that most policymakers and program managers may not associate behavior-based initiatives as having any real market significance or impact. This is to say that if people believe that inducing a change in energy-consuming behaviors requires only modest program support, they may overlook the potential scale of both investment opportunities and resulting energy-saving outcomes. Hence, there is a tendency to overlook the potential scale implied by the behavior wedge. As we explain in the scenarios evaluated later in this assessment, even if we limit feedback programs to residential electricity savings we might find a market investment potential that ranges from $2 to $40 billion which, in turn, might save households anywhere from $24 to $160 billion over the period 2012 through 2030. At the same time, those investments and electricity bill savings might drive an average annual net employment gain of 6,000 to 56,000 jobs over that same time horizon. The section that follows describes the methodology used to generate these results. A subsequent section then discusses the key results that emerge from the analysis. The report finally draws conclusions and summarizes the larger findings.

METHODOLOGY

The market assessment that follows builds on a four-step process. The first step establishes the analytical context by drawing from the latest economic and energy projections published by the Energy Information Administration. The second step provides a review of past feedback programs and the level of energy savings they have achieved. As detailed below, both the recent past and the current generation of feedback programs have been shown to generate annual residential electricity savings of approximately 4-12 percent for participating households.

The third phase of the assessment uses an exploratory hypothesis to develop plausible estimates of the eventual scale of feedback-induced energy savings, and explore the ways in which those savings might unfold over time by looking across the entire set of the nation's households. The appropriate characterization of key performance and cost assumptions is a critical aspect of this assessment. Such assumptions will serve as drivers of the different scenarios we explore to estimate the scale of impacts that might be realized as a function of the many different program designs. The final step involves the development of assessment tools to generate the estimate of macroeconomic impacts that help us understand the larger benefits of feedback programs should they prove successful. These steps are examined in further detail below.

called the *Biggest Energy Saver Campaign*—an online community to explore ways that might encourage customers to engage in conversations and learn how smart technology can help reduce their electricity bill. Across all participants, the average savings was just under 8 percent. The top 10 percent of the participants, however, achieved a very large 26 percent savings (Hauser 2012). As Ehrhardt-Martinez (2012) reminds us, there are industry segments that will mine these larger savings for insights that can be applied to the 10 percent savers and see how to leverage 10 percent savings into the much larger 20 to 30 percent wedges.

The Analytical Context

Setting Up the Reference Case

The foundation for this assessment is the *Annual Energy Outlook* published by the Energy Information Administration (2011). Although the forecast of energy and other market trends covers all sectors of the economy, here we will explore possible changes in residential electricity use beginning in 2012 through the year 2030. This includes the growth in households over that time as well as the anticipated demands for electricity services within those households. It also includes both expected trends in electricity prices and a discussion of potential drivers of important (and unexpected) shifts in electricity demand that might alter expected trends In addition, since we are exploring the impacts on the economy we will review the anticipated growth in the nation's jobs and Gross Domestic Product (GDP) through the year 2030. Table 1 below provides the assumed reference case projections for key metrics against which we will compare the impacts for the different scenarios of feedback programs.

Table 1. Reference Case Projections for Key Economic Metrics 2012 and 2030

Metric	2012	2030	Annual Rate	Total Growth
GDP (billion 2005 dollars)	13,572	21,736	2.7%	60.2%
Real Investment (billion 2005 dollars)	1,866	4,066	4.4%	117.9%
Households (millions)	116.1	139.3	1.0%	20.0%
Nonfarm Employment (millions)	132.7	161.1	1.1%	21.4%
Residential Electricity Use (billion kWh)	1,418	1,651	0.9%	16.5%
Electricity Use/Household (kWh)	12,216	11,854	-0.2%	-3.0%
Average Residential Electricity Price (2010 $/kWh)	0.113	0.108	-0.2%	-3.9%
Annual Residential Electricity Costs (billion 2010 dollars)	159.9	178.9	0.6%	11.9%

Source: EIA (2011)[4]

A quick review of key assumptions highlighted in the forecast summary in Table 1 above suggests some good news. As measured by EIA's assessment of the nation's Gross Domestic Product or GDP, the economy will grow at a faster clip than either the number of households or their increased use of electricity consumption. While electricity expenditures will also increase, they will increase more slowly than GDP. The obvious conclusion is that there will be a normal improvement in the overall efficiency in how we use electricity to provide the nation's households with needed goods and services. At the same time, however, a recent ACEEE study indicates that much larger efficiency gains are entirely possible. If those opportunities were to be developed and implemented, the new study (Laitner et al. 2012) suggests that by 2030 total residential sector electricity demand would *decline* to 1,200 billion kilowatt-hours rather than *increase* to 1,651 billion kilowatt-hours. What may be less obvious, and as we explore later in this assessment, feedback programs and technologies are among the many ways to help achieve that level of improvement (Ehrhardt-Martinez, Laitner and Donnelly 2011).

Finally, some readers may be surprised how much the economy depends every year on the flow of normal investments as they affect our nation's schools, roads and bridges as well the many electric power plants, transmission lines and industrial facilities needed to maintain a functioning economy. As we might imagine by looking at Figure 2 below, and as shown later in the analysis, even a 4-12 percent household electricity savings can provide the foundation to redirect a small part of normal investment into feedback programs in ways that achieve a much greater level of cost savings compared to the normal rate of energy efficiency improvements. In addition, as we shall also see, the investments will drive a small but net positive gain in the nation's job market.

[4] The economic assessment reported in this study was built on the so-called early release of the AEO 2012. The narrative of the report is updated to reflect the final AEO 2012 release in June 2012. However, the modeling exercise also reported here continues to rely on the values from the early released. An independent review suggests a *de minimus* changes in results, and for convenience of reporting the values in the modeling exercise are retained.

The next section of this report explores how feedback technologies and programs contribute to lower energy or electricity consumption in homes.

Exploring the Range of Feedback Effects

Advanced utility meters (so-called "smart meters") coupled with in-home displays or feedback devices provide the means by which residential energy consumers can become more knowledgeable about their energy consumption practices. Such devices, in effect, enable consumers to become active managers of their own energy resource use, or in this case their home electricity usage patterns. Historically energy use feedback has taken a variety of different forms, but all forms are anchored by longstanding research in the fields of psychology, sociology, communications, and marketing. Most current and past feedback initiatives are based on the notion that individual and household behavior can be shaped by providing people with information and motivation.

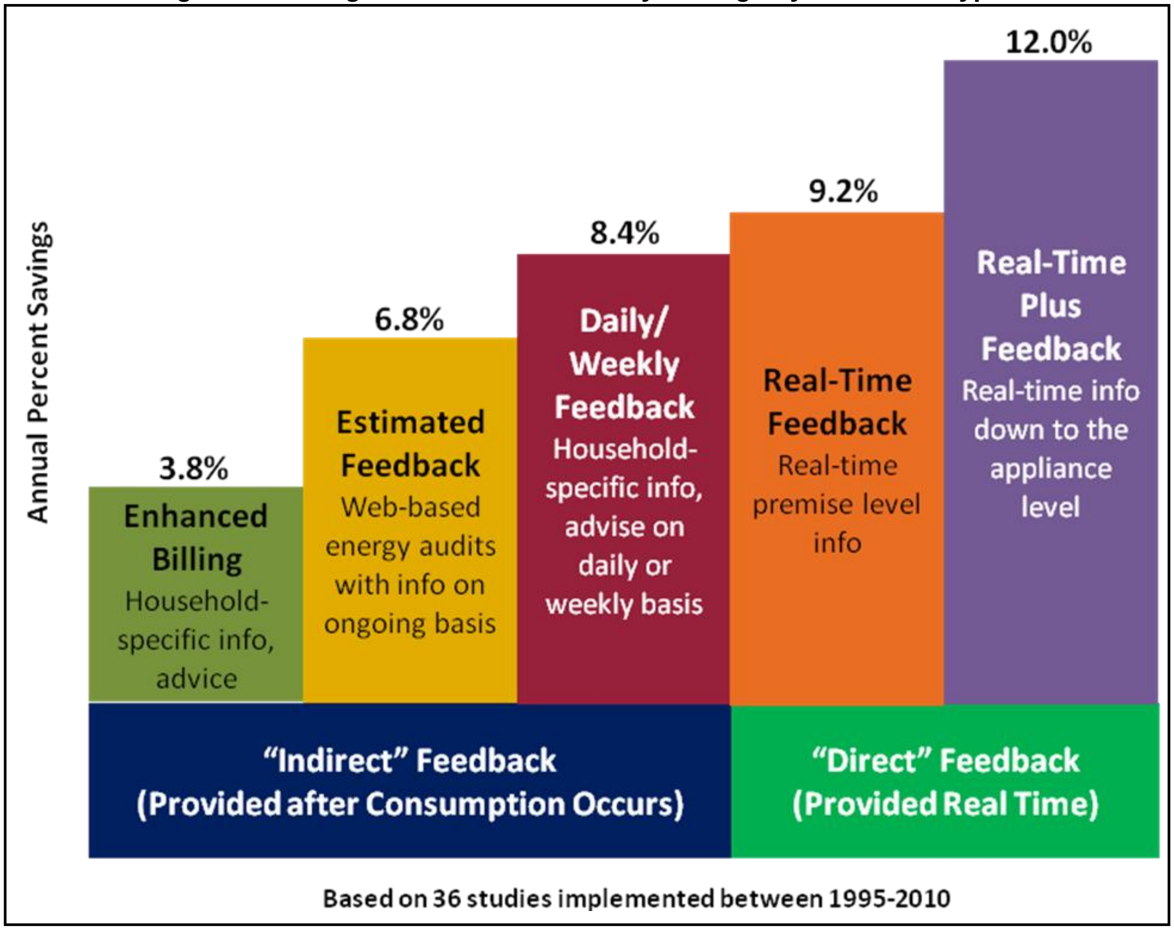
As a source of information, feedback provides consumers with relevant data on current and past levels of energy use. Motivational elements provide context and meaning that enable people to change their current energy consumption practices. Sometimes this is as simple as highlighting the positive consequences of energy-wise consumption behaviors, thereby making those behaviors more attractive to consumers, or emphasizing negative consequences and making unsound behaviors much less desirable (Abrahamse et al. 2005). In the case of household energy consumption, negative consequences often take the form of higher energy bills associated with higher levels of consumption. Time-of-Use (TOU) and other price driven electricity rate structures provide even greater negative economic consequences for households that fail to manage their energy consumption during peak periods or periods of high demand.

How important is the type of feedback in determining residential energy savings? Figure 2 on the following page, taken from a large meta-review of feedback studies (Ehrhardt-Martinez, Donnelly and Laitner 2010), summarizes the effectiveness of five different kinds of feedback as noted below. These include: (1) enhanced billing, (2) estimated feedback, (3) daily or weekly feedback, (4) aggregate real-time feedback, and (5) disaggregated real-time feedback. The first three categories are types of "indirect" feedback, in which information is provided after the consumption of energy has occurred. The latter two categories are 'direct' or 'real-time' feedback wherein information on energy usage is provided as it occurs.

1. Enhanced Billing

One means to shape consumer response is to use social norms and monthly home energy reports to reshape the behavior of residential electricity customers. These programs are based on the idea that residential energy consumers will positively respond when provided a point of comparison so they can assess their energy consumption patterns in a meaningful context—e.g., relative to their peers or a community average. Comparative information comes in the form of historical data as well as social comparisons with other households. Historical data show consumers how their current energy bill compares to past billing periods during the current year as well as prior years. Social comparisons allow consumers to assess their level of energy consumption relative to that of other people in homes and household like theirs. While the studies use a variety of complex data sources to calculate social comparisons, these approaches are relatively low cost, and when designed correctly, they have demonstrated meaningful energy savings. In the larger meta-review summarized in Figure 2, these enhanced billing techniques have shown annual household savings that range from 2.5 to as high as 10.0 percent. The program studies in the meta-review averaged 3.8 percent savings.

Figure 2. Average Household Electricity Savings by Feedback Type



Source: Ehrhardt-Martinez, Donnelly and Laitner (2010), based on 36 studies from multiple countries implemented between 1995-2010.

2. Estimated Feedback

Web-based tools have become an increasingly popular means of providing household energy consumers with estimated feedback. Estimated feedback relies on data provided by the individual or household as opposed to the utility or a third party provider. Figure 2 suggests an average savings of 6.8 percent from these kinds of programs with a range of 5.0 to 8.5 percent.

3. Daily/Weekly Feedback

The last form of indirect feedback (Daily/Weekly) has historically been relatively low-tech in its implementation. Most studies have relied on the use of feedback cards, door hangers, and other hand written methods to inform participants of their actual energy consumption patterns and savings. As such, this approach has been relatively labor-intensive and difficult to scale up as historically implemented. Nevertheless, energy savings have been notable, ranging from 4.0 to 19.0 percent with an average of 8.4 percent. Given these substantial savings, it is important to consider the ways in which web-based technologies could potentially facilitate implementation of this type of feedback program and allow for larger scale studies.

4. Aggregate, Real-Time Feedback

Energy savings associated with aggregate (entire household), real-time feedback vary widely, but typically fall somewhere between 0.5 and 18.0 percent depending on the characteristics of the feedback device and its use in combination with innovative program designs. The average shown in Figure 2 is 9.2 percent.

5. Disaggregated, Real-Time Plus Feedback

Perhaps the most innovative and exciting of the various feedback devices are those that provide disaggregated or end-use specific real-time feedback. These high-tech gadgets offer the promise of providing households with the most detailed and timely energy consumption data, however they tend to be among the most costly approaches to feedback. Nevertheless, preliminary research suggests a range of potential savings of 9 to 18 percent with an average of 12 percent.

Implementing Feedback Assumptions

Feedback mechanisms can be supplemented with behavioral program aspects, such as goal setting, descriptive and inductive norms, behavioral modeling, competitions, scarcity, etc. in a variety of different ways. For example, goal setting can motivate consumers to save energy when combined with daily/weekly feedback. Interestingly, the size of the goal seems to play an important role in determining subsequent energy savings. In one early study (Seligman et al. 1978), households were divided into two groups wherein the first group was given a relatively easy savings goal of 2 percent. The second group was given a much more difficult savings goal of 20 percent. Notably, the group with the difficult savings goal was the only group that achieved significant energy savings, 13 percent on average. A later study (Winett et al. 1982) found that that the effects of behavioral modeling in many cases could be much more important factors than goal setting. In their experiment, participants watched videotapes demonstrating different conservation strategies. When used in conjunction with feedback, this kind of behavior modeling was effective in generating average energy savings of 15 percent.

At this point, we now have a basis for setting up a range of scenarios that incorporate a variety of program efforts with differing scales and components. These efforts rely, in turn, on feedback mechanisms to generate both conservation and efficiency behaviors. In general, the core of those assumptions follow from the estimated 4 to 12 percent savings as summarized above. At the same time, following the emerging investigations on the theory of social construction of decision-making and related research (Wilson and Dowlatabadi 2007), we can extend the program designs further. We can move from ones that merely piggyback onto the fundamentals of feedback design into a richer set of behavioral elements that, over time, might extend or amplify the potential savings. This is especially true as consumers move from purely a change in habits based on feedback mechanisms alone to smarter innovation decisions about cost-effective investments and outcomes. We turn our attention next to a working set of hypotheses that provide a further basis for our scenario exercise.

Working Hypotheses on Shifting Behaviors

Laitner and Ehrhardt-Martinez (2010) suggest that, in fact, energy efficiency behaviors operate along a continuum rather than as part of discrete and unrelated actions. In this context, feedback technologies merely provide a first step for programs designed to promote energy savings. To explore the potentially greater economic impacts that might emerge from the mapping of social science insights, beyond purely feedback mechanisms, into improved program designs, we next examine several additional hypotheses that might inform those future efforts.[5] As we shall see, much of the prospective changes in behavior would result from changes in habit (Duhigg 2012) as program designs anticipate both the feedback and supporting activities or interventions that positively impact existing habits in how we understand and use energy.

[5] Here we acknowledge the contribution of our colleague Ben Foster with whom we discussed this topic. He contributed an initial written discussion that now finds its way into this report. At the same time, the changes that we have added to his initial write up remain the author's responsibility rather than his.

Moving from an Initial Consumer Response

Energy-use feedback in the home tends to involve no-cost behaviors such as changes in daily habits and low-cost energy stocktaking behaviors (Ehrhardt-Martinez 2011). These actions range from simple, no-cost changes in routines and habits (e.g., turning off the lights), to the infrequent, low-cost replacement of equipment (e.g., replacing incandescent light bulbs with CFLs), to investment in more energy-efficient appliances, devices and materials (e.g., purchasing an ENERGY STAR refrigerator, or adding wall insulation). These studies suggest that, although those who invest in energy-efficient technologies and improvements tend to save the most energy, bulk of the savings from feedback programs are due to no-cost or low-cost behavioral changes.

Several caveats caution us from concluding that the behavioral resource is necessarily limited to the range of 4 to 12 percent savings. First, the savings suggested in Figure 2 are averages. Some programs have exceeded 20 percent savings, which suggest that further inquiry and learning might be able to pull up these averages—if properly integrated into new program designs. For example, research suggests that improved market segmentation (Dethman, Degens and Castor 2010) and tailored program design (Abrahamse 2007) can amplify consumer response beyond first expectations.

A further area also explored is whether targeting or tailoring activities can increase the level of consumer interaction and may produce new areas of consumer savings not originally anticipated.[6] The working hypothesis is that many program designs may actually constrain the types of actions that consumers could take as a response to feedback. The reason is they tend to provide only few energy savings strategies or options for individual households such as installing more efficiency lighting or changing the thermostat of household air-conditioners. In contract Mirosa, Lawson and Gnoth (2011) examined 21 different measures while Laitner and Ehrhardt-Martinez (2010) examined more than 100 separate energy saving actions that households could take—including savings from changes in personal transportation practices. At the same time, the studies reviewed to date tend to be of short duration; they therefore do not tease out any new interventions and/or potential changes in behavior over time. Lastly, the evidence indicates feedback is part of a learning process. Hence, changes in consumer responses to feedback over time may tend towards greater investments in technologies rather than just changes in lifestyle or habits.

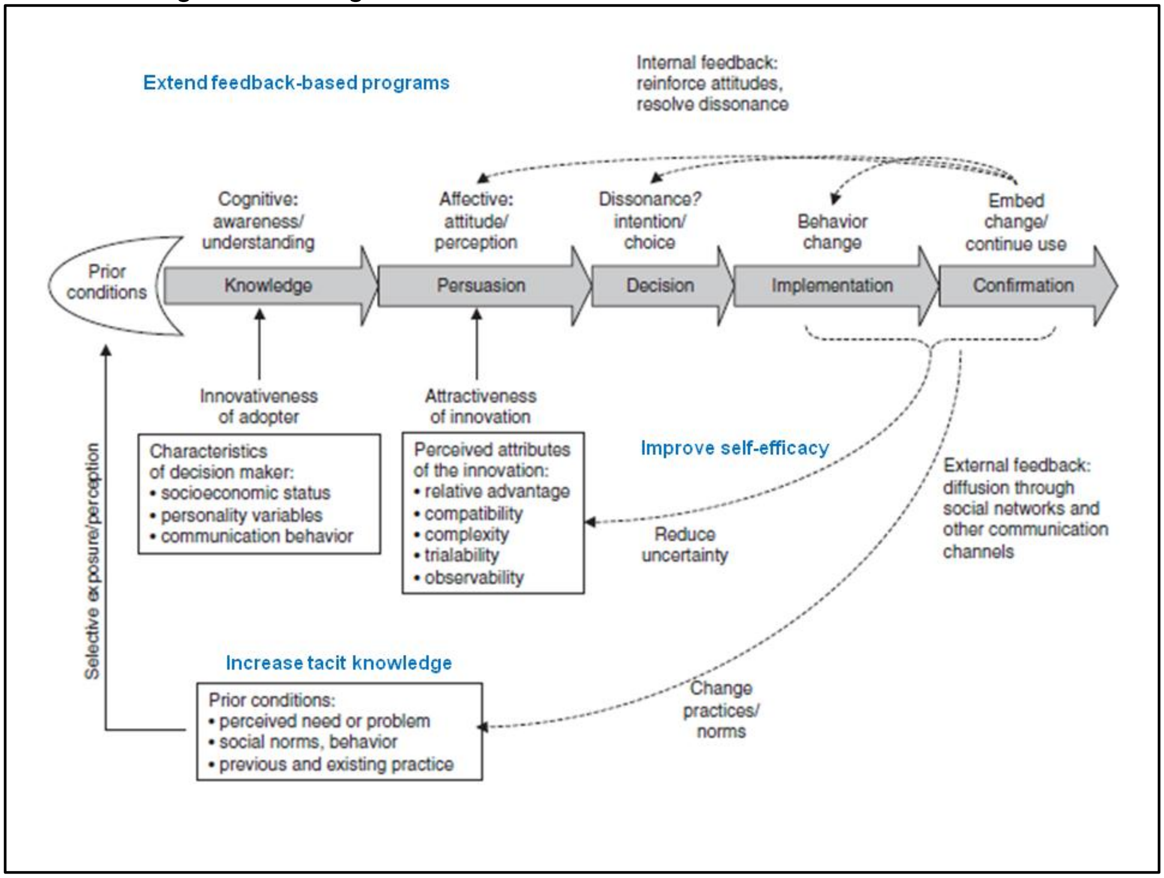
Though there is currently little empirical evidence for this hypothesis as it might affect energy consumption, work in other disciplines strongly point to this prospect. See, for example, Wood, Tam, and Witt (2005) and also Wood and Neal (2007). In the latter study, the authors note that social scientists previously believed that to change behavior, people needed help in changing goals and attitudes. That has worked, they note, for those behaviors that are not performed too frequently, like donating blood. Nevertheless, to quit smoking they suggest that the physical environment must be changed at least to some degree as it shapes second-nature or what we might call automatic responses. About 45 percent of what people do is guided by habit. To drive a different outcome, they note, we need to disrupt environmental cues (Neal et al. 2011). Thus, melding these insights with feedback programs are likely to amplify, as we suggested earlier, savings beyond what we might otherwise anticipate. In this exercise, we adopt that assumption, albeit in a more limited fashion, as we explain below.

Moving from making simple behavior changes to making capital investments based on feedback may require more than just continued information about one’s energy use. There is evidence that making energy use more visible through feedback works best when combined with information

[6] As one reviewer suggested, almost all of the feedback studies to date have yet to integrate the emergent opportunities associated with smart-phone and iPad applications. This would allow for a greatly improved segmentation and tailor-made program design that might enable a greater level of response than generally seen to date.

about social norms and with commitment or goal-setting devices, and when it is included as part of a competition process (Friedrich, Amann et al. 2010). With these perspectives in mind, we can imagine possible savings might both approach and exceed 18 percent.

Figure 3. Moving from Feedback to an Innovation Decision Process



Source: As adapted from Wilson and Dowlatabadi (2007) and extended here to include increasing tacit knowledge and improved self-efficacy.

Feedback as a Learning Process

With continued feedback and the integration of other individual and social behavioral drivers into extended program designs, consumer receptiveness to new thinking and the many new intervention points, energy efficiency behaviors and investments might increase. In this respect, we draw on and adapt the work of Wilson and Dowlatabadi (2007) as shown in Figure 3 with additional notation highlighted in a blue font. Here we suggest that by extending feedback programs to build up tacit knowledge (see the discussion below) among the many different segments of consumers, we might also increase what sociologists and social psychologists refer to as self-efficacy—that is, enhancing an individual's belief in their own competence and in their own capacity to take positive action. Said differently, self-efficacy is the belief that one is capable of performing in a particular manner to attain a certain set of goals, in this case to achieve a given or even a higher level of energy savings. The ‘Energy Cultures’ research in New Zealand, for instance, used “laddering approaches” to undertake qualitative analysis on peoples’ values and behavior drivers found that ‘being capable or competent’ was one of the most important drivers for effecting behavioral change (Mirosa, Lawson and Gnoth 2011).

In contrast to the earliest conceptions of energy-use feedback that portrayed consumers as relatively passive, and reactive, and perhaps motivated only by reward and punishment, Darby (2006a; 2006b) offers evidence that providing comprehensible feedback, which makes energy uses more visible, is part of a process by which people build up a body of "tacit" (implicit) knowledge about the supply and use of energy through everyday experience. In other words, feedback—when it is comprehensible and timely—can be part of a relatively easy process of learning about one's energy use.

In her research on residential energy use in an English village, Darby found that this learning process takes place through a combination of absorbing general information about energy use from many sources, seeking out regular feedback on one's specific energy use and taking specific actions related to that use. As a person builds up tacit knowledge, he or she gains "the ability to learn unaided, evaluate information, invent solutions to problems and share knowledge with others [related to energy use]" (Darby 2006b). This gradual building up of experience may positively influence one's willingness to undertake bigger and/or increasingly costly (in terms of convenience or dollars) investments in reducing energy consumption.

Fuller et al (2010) also found that the effectiveness of feedback depends on understanding the audience to which it is targeted. Reducing energy use is, by itself, not a pressing problem for most people. Connecting the information received through feedback to non-energy benefits of energy efficiency that are relevant to different market segments may be a key to greater market penetration of deep energy upgrades, for example. Depending on target audience, such benefits might include comfort, health, financial savings, "keeping up with the Joneses," community involvement or self-reliance.

Fuller also points out that there is some evidence that consumers can be encouraged to move from smaller to larger actions and investments that affect energy use. She notes that, with continued contact through an energy efficiency program—similar to receiving continued feedback—consumers may be encouraged to make a larger commitment to reducing energy use after already having taken a smaller one, and that as individuals begin to view themselves as more "energy efficient" they may be more likely to make larger efficiency investments in the future.

Analogous to capital cycles in an industrial setting where investments in new capital stock are largely shaped by market forces, not the rated lifetime of equipment (Lempert et al. 2002), there may be several "intervention points" defined by market conditions or a person's life stage that impact the decision to make large energy efficiency investments. These might include the sale or purchase of a home, life transitions like becoming an empty nester or starting retirement, or the growing awareness of the need to reduce waste and improve overall levels of energy security. The following section explains how these concepts have been implemented in the scenario exercises that follow.

Market and Cost Assumptions

With the overall framework now created to explore how feedback-induced programs might drive large-scale residential electricity savings, we now describe the assumptions that underpin our working estimates of investment magnitudes and the resulting benefits to the economy. We start with the initial program design that sets up five different approaches to feedback responses. We then lay out the possible magnitudes of electricity savings that feedback programs may encourage including both the initial response to feedback and the build-up of both tacit knowledge and increased self-efficacy. We conclude this section with a review of cost and performance assumptions before we dig into characterizing the analytical framework that provides us with the working estimates of program outcomes.

Initial Program Design

The assumption is that while "smart meters" are likely to be installed in nearly all customer premises by 2030, without specific policies or appropriate standards, their use is likely to be limited to managing the grid and peak demand more efficiently, and also to monitor, track, and bill customer electricity consumption as a utility cost-saving measure. In other words, absent policy mechanisms or economic incentives for the utilities, the use of advanced meters to encourage the more efficient use of electricity by the consumer, throughout the entire year and across all customer end uses, may be significantly less than the use of smart meters to benefit the utilities directly. Using the Monte Carlo technique (see the discussion in the next subsection), we develop five alternative electricity consumption scenarios. Each is associated with a specific type of feedback, and each scenario is based on a randomization of feedback-related savings and participation rates (within a specified range) as they apply to that type of feedback.

Given the unique working assumptions, the Monte Carlo exercise then runs 10,000 simulations for each of the five scenarios to explore the potential impact over a time horizon that runs from 2012 through 2030. Adapting the relevant data on savings and participation from the meta-review (Ehrhardt-Martinez, Donnelly and Laitner 2010), Table 2 highlights the key assumptions used to generate each of the five alternative scenarios.

In Scenario A, we assumed enhanced billing only as the source of feedback. The level of savings is small but the range of participation can be quite large. In Scenarios B and C, we examine Real Time feedback with a somewhat larger range of savings. For Scenario B we assume that consumers would have to take an active step to "opt in" as active participants. Hence, there would be a much smaller level of consumer or household participate. In the Scenario C "opt out" assessment, we envision a much larger level of household participation. In Scenario D we assume a more active use of insights from the social sciences with both a higher level of savings and household participation. Finally, in Scenario E we extend Scenario D to include the build-up of tacit knowledge that amplifies consumer savings beyond the initial feedback-related responses.

Table 2. Key Assumptions for Policy Impact Scenarios

Primary Feedback Mechanism	Range of Savings	Range of Participation
A. Enhanced Billing	2 to 4%	90 to 95%
B. Real Time (opt in)	4 to 12%	3 to 8%
C. Real Time (opt out)	4 to 6%	65 to 75%
D. Well-Designed, Behavior-Savvy Program[7]	6 to 18%	70 to 80%
E. Behavior-Savvy with Tacit Knowledge[8]	8 to 28%	70 to 80%
Key Technology Costs		
Unit Technology Cost	None for Scenario A. For the remaining scenarios, initially $150 per customer declining to $105 by 2030.	
Program Cost	For Scenario A, an average four cents per kWh. For the remaining cases, initially 25% of technology cost declining to 15% by 2030.	

Notes: The savings ranges in this analysis are based on the overall multi-continent sample. Savings in the U.S. have tended to be lower and hence this analysis implicitly assumes that with continued program development, savings in the U.S. can approximate the overall multi-continent results. Savings from tacit knowledge are explained in the text. The unit technology cost estimates do not include the cost of establishing a "smart grid" but instead cover in-home costs of monitors and displays, with or without a smart grid.

In-Home Technology Costs

Also highlighted in Table 2 are the technology and program implementation costs for each participating customer. For Scenario A, the assumption was that no customer meter or similar technology was required to implement the program. Rather, following the program efforts such as those implemented by OPOWER, C3 Energy, Tendril and others, the costs are purely program or

[7] Well-designed feedback approaches effectively integrate multiple, non-economic motivational strategies and include both direct and indirect forms of feedback and (ideally) real-time, appliance-level feedback (Ehrhardt-Martinez 2011). The working estimate shown in Scenario D falls within the upper range of studies reviewed by Ehrhardt-Martinez, Donnelly and Laitner (2010). However, this should be seen as the author's professional judgment of what might be possible as energy efficiency becomes a more available resource option within the range of services provided by the nation's electric utilities.

[8] Tacit knowledge is explained on the next page.

administrative costs that might be amortized at the rate of four cents per kWh (Mahone and Haley 2011).[9] In an earlier work (Ehrhardt-Martinez, Donnelly and Laitner 2010), in-home displays and related technologies were found to start at a higher level of $500 dropping to $350 per unit by 2030.

Significantly, lower costs have been reported elsewhere. For example, Faruqui and Wood (2008) suggested feedback monitors could be purchased and installed by individual customers for under $150. Collins (2011) found a range from $99 to $268 for 10 different devices. Karlin, Ford and Squiers (2011) have a database of more than two hundred different industrial, commercial and residential feedback devices. The residential devices have a typical cost range of $100 to $300, depending on the kind of services and reporting that might be provided. Many show a much lower cost. Moreover, we have seen dramatic decreases in new costs even in the last two years. A Palo Alto, California company, People Power, is focusing on what they call the “connected home” and have developed software and a cloud-based service that allows people to hook up any device, wirelessly or by way of an enabled power strip, to see their energy use real time. Their cost is listed at $100 to $150.[10] A Santa Cruz, Calif.-based startup company called Glen Canyon recently “unstealthed” its promise to deliver smart meters for the unheard-of cost of $25 or less. And it claims it has already landed a 1.5-million-meter order from China.[11] For purposes of our analysis here, we assume an initial $150 cost dropping by 30 percent by 2030.

The further presumption is that costs associated with smart grid expenses are sunk costs that would be made regardless of customer participation in feedback-induced energy efficiency programs. Hence, the technology costs reflected in this scenario analysis are incremental costs necessary to bring customers into full participation in a specific program (as highlighted in Table 2). A further assumption for Scenarios B through E is that utility administration and program costs initially will be 25 percent of the per unit technology costs but declining to 15 percent by 2030 as the program builds momentum and both utilities and customers gain experience in working with the new technologies and feedback mechanisms.

The Impact of Building Up Tacit Knowledge

Up to this point, the paper describes magnitudes and costs with what might termed “pure feedback savings.” At the same time, we want to explore the potential impacts of savings that might accrue from the build-up of tacit knowledge in the residential sector. Therefore, the analysis also includes how building consumer confidence may give rise to additional savings. The assumption is that pure feedback savings involve primarily a change of habits and/or very low cost-no cost efforts with bigger investments accounting for only 30 percent of the response with technologies that have paybacks of about four years. As experience, knowledge, and confidence build, however (increasing the level of self-efficacy), savings might be expected to expand beyond pure feedback as we suggest in Scenario D.

For purposes of this analysis, we extend Scenario D to assume in Scenario E that there will be a three-year lag from year from year when feedback becomes routine to when the greater savings begin to emerge as self-efficacy builds and as other interventions take hold. Moreover, we assume in Scenario E an average equipment life of 13 years for household equipment and appliances.[12] This means that, on average, about 8 percent of household electricity savings might

[9] Drawing on OPOWER data, Mahone and Haley suggested $10 per household per year. If savings are 250 kilowatt-hours annually for enhanced billing feedback, that averages to $0.04/kWh.

[10] For more background on this technology with a demo given by the company’s CTO David Moss at the January 2012 Consumer Electronics Show in Las Vegas, when they announced a partnership with Monster, see http://socialcam.com/v/CDRHPzMR?autostart=true.

[11] See http://www.greentechmedia.com/articles/read/glen-canyon-promises-the-25-smart-meter/.

[12] In some ways, Scenario E explores the difference between what economists call short-run and long-run elasticities. Scenarios A through D examine the response to feedback given a more or less fixed set of capital, or appliances and equipment in the home. Scenario E opens up the possible range of responses by enabling greater learning to take place over a longer period of time—hence the three-year lag—and the slow

be upgraded as those end uses are replaced (once every 13 years). We finally assume 10 percent additional savings resulting from those new upgrades in homes benefitting from feedback over a longer period. This results in additional savings of 0.8 percent per year, or a total of 10 percent additional savings after 13 years.

Impact on Electricity Costs

One final element reviewed in this study is the impact on electricity prices because of a lower consumption of electricity over time. The presumption is that reduced electricity demand is likely to lead to somewhat lower costs of electricity for everyone. We can confirm this by turning to the Annual Energy Outlook 2012 to look at the so-called "High-Technology" case and the Reference Case to compare both electricity consumption and electricity prices. As it turns out, the High Technology case reduces the economy-wide demand for electricity nine percent by 2030. Because of a different mix of generation resources, economy-wide electricity prices are lowered by seven percent. Following the time series data over the period 2012 through 2030, and for our purposes here, we assume that each one percent that residential electricity savings drives down total economy-wide electricity consumption, electricity prices will drop about three-quarters of a percent.[13] For this reason, feedback-induced energy savings can benefit all users of electricity, both those who save electricity and those who do not. In effect, the slightly smaller demand for electricity will also place a downward pressure on the average price of electricity so that all remaining consumption of electricity will generate a further economic savings.

Methods of Assessment

Taking the aggregate of all the data and assumptions that were previously identified, the economic impacts of the pure feedback and the feedback-induced electricity savings are calculated using two different tools. The first tool lays out the appropriate accounting of residential electricity savings as they are estimated from the economic relationships explained. The second evaluates the feedback-induced investments and especially the electricity bill savings for their employment impact within the U.S economy. We describe each of these two analytical tools next.

The Accounting Tools

The assessment begins with a reasonably straightforward set of time series data that includes the total number of households, total electricity consumption by those households, and average electricity prices. These data are all shown in the Appendix for the period 2012 through 2030. Following the logic of each of the five scenarios summarized in Table 2, we then use a Monte Carlo simulation within an Excel workbook to make annual adjustments to the reference case assumptions, given the range of new homes that each scenario assumes will be involved in feedback programs, and that will have access to in-home displays. Also following the Table 2 assumptions, we estimate the savings response from within each of those households.

Monte Carlo simulations are a form of probability analysis. In this case, we draw on the findings of Ehrhardt-Martinez, Donnelly and Laitner (2010) to establish the lower and upper bounds for key

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changing out or need to change equipment. Some of the appliances may have a relatively short life as 3-5 years (think consumer electronics) while other large-scale devices as washing machines, refrigerators, and windows more last 20 years or more. The number chosen here, or 13 years, is typical of a weighted average. If a shorter period, that would speed up adoption rates compare to what is explored in Scenario E. That said, and following a very interesting study by Mirosa, Lawson, and Gnoth (2011), there is a critical need for studies to better understand a combination of both personal values and timing as they affect behaviors in the home.

[13] More technically the data suggested that, given an economy-wide index of post-feedback electricity use compared to total reference case electricity consumption, the change in electricity price would be $\text{Index}^{0.77}$. So, for example, if we see a residential energy savings of 6 percent, and that drives total electricity use down 2 percent, then the new electricity price would be $0.98^{0.77} = 0.985$, or 1.5 percent lower for everyone.

variables as suggested in Table 2. The simulation then generates a set of random numbers to help us explore the interactions among those variables as they shape a different pattern of electricity consumption. Each of the four scenarios reflects a composite profile based on 10,000 simulations. Although the probabilistic results should be taken as approximate, the overall results fit intuitively within the expected pattern of other concrete estimates of energy savings over time.

Once each of the first four scenarios generates estimates of feedback savings, we then introduce the impact of tacit knowledge in the fifth scenario, or Scenario E, as it builds up from Scenario D assumptions over time. As information becomes routine and as households experience more success in their ability to manage effectively their use of electricity, as equipment and appliances need replacement, the assumption (as explained in the prior section) is that they will see further electricity savings. While only 30 percent of the initial feedback savings are shown to involve the purchase of equipment, all of the incremental savings are assumed to require the purchase of new, more energy-efficient appliances and equipment. Building from the aggregate savings, the accounting tool then provides annual estimates of total investment, changes in household electricity use, and the impact on residential electricity prices.

The Macroeconomic Impacts

Over the last several years, ACEEE has been developing and using what we call the DEEPER modeling framework to evaluate the larger macroeconomic and net employment impacts of the various policy scenarios we have been asked to review. DEEPER is the **D**ynamic **E**nergy **E**fficiency **P**olicy **E**valuation **R**outine, a quasi-dynamic input-output model now calibrated to the 2009 economic accounts for the United States. Based on those 2009 economic accounts it turns out that the electric utility sector supports only about nine direct and indirect jobs per million dollars of revenue. All other sectors of the economy support about 17 direct and indirect jobs per million dollars of revenue. Hence, a cost-effective movement away from energy consumption should support a small but net positive gain in the nation's employment base. In simple terms, if an electric utility has $1 million in fewer revenues because of efficiency gains, on average it may support eight fewer jobs in the economy. However, if consumers enjoy a net electricity bill savings of $1 million, then their re-spending of that savings will support on average 17 jobs.[14] In that case, the economy is better off by nine net jobs on the positive side of the ledger.

In this case, we use the DEEPER modeling framework to match both the positive and negative changes in revenues to the appropriate sector multipliers to determine the net job impacts found in Table 4 below. These multipliers are modified over time to reflect changes in labor productivity as reported by the AEO 2012 reference case. As it reports for the period 2012 through 2030, the AEO suggests that labor productivity will increase by about 1.9 percent per annum. This means that $1 million in spending in 2030 will support only 67 percent of the jobs yielded in the base year of the model. In the example above, a net gain of nine jobs in 2009 might be only six jobs by 2030.

[14] One reviewer asked whether these results might be affected by the so-called rebound effect; that is, the "the social and behavioral responses to the introduction of more energy efficiency technologies and processes by which there is a corresponding increase in energy service demands" (Ehrhardt-Martinez and Laitner 2010). Based on a review of the literature and the shift in behavioral perceptions, Ehrhardt-Martinez and Laitner and most recently Nadel (2012) concluded the effect would be very small. Moreover, since Scenarios A through E effect economy-wide savings of 1-10 percent across our nation's households (as shown in Table 3 that follows), it is unlikely to significantly change either the net financial benefits or the employment gains. At the same time, should the combination of behavioral changes in productive investments begin to scale through all sectors of the economy rather than just households, there may indeed be a need to review the so-called rebound or take-back effect.

KEY FINDINGS

Table 3 highlights the key results of each scenario as the Monte Carlo simulations randomly select from the range of participation levels and electricity savings. The table shows the estimated outcomes, including estimated savings per customer by 2030, estimated residential end-use electricity savings by 2030, and the expected net present value of total costs and total energy bill savings (represented in constant 2010 dollars discounted 5 percent annually).

The numbers reported in Table 3, and the study as a whole, should be interpreted as exploring the cost-effective residential electricity savings that could potentially be achieved by 2030—under a variety of assumptions about the types of feedback mechanisms and programs implemented, and given the overall market acceptance of those programs. In this regard the analysis explores the impact of an individual response or range of individual customer savings across multiple households that are assumed to participate in feedback programs to produce what is termed a scenario savings. In this analysis, it is likely that the error range for any particular estimate in each of the scenarios studied is large. This remains the case even with the reliance on the many studies reviewed. With that caveat, a number of critical insights emerge from the five scenarios as they are reported in Table 3 below.

Table 3. U.S. Residential Electricity Savings from the Feedback Scenarios

Scenario Impacts by 2030	A	B	C	D	E
Reference Case Electricity Demand (billion kWh)	1,651	1,651	1,651	1,651	1,651
Reference Case Electricity Customer (thousands)	139	139	139	139	139
Participating Feedback Customers (thousands)	85.5	11.6	71.3	74.1	74.1
Total Feedback Electricity Savings (in Billion kWh)	30.4	11.5	42.1	104.6	104.6
Total Induced Electricity Savings (in Billion kWh)	0.0	0.0	0.0	0.0	50.2
Total Scenario Electricity Savings (in Billion kWh)	30.4	11.5	42.1	104.6	154.8
Savings per Customer (in kWh)	356	992	591	1,412	2,090
Savings per Customer (percent reference case)	3.0%	8.4%	5.0%	11.9%	17.6%
Scenario Electricity Savings (percent reference case)	1.8%	0.7%	2.5%	6.3%	9.4%
Resource Cost (million 2010 dollars, 2012 -2030)	$16,027	$1,673	$14,861	$23,906	$41,231
Energy Bill Savings (million 2010 dollars, 2010 -2030)	$26,723	$13,813	$37,377	$91,737	$120,084
Total Resource Cost: Benefit-Cost Ratio at 5% NPV	1.63	7.70	2.17	3.28	2.61

The first critical insight is that advanced metering, together with active customer participation in well-designed utility feedback programs, can save consumers and businesses a considerable amount of money. Depending on the breadth and effectiveness of program design, and with the set of program assumptions described above, individual consumer electricity savings in these exploratory scenarios might range anywhere from 3.0 to 17.6 percent annually by 2030. The sector-wide savings might range from a much smaller 0.7 to 9.4 percent annually. Over the 19-year time horizon 2012 through 2030 the present value of technology and program costs might range from roughly $2 to $41 billion dollars while saving the economy a total of $14 to $121 billion (in constant 2010 dollars).

Using a total resource cost test (in effect, examining total economy-wide costs and total economy-wide savings from avoided electricity generation), the benefit-cost ratio appears to range from a low of about 1.63 in Scenario A to a high of 7.70 in Scenario B. This means that the 0.7 percent savings in Scenario B appears to be highly cost-effective since it will return an average discounted savings of $7.70 for every dollar of technology and program costs expended over the 19-year period. At the same time, however, the very high benefit-cost ratio for Scenario B yields only a very small return for the economy since the participation rate is very small (ranging from 3 to 8 percent of total households as suggested by Table 2). On the other hand, the smaller but still positive benefit-cost ratios in Scenarios C and D reflect real-time feedback programs that elicit a greater responsiveness from consumers with a much greater level of household participation throughout the entire economy (from Table 2, ranging from 65 to 80 percent of total residential meters). Finally, Scenarios D and E explore the possibilities of a more proactive approach designed to elicit a larger individual response. Scenario D averages a 12 percent savings from a large group of customers (with a participation ranging from 70 to 80 percent) while Scenario E bumps the total savings to nearly 18 percent as the tacit knowledge and confidence of consumers build. In Scenario D the 12 percent residential sector savings from feedback programs return a net positive 3.28 benefit-cost ratio. In Scenario E the larger 18 percent savings reduces the benefit-cost ratio to 2.61 as consumers begin to extend their "pure feedback" savings to include a higher level of equipment and appliance purchases.

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

At this point, we can also turn our focus to the larger economy-wide impacts as they are summarized in Table 4 below.

Table 4. Larger Economic Benefits from the Feedback Scenarios

Scenario Impacts	A	B	C	D	E
Program Costs (million 2010 dollars, 2012 -2030)	12,623	144	1,623	1,694	1,694
Investment (million 2010 dollars, 2012 -2030)					
Feedback Technologies	0	733	8,222	8,574	8,574
Efficiency Upgrades	3,403	796	5,016	13,638	30,963
Electricity Savings (Million 2010 dollars, 2012-2030)	26,723	13,813	37,377	91,737	120,084
Average Annual Net Jobs (actual)	6,000	8,000	21,000	51,000	56,000

Perhaps the immediate insight emerging from Table 4 is that feedback programs do, indeed, drive investment—depending on the design and scale of the program effort, and depending on the increased consumer knowledge and willingness to act as these programs persist over time. The combination of program costs, which drive a range of investments in both feedback technologies and more energy efficiency equipment and appliances, also drive a greater electricity bill savings for residential consumers. Both the investments and savings, in turn, provide a small but net positive increase in jobs that might be available throughout the economy. The smaller scale program efforts characterized by Scenarios A and B provide a smaller number of jobs with net employment gain of 6,000 and 8,000, respectively. The larger scaled Scenarios C and D show a net employment benefit of 21,000 and 51,000. With the addition of induced savings in Scenario E, the net employment expands to 56,000 jobs. All of the scenario totals reflect average annual jobs that are likely to be supported over the 19-year period 2012 through 2030.

One final question that might yet be explored is to ask how important are the estimated two to ten percent residential sector savings from feedback programs, especially as they might compare to other recent estimates of national electricity savings potential from all sectors at some point in the future. One recent ACEEE study, for example, found a cost-effective electricity savings potential as high as 40 to 50 percent by the year 2050 (Laitner et al. 2012). Based on this simple comparison, we might conclude that it might make sense to move directly to a technology-based policy perspective since it is likely to achieve a multiple from five to 25 greater impacts. Alternatively, as suggested by McKenzie-Mohr (2010), expanding feedback programs could catalyze a social and cultural shift that can result in even greater efficiency gains that complement other policy mechanisms—should we choose to explore that possibility. And should we choose to make the necessary policy adjustments and investments that, in turn, will develop that opportunity.

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APPENDIX: REFERENCE CASE DATA AND DETAILED SCENARIO RESULTS

Reference Case Data for Residential Electricity Consumption

Year	Households Millions	Electricity Usage Billion kWh	Electricity Price $2010/kWh
2012	116.06	1,417.7	0.1128
2013	116.59	1,404.4	0.1122
2014	117.54	1,404.4	0.1124
2015	118.79	1,405.3	0.1133
2016	120.20	1,413.2	0.1129
2017	121.69	1,427.7	0.1120
2018	123.16	1,443.8	0.1115
2019	124.60	1,460.7	0.1109
2020	126.00	1,472.6	0.1108
2021	127.34	1,487.2	0.1106
2022	128.66	1,502.3	0.1105
2023	129.98	1,518.2	0.1103
2024	131.32	1,535.8	0.1102
2025	132.69	1,554.3	0.1102
2026	134.06	1,572.6	0.1102
2027	135.40	1,591.2	0.1103
2028	136.71	1,610.0	0.1100
2029	138.00	1,630.2	0.1090
2030	139.30	1,651.2	0.1084

Source: Annual Energy Outlook 2012

Scenario A. Enhanced Billing

Year	Residential Elec Use (Bln kWh)	Total Customers (Mln)	Feedback Customers (Mln)	Feedback Savings (Bln kWh)	Induced Savings (Bln kWh)	Total Savings (Bln kWh)	Feedback Technology Investment Cost ($2010 Mln)	Feedback Program Cost ($2010 Mln)	Consumer Feedback Technology Cost ($2010 Mln)	Consumer Learning Technology Cost ($2010 Mln)	Total Annual Cost ($2010 Mln)	Wholesale Electricity Savings ($2010 Mln)	Participant Electricity Retail Savings ($2010 Mln)	NonParticipant Electricity Retail Price Savings ($2010 Mln)	Total Electricity Savings ($2010 Mln)
2012	1,418	116	9.6	3.6	0.0	3.6	0	143	-298	0	-155	150	403	118	521
2013	1,404	117	13.4	5.0	0.0	5.0	0	199	192	0	391	213	557	162	719
2014	1,404	118	17.3	6.4	0.0	6.4	0	254	191	0	445	278	714	205	919
2015	1,405	119	21.2	7.7	0.0	7.7	0	310	193	0	503	345	877	250	1,127
2016	1,413	120	25.2	9.1	0.0	9.1	0	366	193	0	559	416	1,031	293	1,323
2017	1,428	122	29.2	10.6	0.0	10.6	0	423	195	0	618	490	1,181	335	1,516
2018	1,444	123	33.3	12.0	0.0	12.0	0	480	198	0	677	567	1,334	378	1,712
2019	1,461	125	37.4	13.4	0.0	13.4	0	538	200	0	738	649	1,488	422	1,910
2020	1,473	126	41.5	14.9	0.0	14.9	0	596	201	0	797	734	1,646	466	2,112
2021	1,487	127	45.7	16.4	0.0	16.4	0	655	203	0	859	822	1,805	511	2,317
2022	1,502	129	50.0	17.9	0.0	17.9	0	715	205	0	920	915	1,968	558	2,526
2023	1,518	130	54.3	19.4	0.0	19.4	0	775	208	0	983	1,012	2,130	606	2,736
2024	1,536	131	58.6	20.9	0.0	20.9	0	836	209	0	1,045	1,113	2,293	654	2,948
2025	1,554	133	63.0	22.4	0.0	22.4	0	897	212	0	1,109	1,219	2,463	705	3,167
2026	1,573	134	67.4	24.0	0.0	24.0	0	960	215	0	1,175	1,330	2,632	755	3,387
2027	1,591	135	71.9	25.6	0.0	25.6	0	1,023	217	0	1,240	1,446	2,808	808	3,616
2028	1,610	137	76.4	27.2	0.0	27.2	0	1,086	219	0	1,306	1,566	2,973	858	3,831
2029	1,630	138	80.9	28.8	0.0	28.8	0	1,151	223	0	1,374	1,693	3,120	903	4,023
2030	1,651	139	85.5	30.4	0.0	30.4	0	1,216	225	0	1,442	1,825	3,277	952	4,230
				NPV at a 5.0% disount rate =			0	6,995	1,976	0	8,971	9,087	19,280	5,517	24,797

Average Customer Impacts 2030		
Base Usage	11,854	kWh per year
Feedback Save	356	kWh per year
Induced Save	0	kWh per year
Total Save	356	kWh per year
Pcnt Save	3.0%	per year

Benefit Cost Ratios	
Utility Cost Test	1.30
Participant Cost Test	9.76
Total Resource Cost Test	1.63

Scenario B. Real Time Feedback (Opt In)

Year	Residential Elec Use (Bln kWh)	Total Customers (Mln)	Feedback Customers (Mln)	Feedback Savings (Bln kWh)	Induced Savings (Bln kWh)	Total Savings (Bln kWh)	Feedback Technology Investment Cost ($2010 Mln)	Feedback Program Cost ($2010 Mln)	Consumer Feedback Technology Cost ($2010 Mln)	Consumer Learning Technology Cost ($2010 Mln)	Total Annual Cost ($2010 Mln)	Wholesale Electricity Savings ($2010 Mln)	Participant Electricity Retail Savings ($2010 Mln)	NonParticipant Electricity Retail Price Savings ($2010 Mln)	Total Electricity Savings ($2010 Mln)
2012	1,418	116	6.1	6.1	0.0	6.1	52	13	49	0	114	256	686	201	887
2013	1,404	117	6.4	6.4	0.0	6.4	51	12	39	0	103	273	714	207	921
2014	1,404	118	6.7	6.7	0.0	6.7	34	8	39	0	81	291	747	215	962
2015	1,405	119	6.9	6.9	0.0	6.9	34	8	39	0	80	309	785	224	1,009
2016	1,413	120	7.1	7.2	0.0	7.2	33	7	39	0	80	328	814	231	1,045
2017	1,428	122	7.4	7.5	0.0	7.5	33	7	40	0	80	348	840	238	1,078
2018	1,444	123	7.6	7.8	0.0	7.8	33	7	40	0	80	369	868	246	1,114
2019	1,461	125	7.9	8.1	0.0	8.1	33	7	40	0	79	390	896	254	1,150
2020	1,473	126	8.1	8.4	0.0	8.4	32	6	41	0	80	413	927	263	1,190
2021	1,487	127	8.4	8.7	0.0	8.7	32	6	41	0	79	436	958	272	1,230
2022	1,502	129	8.8	9.0	0.0	9.0	47	9	41	0	98	460	991	282	1,273
2023	1,518	130	9.2	9.3	0.0	9.3	47	9	42	0	98	485	1,022	292	1,315
2024	1,536	131	9.6	9.6	0.0	9.6	47	8	42	0	97	511	1,055	302	1,357
2025	1,554	133	9.8	9.9	0.0	9.9	31	5	43	0	79	538	1,090	313	1,403
2026	1,573	134	10.1	10.2	0.0	10.2	30	5	43	0	79	566	1,124	324	1,448
2027	1,591	135	10.4	10.5	0.0	10.5	30	5	44	0	79	596	1,160	336	1,496
2028	1,610	137	10.8	10.9	0.0	10.9	45	7	44	0	96	626	1,192	346	1,538
2029	1,630	138	11.2	11.2	0.0	11.2	44	7	45	0	96	658	1,216	355	1,571
2030	1,651	139	11.6	11.5	0.0	11.5	44	7	45	0	96	691	1,245	364	1,609
				NPV at a 5.0% disount rate =			468	96	503	0	1,067	5,020	11,114	3,192	14,306

Average Customer Impacts 2030		
Base Usage	11,854	kWh per year
Feedback Save	992	kWh per year
Induced Save	0	kWh per year
Total Save	992	kWh per year
Pcnt Save	8.4%	per year

Benefit Cost Ratios	
Utility Cost Test	8.90
Participant Cost Test	22.09
Total Resource Cost Test	7.70

Scenario C. Real Time Feedback (Opt Out)

Year	Residential Elec Use (Bln kWh)	Total Customers (Mln)	Feedback Customers (Mln)	Feedback Savings (Bln kWh)	Induced Savings (Bln kWh)	Total Savings (Bln kWh)	Feedback Technology Investment Cost ($2010 Mln)	Feedback Program Cost ($2010 Mln)	Consumer Feedback Technology Cost ($2010 Mln)	Consumer Learning Technology Cost ($2010 Mln)	Total Annual Cost ($2010 Mln)	Wholesale Electricity Savings ($2010 Mln)	Participant Electricity Retail Savings ($2010 Mln)	NonParticipant Electricity Retail Price Savings ($2010 Mln)	Total Electricity Savings ($2010 Mln)
2012	1,418	116	8.9	5.5	0.0	5.5	470	118	-28	0	560	233	624	183	807
2013	1,404	117	12.1	7.4	0.0	7.4	480	117	261	0	858	318	832	241	1,074
2014	1,404	118	15.2	9.3	0.0	9.3	441	104	262	0	806	408	1,047	301	1,348
2015	1,405	119	18.3	11.2	0.0	11.2	437	100	262	0	799	501	1,270	362	1,632
2016	1,413	120	21.5	13.1	0.0	13.1	450	100	264	0	814	597	1,479	420	1,899
2017	1,428	122	24.9	15.1	0.0	15.1	463	100	266	0	829	699	1,683	476	2,159
2018	1,444	123	28.1	17.0	0.0	17.0	426	90	268	0	785	805	1,890	534	2,425
2019	1,461	125	31.6	19.0	0.0	19.0	456	93	272	0	821	916	2,098	593	2,691
2020	1,473	126	34.9	21.0	0.0	21.0	419	84	274	0	777	1,032	2,314	653	2,967
2021	1,487	127	38.3	23.0	0.0	23.0	431	84	277	0	792	1,154	2,529	714	3,244
2022	1,502	129	41.9	25.0	0.0	25.0	443	83	280	0	806	1,280	2,750	777	3,528
2023	1,518	130	45.6	27.1	0.0	27.1	439	80	283	0	802	1,413	2,970	842	3,812
2024	1,536	131	49.1	29.1	0.0	29.1	419	75	286	0	780	1,552	3,192	908	4,100
2025	1,554	133	52.8	31.2	0.0	31.2	431	74	290	0	795	1,697	3,423	976	4,399
2026	1,573	134	56.6	33.4	0.0	33.4	427	72	292	0	791	1,849	3,652	1,043	4,695
2027	1,591	135	60.4	35.5	0.0	35.5	422	69	296	0	787	2,007	3,891	1,115	5,006
2028	1,610	137	63.9	37.7	0.0	37.7	388	62	299	0	749	2,172	4,115	1,183	5,298
2029	1,630	138	67.5	39.9	0.0	39.9	384	59	304	0	747	2,345	4,314	1,243	5,557
2030	1,651	139	71.3	42.1	0.0	42.1	395	59	308	0	762	2,526	4,528	1,309	5,837
						NPV at a 5.0% disount rate =	5,295	1,088	3,053	0	9,435	12,775	27,123	7,736	34,859

Average Customer Impacts 2030		
Base Usage	11,854	kWh per year
Feedback Save	591	kWh per year
Induced Save	0	kWh per year
Total Save	591	kWh per year
Pcnt Save	5.0%	per year

Benefit Cost Ratios	
Utility Cost Test	2.00
Participant Cost Test	8.88
Total Resource Cost Test	2.17

Scenario D. Robust Consumer Participation

Year	Residential Elec Use (Bln kWh)	Total Customers (Mln)	Feedback Customers (Mln)	Feedback Savings (Bln kWh)	Induced Savings (Bln kWh)	Total Savings (Bln kWh)	Feedback Technology Investment Cost ($2010 Mln)	Feedback Program Cost ($2010 Mln)	Consumer Feedback Technology Cost ($2010 Mln)	Consumer Learning Technology Cost ($2010 Mln)	Total Annual Cost ($2010 Mln)	Wholesale Electricity Savings ($2010 Mln)	Participant Electricity Retail Savings ($2010 Mln)	NonParticipant Electricity Retail Price Savings ($2010 Mln)	Total Electricity Savings ($2010 Mln)
2012	1,418	116	9.1	13.5	0.0	13.5	505	126	1,071	0	1,702	567	1,518	444	1,962
2013	1,404	117	12.4	18.2	0.0	18.2	480	117	651	0	1,248	781	2,036	588	2,624
2014	1,404	118	15.8	22.9	0.0	22.9	491	116	650	0	1,257	1,002	2,566	732	3,298
2015	1,405	119	19.0	27.7	0.0	27.7	453	104	652	0	1,210	1,233	3,117	882	3,999
2016	1,413	120	22.5	32.4	0.0	32.4	483	108	655	0	1,246	1,473	3,634	1,021	4,655
2017	1,428	122	26.0	37.2	0.0	37.2	479	104	662	0	1,246	1,726	4,138	1,158	5,296
2018	1,444	123	29.3	42.1	0.0	42.1	443	93	670	0	1,207	1,990	4,652	1,299	5,950
2019	1,461	125	32.8	47.0	0.0	47.0	456	93	677	0	1,226	2,267	5,164	1,440	6,603
2020	1,473	126	36.5	51.9	0.0	51.9	468	93	685	0	1,246	2,556	5,695	1,584	7,279
2021	1,487	127	39.9	56.9	0.0	56.9	431	84	690	0	1,205	2,859	6,227	1,730	7,957
2022	1,502	129	43.6	62.0	0.0	62.0	459	86	695	0	1,241	3,174	6,769	1,881	8,650
2023	1,518	130	47.1	67.1	0.0	67.1	423	77	702	0	1,203	3,503	7,305	2,033	9,338
2024	1,536	131	51.0	72.2	0.0	72.2	450	80	713	0	1,243	3,849	7,852	2,189	10,040
2025	1,554	133	54.5	77.5	0.0	77.5	415	72	722	0	1,210	4,210	8,418	2,350	10,768
2026	1,573	134	58.4	82.8	0.0	82.8	442	74	735	0	1,251	4,590	8,984	2,511	11,495
2027	1,591	135	62.3	88.2	0.0	88.2	438	71	741	0	1,250	4,986	9,572	2,680	12,253
2028	1,610	137	66.3	93.6	0.0	93.6	433	69	746	0	1,247	5,397	10,120	2,839	12,958
2029	1,630	138	70.2	99.1	0.0	99.1	414	64	754	0	1,232	5,827	10,602	2,979	13,581
2030	1,651	139	74.1	104.6	0.0	104.6	410	61	766	0	1,237	6,276	11,124	3,132	14,256
					NPV at a 5.0% disount rate =		5,528	1,137	8,691	0	15,356	31,647	66,674	18,690	85,364

Average Customer Impacts 2030		
Base Usage	11,854	kWh per year
Feedback Save	1,412	kWh per year
Induced Save	0	kWh per year
Total Save	1,412	kWh per year
Pcnt Save	11.9%	per year

Benefit Cost Ratios	
Utility Cost Test	4.75
Participant Cost Test	7.67
Total Resource Cost Test	3.28

Scenario E. Robust Consumer Participation with Induced Savings

Year	Residential Elec Use (Bln kWh)	Total Customers (Mln)	Feedback Customers (Mln)	Feedback Savings (Bln kWh)	Induced Savings (Bln kWh)	Total Savings (Bln kWh)	Feedback Technology Investment Cost ($2010 Mln)	Feedback Program Cost ($2010 Mln)	Consumer Feedback Technology Cost ($2010 Mln)	Consumer Learning Technology Cost ($2010 Mln)	Total Annual Cost ($2010 Mln)	Wholesale Electricity Savings ($2010 Mln)	Participant Electricity Retail Savings ($2010 Mln)	NonParticipant Electricity Retail Price Savings ($2010 Mln)	Total Electricity Savings ($2010 Mln)
2012	1,418	116	9.1	13.5	0.0	13.5	505	126	1,071	0	1,702	567	1,518	444	1,962
2013	1,404	117	12.4	18.2	0.5	18.7	480	117	651	168	1,416	801	2,036	603	2,639
2014	1,404	118	15.8	22.9	1.2	24.1	491	116	650	253	1,510	1,055	2,565	771	3,336
2015	1,405	119	19.0	27.7	2.2	29.9	453	104	652	340	1,550	1,331	3,116	951	4,066
2016	1,413	120	22.5	32.4	3.5	35.9	483	108	655	431	1,677	1,631	3,631	1,127	4,759
2017	1,428	122	26.0	37.2	5.0	42.2	479	104	662	517	1,763	1,955	4,134	1,308	5,442
2018	1,444	123	29.3	42.1	6.7	48.8	443	93	670	613	1,819	2,308	4,645	1,500	6,145
2019	1,461	125	32.8	47.0	8.8	55.8	456	93	677	710	1,935	2,691	5,155	1,699	6,854
2020	1,473	126	36.5	51.9	11.1	63.0	468	93	685	797	2,044	3,103	5,683	1,908	7,591
2021	1,487	127	39.9	56.9	13.7	70.6	431	84	690	892	2,097	3,546	6,211	2,126	8,337
2022	1,502	129	43.6	62.0	16.6	78.6	459	86	695	992	2,233	4,022	6,748	2,357	9,105
2023	1,518	130	47.1	67.1	19.7	86.8	423	77	702	1,085	2,288	4,533	7,277	2,596	9,874
2024	1,536	131	51.0	72.2	23.2	95.4	450	80	713	1,189	2,433	5,083	7,817	2,847	10,664
2025	1,554	133	54.5	77.5	26.9	104.4	415	72	722	1,287	2,497	5,672	8,375	3,110	11,485
2026	1,573	134	58.4	82.8	30.9	113.7	442	74	735	1,394	2,645	6,305	8,932	3,380	12,312
2027	1,591	135	62.3	88.2	35.3	123.5	438	71	741	1,495	2,745	6,980	9,509	3,668	13,177
2028	1,610	137	66.3	93.6	39.9	133.5	433	69	746	1,606	2,853	7,700	10,045	3,948	13,992
2029	1,630	138	70.2	99.1	44.9	144.0	414	64	754	1,720	2,952	8,469	10,515	4,208	14,722
2030	1,651	139	74.1	104.6	50.2	154.8	410	61	766	1,837	3,074	9,291	11,022	4,492	15,514
					NPV at a 5.0% disount rate =		5,528	1,137	8,691	9,314	24,669	40,870	66,407	23,487	89,894

Average Customer Impacts 2030		
Base Usage	11,854	kWh per year
Feedback Save	1,412	kWh per year
Induced Save	678	kWh per year
Total Save	2,090	kWh per year
Pcnt Save	17.6%	per year

Benefit Cost Ratios	
Utility Cost Test	6.13
Participant Cost Test	3.69
Total Resource Cost Test	2.61