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Residential Feedback Devices and Programs: Opportunities for Natural Gas

R. Kerr and M. Tondro

Building America Partnership for Improved Residential Construction (BA-PIRC)

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Residential Feedback Devices and Programs: Opportunities for Natural Gas

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15013 Denver West Parkway

Golden, CO 80401

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Prepared by:

Ryan Kerr and Meredith Tondro

Gas Technology Institute for

Building America Partnership for Improved Residential Construction

1679 Clearlake Road

Cocoa, Florida 32922-5703

NREL Technical Monitor: Stacey Rothgeb

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List of Abbreviations

AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
BBEE	Behavior-Based Energy Efficiency
BPA	Bonneville Power Administration
CO2	Carbon Dioxide
CSR	Customer Service Representative
DIY	Do-it-Yourself
DOE	Department of Energy
DSM	Demand Side Management
EE	Energy Efficiency
EIA	Energy Information Administration
EISA	Energy Independence and Security Act
EMS	Energy Management System
EM&V	Evaluation, Measurement, and Verification
FERC	Federal Energy Regulatory Commission
HAN	Home Area Network
HEM	Home Energy Management
HVAC	Heating, Ventilation, and Air Conditioning
IHD	In-Home Display
NIST	National Institute for Standards and Technology
ODC	Opinion Dynamics Corporation
PNNL	Pacific Northwest National Laboratory

R&D	Research and Development
RFI	Request for Information
RECS	Residential Energy Consumption Survey
SMUD	Sacramento Municipal Utility District
SPP	Simple Payback Period
TOU	Time-of-Use
Wi-Fi	Wireless Fidelity

Executive Summary

Energy use is largely invisible to most consumers—they may notice when lights are on, but they are far less likely to be aware of how much natural gas their water heater is consuming at any given time. Energy monitoring devices are able to transform the invisible to the visible by providing consumers with a more comprehensive and nuanced understanding of their usage patterns. This meaningful boost in knowledge enables consumers to make more informed short- and long-term decisions about their energy use, from highlighting the importance of shutting off lights to showing the value of replacing an old furnace with a new higher efficiency model.

Residential energy feedback has growing interest among consumers, utilities, and researchers as a way to save energy, save money, and increase consumer understanding of their home energy use. Providing more detailed information about how—and possibly when—a consumer uses energy in their home can help identify opportunities for energy efficiency upgrades. Though still a relatively young market, residential feedback has focused historically on electricity. The ubiquity of electricity, combined with the potential for utilities to achieve demand response savings and the high number of electric devices in a home, has made it the fuel of focus. Low natural gas prices and a relatively limited set of gas devices in the home have made gas feedback a less compelling option. Yet, given that nearly 43% of energy used in the residential sector in 2010 was natural gas, the lack of development of the gas feedback market is surprising.

This project aimed to provide a better understanding of gas feedback by:

- Reviewing the body of research on electricity feedback to identify parallel lessons that could be drawn for gas
- Discussing benefits and challenges of different types of feedback as related to gas
- Examining commercially available feedback options
- Identifying three gas feedback options that show strong potential and should be the focus of future research and demonstration projects.

The large body of literature on residential energy feedback spans the past four decades. From this literature, key variables to designing feedback that can effectively drive energy-saving behaviors have been identified, including frequency, level of granularity, display medium, display design, and consumer targeting, among others. Feedback can be categorized as direct (real time) or indirect (post facto), and existing research has demonstrated that these two types achieve different levels of savings. Direct feedback can achieve whole home energy savings averaging about 5% to 15% while indirect feedback generally yields savings averaging about 4% to 8%.[1,2] It should be noted that the majority of research pilots have been for a year or less, which means there is a lack of data on how savings may change year-to-year. These savings ranges are also based on largely electric-driven research, though recent data tends to indicate gas savings are somewhat lower. For example, work by large indirect feedback provider Opower indicates enhanced billing can achieve annual gas savings of about 1% to 2% while electricity savings can be 1.5% to 3.5%.[3,4] Direct feedback is also more costly than indirect feedback as it often requires additional hardware, which plays a strong role in cost effectiveness of each option.

A primary direct feedback option is an in-home display (IHD) that can show a variety of information, such as real-time energy use, energy cost for a day or month to date, and historical energy use, among many others. Commercially available IHDs monitor electricity and even water use in some cases, but no options for monitoring gas were identified. The challenge of connecting a gas meter to an IHD is driven by the mechanical nature of most conventional gas meters, the limited roll-out of advanced smart gas meters, modest to no market pull for such a device, and concerns surrounding attaching an electrical monitor to a gas meter. There has been ongoing debate about how critical or not an IHD is to providing effective feedback, and given the challenges faced by an IHD for gas monitoring, it is clear that non-IHD options should be considered.

Indirect gas feedback through enhanced billing does not offer consumers information in real time, but does provide significantly more information than a typical utility bill, including neighbor comparisons, tips and recommendations, and normative ratings. Enhanced billing has grown rapidly over the past three years, with estimates that about 5% of U.S. households received these types of comparative reports in 2011.[5] Recent research suggests a paper bill or report is the favored medium for many consumers to monitor their energy use, so providing enhanced billing would leverage this already favored communication channel.[6]

While not considered a feedback device in itself, the development of advanced, Internet-connected thermostats presents an early market entry point for residential gas feedback. As the primary control system for space conditioning, which represents the majority of residential gas use, the thermostat is a leverage point for incorporating feedback into the home. Recent efforts have centered on next-generation thermostat designs, as evidenced by the Nest learning thermostat. Given the historical difficulties with understanding how programmable thermostats may or may not save energy, the market and key stakeholders (like ENERGY STAR®) are placing increased emphasis on good, user-friendly thermostat design. This provides a ripe development environment for advanced thermostats, which could provide users with increased control, feedback, remote access capabilities, and overall energy savings.

The nascent, but growing smart gas grid infrastructure represents another feedback opportunity. Though less market ready than enhanced billing and smart thermostats, gas Advanced Metering Infrastructure (AMI), commonly called smart meters, offer two-way communication potential and the ability to access real-time meter data. This could be used to develop an alert/notification system for consumers regarding their gas use, including warning of unusually large usage, providing recommendations, or even participation in an energy savings goal-setting program.

Natural gas use patterns are highly seasonal yet are not affected by the same capacity constraints as electricity, which means there is not the same level of interest in demand response programs. Taking into account these unique characteristics, it’s important to balance the potential for gas savings offered by a feedback option with the overall cost. Given how gas is used, feedback options must make sense from both an energy efficiency and economic standpoint. Based on the existing body of research as well as results from limited pilot project efforts in recent years, we identify three high priority feedback options for natural gas: enhanced billing, advanced thermostats, and AMI-driven alerts.

1 Introduction

The opportunity presented by regular and detailed feedback to inform individual decisions about energy use is strong, though many barriers have been identified. Results vary across research studies, pilot projects, national borders, and time periods, but generally the development and wide-commercialization of residential home energy management (HEM) devices and programs has shown great potential for energy and cost savings, both to the consumer and the utility. According to a large, recent review of research in this area, these devices can yield a 3.8% to 12% savings over total electricity use depending on the type of feedback provided (Figure 1). The savings range expands slightly when gas and electricity studies are reviewed, which have been shown to result in 5% to 15% savings in total home energy use.

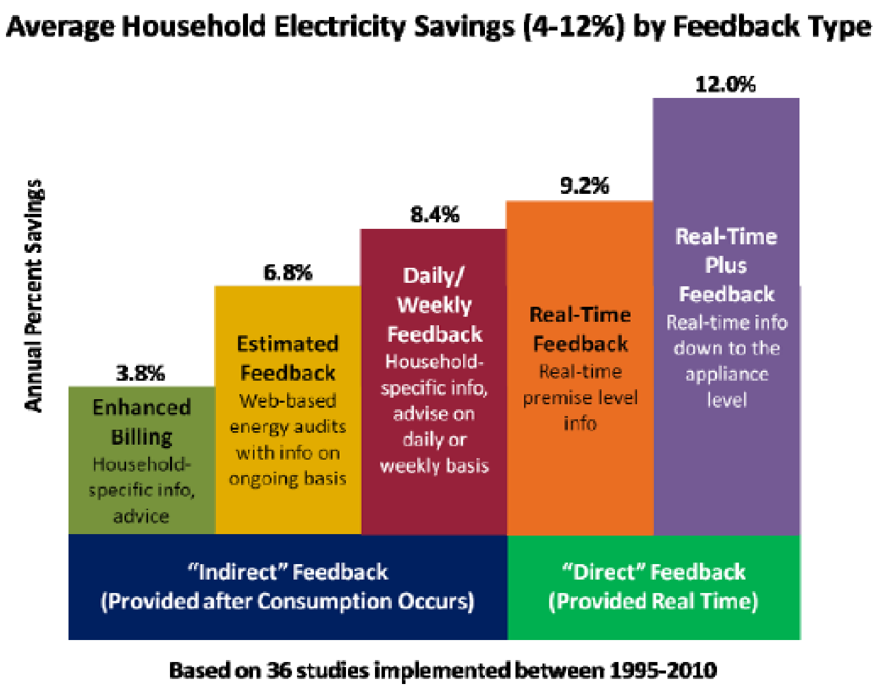

Figure 1. Metadata review of average residential electricity savings by feedback type (Source: Ehrhardt-Martinez et al., American Council for an Energy-Efficient Economy, 2010, reprinted with permission)

Research in the field of residential energy feedback has been ongoing since the 1970s. In the past two decades, a substantial amount of research has been conducted on incorporation of feedback devices with smart meters and advanced metering infrastructure (AMI), high efficiency appliances, and controls/automation. Other drivers include:

- Rising capital costs of building new generation facilities
- Growing concern about fossil fuel-related climate change
- Expanding utility energy efficiency programs (Figure 2)
- Rising consumer awareness over energy conservation
- Increasingly technology-savvy consumers
- Improved wireless capabilities.

This momentum has led to the recent surge of research in the effective design, application, and impacts of residential energy feedback devices and their potential inclusion as part of a utility-run energy efficiency program.

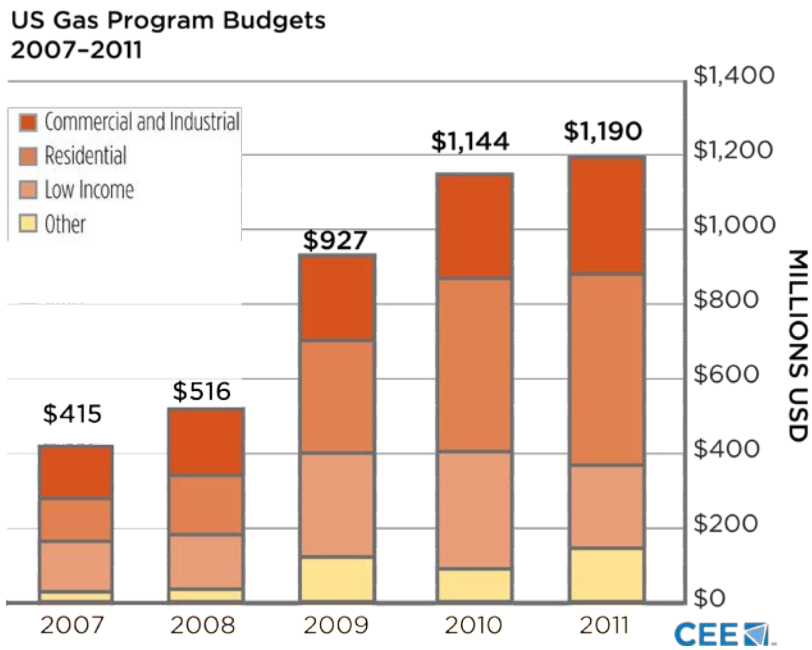

Figure 2. U.S. gas energy efficiency program budgets, 2007-2011 (Source: Consortium for Energy Efficiency, 2011[7], reprinted with permission)

2 Importance of Natural Gas Feedback

The focus of research is strongly skewed toward electric feedback with much less attention to gas. Peak demand issues associated with electricity use have long made demand-side management options, such as real-time information on energy use and pricing, a focus of electric utility interest. Another reason that electricity has garnered so much research is its ubiquity in U.S. homes. Although gas use is also widespread, there are areas where it is either not available or less prevalent.

About 61% of the 114 million U.S. households use gas for any of a variety of applications.[8] The reasons behind this may be lack of gas infrastructure in rural/remote areas or chronically low electric-to-gas price ratios (such as in the Southeast), which result in lower levels of residential gas connections. Though less than two-thirds of American households utilize gas, the residential sector consumed nearly 5 Quads of natural gas in 2010, largely for space heating, followed by water heating (Figure 3).

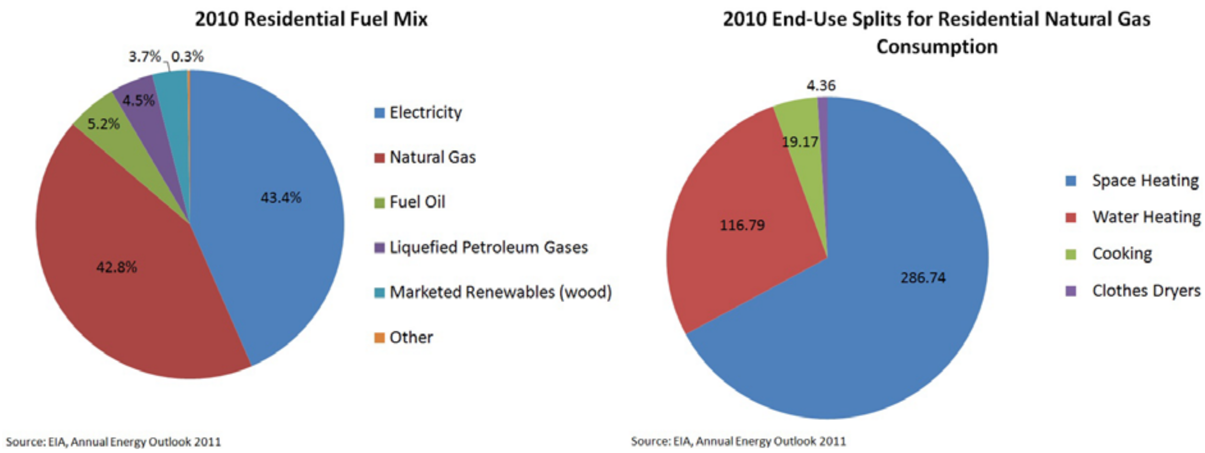

Figure 3. 2010 residential fuel mix and 2010 end-use splits for residential gas use (Source: EIA 2011)

Beyond significant residential gas use, there are other reasons that consumers and utilities are interested in communicating gas feedback to achieve energy savings. The considerable growth in gas energy efficiency (EE) programs over the past five years has resulted in utility budgets exceeding $1.1 billion for these programs, which has spurred research and commercial development. As these programs have developed and captured the initial "low hanging fruit" such as furnace upgrades and tune-ups, a growing need for next generation gas EE measures has come into focus to meet the increasing goals set by regulatory commissions. Behavior-based measures, such as energy feedback, can represent the next tier of EE options and have gained the growing interest of utilities and consumers. Energy feedback programs also have the potential to boost consumer participation rates in other utility EE program offerings by up to 20% or more while potentially reducing call volumes to utility call centers.[3,9] Similarly, by providing consumers with a stronger understanding of their gas usage patterns, they are able to focus technological fixes and behavioral change on those end uses that will make the largest difference to their bill.

Energy and cost savings, meeting gas utility EE program targets, improving service and customer satisfaction, and reducing greenhouse gas emissions are just some of the reasons that residential gas feedback is a valuable resource worth developing. Natural gas must be considered as feedback research, development, and commercialization efforts move forward.

3 Types of Energy Monitoring and Feedback

The goal of monitoring and feedback is to provide the user with detailed information on consumption patterns to inform decisions about current and future use. This information must be sufficiently detailed, easy to understand, and reported regularly (Table 1 explores these design variables in detail). This information, referred to here as "feedback," is generally categorized as direct or indirect, with various distinctions underneath these two groups.

3.1 Direct Feedback

Direct feedback, also referred to as real-time or near real-time feedback, provides energy usage information to a consumer in the moment. Research estimates direct feedback can yield whole home energy savings of 5% to 15% percent.[1] Most commonly, direct feedback is conveyed via a display monitor in the home. The IHD can be fixed or mobile and can provide usage information from the whole house level down to the level of individual appliances. Appliance level disaggregation is much less common, and more expensive and complex to install. Many commercially available devices offer the ability to monitor use away from home via Web access or a mobile phone application. This supplemental Web software can offer additional features and details, such as goal setting, neighbor comparison, alarms, or long-term projections. This helps the user interpret the data in meaningful ways and can be a strong driver in maintaining energy savings and contributing to the overall "energy literacy" of the consumer.

3.1.1 Device Types and Features

Though IHDs are most common, they are not the only means of direct feedback. Other types of direct feedback include:

- Manually self-reading the home's meter
- Plug meters for individual appliances
- Select advanced thermostats that include feedback information
- Novel visual/ambient devices.

The ZigBee Alliance website contains an extensive list of ZigBee Smart Energy Certified products, including IHDs, thermostats, and other products, though the majority of these offerings are electric. The features offered by these devices vary, though typically there is some form of data storage offered (ranging from about a month to multiple years). A few of the devices that offer information on total whole-house energy use can also be configured to display data at the circuit level. Circuit-level data gives consumers more granularity in how they view their home energy use, which can inform decision-making while also identifying areas of high consumption. Devices typically report a key set of basic information, such as current use and cost estimates, and some devices include information on slightly more complex variables such as peak use or energy-related carbon dioxide emissions.

Reports have highlighted the fact that direct feedback devices are experiencing a boom in development and commercialization, with frequent new product offerings and steadily decreasing prices.[2,10] Currently, the vast majority of these devices monitor electricity usage exclusively. Almost all of these devices are available direct to user and can be purchased online. Although there are some early adopters that are driving the small but growing direct purchase market, utilities are also becoming involved by offering rebates or launching pilot programs to test these devices.[11,10]

3.1.2 Benefits and Challenges

Direct feedback generally yields the greatest level of energy savings due to the refined-level of detail provided by these devices and their constant flow of information to the consumer. Direct feedback also has the opportunity for incorporating even more data if a utility should decide to maintain two-way communication between the IHD and a smart meter. Recent reviews of real-time electric feedback studies suggest that it can provide incremental savings of 2% to 4% above the savings achieved by after the fact, indirect feedback, such as enhanced billing as discussed in a later section of this report.[12]

The key challenge faced by direct real-time feedback is cost. Device price will vary based on features, energy types, and consumer needs. Electric-only monitoring devices can range in price from about $100 to over $400 depending on design. Basic, off-the-shelf devices can be more affordable but the functionality of the devices is often limited (no integration of controls) and the hardware provided may not be sufficient to monitor the whole home, necessitating the purchase of additional sensors or wires. For devices that provide greater functionality and can gather and display more complex information, the cost increases. The cost of these devices paired with their relative savings can lead to long payback periods. Initial costs may be further increased if the device must be professionally installed. This has been identified as a key barrier within the industry and many manufacturers are aiming to keep installation as simple as possible, preferably making it easy for the consumer to complete.

3.1.3 Disaggregated Direct Feedback

Disaggregated, or appliance-level monitoring (also called “real-time plus”), is more complex and expensive than conventional real-time devices due to increased system and installation complexity. Disaggregated data can be collected either through distributed direct sensing or single-point sensing. The most conceptually straightforward approach is distributed direct sensing, which is the placement of a sensor on each individual plug or pipe in the home. However, research has also focused on the development of single-point sensing, which would utilize a single-sensor to assess and disaggregate appliance-level use. For electricity, the breaker box can serve as an ideal candidate for single-point sensing, while for gas the meter itself represents the most likely single point for sensing. Single-sensor systems would have the advantage of greater simplicity, easier installation, and reduced hardware costs.

An example of a disaggregated, real-time plus system is the SeriousEnergy Manager by Serious Energy, which provides real-time information on electric, gas, and water use within a commercial building with details possible down to the appliance level; however, the added information comes at a significantly increased cost, with systems costing upwards of $5,000 or more depending upon functionality and user needs. This high cost means that unless substantial price reductions are achieved, either through rebates or economies of scale, these systems are likely to be limited to industrial, commercial, and possibly large multiunit residential applications, such as nursing homes or dormitories. It is worth noting that Serious Energy exclusively focuses on commercial and industrial applications for their products, which makes the cost more manageable for their target customer base given the increased level of savings supplied by the system.

Disaggregation can offer unique advantages by providing high-resolution usage data. These data could be used to develop better targeted efficiency recommendations. For example, given the high energy use of the refrigerator, the end user may have an older model and may respond to a utility rebate for a more efficient model. From a utility-perspective, the increased level of detail could be rolled up to better determine which appliance classes have the greatest potential energy savings for energy efficiency or retrofit programs and rebates. An ancillary benefit to utilities may also include the use of this information to inform state and federal appliance efficiency rulemakings by creating a more accurate understanding of residential energy use rather than relying on modeled scenarios.

3.2 Indirect Feedback

Indirect feedback provides energy usage information to the end user after the fact. A recent review of research indicated a range of electricity savings from 3.8% to 8.4%.[2] Far fewer studies have been completed for gas, but savings are estimated to be roughly similar though slightly smaller since gas use is focused on a limited number of appliances, resulting in fewer opportunities for behavioral intervention. Two of the most recent and sizable studies include one in Massachusetts and one in Ireland. A Massachusetts utility, National Grid, released preliminary results of a gas indirect feedback pilot with Opower, which showed average annual savings of 0.77% across nearly 48,000 households.[3] Savings are expected to be higher if consumer targeting efforts are made. The National Grid and Opower pilot indicated that high consumption households had an average annual savings of 1.1%—an increase of over 25% from the average across the program. In 2011, Ireland's Commission for Energy Regulation presented findings on a gas customer behavior pilot program that showed average annual gas savings of 2.2% to 3.6%, depending on the type of behavioral intervention.[13]

The current Automatic Meter Reading (AMR) infrastructure and billing used by utilities is the most general and basic example of indirect feedback. The usage information is sent to the utility via a one-way communication protocol, this information serves as the basis for the monthly gas bill, and the bill is delivered to the consumer thereby informing them of their gas use after the fact. In contrast, Advanced Metering Infrastructure (AMI), more commonly called smart metering, is capable of providing two-way communication (the role of smart metering will be discussed in more detail below). AMI is able to provide both direct and indirect feedback, though these functions have not yet been widely pursued by the utility industry. According to the Federal Energy Regulatory Commission, less than 1% of AMI meters have been integrated with home area networks and other feedback devices.[14]

3.2.1 Device Type and Features

Though indirect feedback is more simplistic and affordable than direct feedback, its availability is relatively limited. This may be because it is initiated by the utility rather than by the consumer (though in select cases direct feedback may also require work on a utility's part, such as the placement of a smart meter). Indirect feedback must be initiated by the utility because it relies on the utility's ability to process raw data and present it back to consumers, or at least enable a third party to do so. Historically, indirect feedback from utilities has been limited to pilot projects and programs in order to assess the potential for energy savings; these efforts varied from case to case, but generally indirect feedback programs have attempted to provide billing information with increased frequency, detail, and/or accuracy in order to affect consumer change. Indirect feedback includes enhanced billing services and estimated feedback that uses statistical techniques to model disaggregated home energy use.

Recently, utilities have begun to partner with third parties to provide indirect feedback. For example, Opower is a private company that specializes in providing indirect feedback to more than 10 million households in the form of home energy reports. It is estimated that Opower accounts for roughly 90% of the enhanced billing market.[15] Opower indicates that typical natural gas savings from their program fall in the range of 0.9% to 1.5%.[4,16] In 2011, Opower indicated that the average cost of their program was about $10 per household per year, depending on the particular structure and features of the program.[5]

Other vendors working in this space include Efficiency 2.0, Aclara, and Enerlyte. Each of these vendors offers different variations of indirect feedback to try to maximize energy savings and maintain customer engagement. Some vendors offer feedback through multiple mediums—mobile applications, online dashboards, and printed reports. Online dashboards may incorporate bill paying functionality as a way to ensure consumers are driven to the website. The use of a rewards program is a prime example of the way in which consumer behavior and psychology can be integrated into indirect feedback to maintain consumer engagement. Financial rewards are a relatively unique feature in feedback programs to date.

Indirect feedback can include monthly energy use estimates that are statistically disaggregated by end uses based on hourly weather data, home characteristics (such as water heating fuel type), home type, square footage, and numerous other factors. Some vendors implement hybrid opt-in/opt-out programs by identifying a target population that is automatically enrolled in the program (who must opt-out) while still allowing the remaining utility customers to participate if they wish (who must opt-in). This helps capture both high energy users that have good savings potential and other more modest users that are particularly interested in maximizing energy savings. A recent evaluation of a year-long feedback pilot partnership between Efficiency 2.0 and Citizens Utility Board in Illinois demonstrated electricity only savings of about 6% for opt-in users and 1.47% to 1.63% for passive opt-out users, demonstrating just how strongly savings can be influenced by consumer targeting and program opt-in/out-out design.[17]

3.2.2 Benefits and Challenges

One of the most highlighted benefits of indirect feedback is its relatively low costs compared to other methods of feedback. Estimated utility costs for indirect feedback programs are about $0.03/kWh for the first year compared to about $0.30/kWh for a real-time direct feedback program.[18,19] Part of the reason for the low cost of indirect feedback is that no additional advanced metering hardware is required.

Though the disaggregation provided by indirect feedback is achieved through statistical analysis and modeling rather than direct measurement, this information can still yield energy savings. The efficacy of indirect feedback is strongly influenced by how the information is displayed. From a utility-perspective, a key benefit of using a third party vendor for this service is that they have typically performed field-testing of their report designs to maximize their impact. For example, Opower partnered with the Sacramento Municipal Utility District (SMUD) early in their development to pilot test a range of report styles, including text versus graphics-weighted and monthly versus quarterly reports, to determine the approach with the most customer appeal.[20]

The primary challenge to third party-provided indirect feedback is the relative immaturity of the market. Vendors have only become more accepted in the industry within the past 3 to 5 years and some, such as Google and Microsoft, have cited slow growth as the driver for discontinuing the service. Another challenge is the difficulty in engaging passive customers to become more involved in saving energy. As has been noted in a number of pilot programs, there is often a small percentage of individuals that choose to opt out. A recent study of indirect feedback to about 25,000 households showed that less than 1% of participants opted out of receiving gas feedback.[3] Although programs structured around indirect feedback may be relatively affordable to implement, the cost comes with modest energy savings. A review of the pilot program partnership between SMUD and Opower two years after implementation demonstrated that average annual savings were about 2% to 3% across the customer base with the potential for higher savings by targeting high use customers.[21] These results are consistent with the reported results from other third parties feedback providers, such as Efficiency 2.0 and fall within the estimated savings range for "Enhanced Billing" and "Estimated Feedback" shown in research literature.[2,16]

The significance of these savings will depend on the overall savings goals of a utility EE program and how many of their consumers receive feedback. However, recent data reviews have shown that most utilities are saving between 0.5% and 1.0% of their overall gas sales through their EE programs, which means that feedback can be a good complementary measure to conventional EE measures, such as furnace rebates, especially if it is launched widely or targeting high consumption users.[22]

3.3 Design and Efficacy

Research over the past four decades has consistently emphasized the importance of feedback design to achieve energy savings. Though much of the focus has been on electric devices, the fundamental lessons about what information should be provided, frequency of reporting, and how information is presented are still applicable to other energy sources, including gas. Design considerations may vary slightly if the feedback is direct or indirect, but as was noted by Froehlich (2009), there is a consistent core set of critical variables.[23] Table 1 reviews these variables and discusses their previous substantiation in research literature and application to gas feedback.

Table 1. Core Variables for Gas Feedback Design, Adapted from Froehlich (2009)[24]

Feedback Design Variable	
Frequency	Frequency of feedback to consumers is a strong influencing factor with regards to energy savings. Many studies found that more frequent feedback resulted in higher energy savings.[19, 25, 26, 27, 28] The ideal frequency may vary by consumer and device/program, and although monthly reports may lead to higher savings, quarterly reports may be sufficiently cost effective.[19,29] Given the seasonality of gas usage, a key question may be if frequency should vary between winter and summer months.
Unit of Measurement	Feedback must be easily understood and interpreted by the consumer. This can be a challenge as it is difficult for most people to visualize a therm of natural gas. Other information, including cost ($/ccf, $/therm, $/day, total for week, month, etc.) and environmental effects can also be hard to visualize but powerful drivers. These units can be converted or compared to equivalents (e.g. number of trips in a car) which may make them more accessible for users.[23] Given the limited amount of research to date on consumer response to gas usage data it is not possible to say which of these units of measurement would be most likely to spur energy savings.
Level of Granularity	Research to date has focused on the effects of aggregated data provided to users but with increased frequency or detail. The effects of disaggregated, appliance-level data have been less well-explored though it is speculated that such fine-scale feedback may be more effective.[23] The level of granularity can be increased using statistical methods to estimate disaggregated use based on household characteristics and total energy use, though since this is a modeled approach that relies on assumptions, there may be accuracy concerns. To date, this type of statistical estimation is heavily used in indirect feedback.
Display Medium	The presentation medium affects the accessibility of the information. Information can be communicated to consumers via a paper bill, electronic display, website, mobile phone application, or a combination of these. Design of the medium has implications both for the cost of the device/program and the potential energy savings.
Location	This variable is most applicable for direct feedback. The location of a device within a home will affect how frequently it is viewed and by how many people. A display in the kitchen or living room will undoubtedly get more attention than one in the laundry room or garage. Location may also play a role in other localized types of feedback, such as a display on a smart appliance.

Display Design	Limited publically available research has focused on the effect the visual display of information has on the overall energy savings. However, it is likely that some proprietary research has been completed during the development of feedback devices and programs to judge consumer reactions. Nonetheless, research from the communication sciences has strongly shown that the clear and visually appealing display of the information is critical to user engagement and learning.[28,30] Research has shown statistically different consumer reactions to a range of energy information Web interface designs, demonstrating the importance of this design variable.[31]
Tips	Many feedback devices and programs provide consumers with recommendations for increasing energy efficiency and savings. Research has suggested that these recommendations should be limited and targeted. For example, individuals in apartments are unlikely to heed recommendations to upgrade their appliances whereas a homeowner may be more receptive. Likewise, providing too many recommendations can overwhelm consumers, which actually reduces the likelihood that they'll take any action at all (called the "status quo effect").[32]
Consumer Targeting	The use of basic customer segmentation and targeting efforts has shown the potential for increasing energy savings. Analysis of the savings from enhanced billing/indirect feedback has shown that targeting users that have higher baseline energy use patterns can increase the average savings effect, sometimes by over three-fold.[16, 19,27] High energy users are arguably the most reliable variable on which to target consumers, but research has also indicated that smaller square footage homes, homes with fewer occupants, and homes that have older heads of house may also be ways to increase the effectiveness of feedback treatment.[16] Similarly, program design that allows for "opt-in" users can capture those customers that are actively seeking more information to help them achieve gas savings. Not only does this increase the effectiveness of the feedback, but it also improves the cost effectiveness of providing the feedback.
Comparisons	Providing comparisons—historical, normative, or relative—can be an extremely useful driver for energy savings. Each of these types of comparisons has its pros and cons. For example, the usefulness of historical comparisons (comparing a consumer's use to the use on the same date the previous month or year) may be limited if the consumer is still utilizing above average levels of energy since it will not signal the need for reduction. Relative comparisons (comparing a consumer's use to the use of other similar homeowners) can be viewed suspiciously by users who question their accuracy. Nonetheless, comparisons are a critical means of benchmarking for consumers and provide context for current energy use. Use of social norms to spur energy savings has arguably been one of the most addressed variables in recent research.[19,32, 33, 34]

Push/Pull	This less clear-cut variable requires device and program designers to weigh and trade off the merits of different types of user push and pull in order to achieve energy savings. Should the device provide feedback constantly or only when usage exceeds some threshold set by the user? Should the program be opt-in/opt-out or a hybrid of both? How many recommendations should be provided to be helpful but not overwhelming? Should goal setting be incorporated? All these design options must be considered.

Just as with the ranges of estimated energy savings, the persistence of the savings varies widely, with some programs indicating that savings dropped off after a trial was complete while other programs indicate that savings persisted for considerable lengths of time. This variation is a function of differences in feedback program/device design, targeting of participants, and the length of the pilot. The length of the feedback pilot may be especially important as it must allow time for consumers to reshape their energy habits, which will increase the persistence of the savings. As was noted by Darby (2006) "a new type of behavior formed over a three-month period or longer seems likely to persist—but continued feedback is needed to help maintain the change and, in time, encourage other changes".[1] This is supported by recent findings indicating that over a multiyear trial, average annual gas savings not only persisted, but in some cases grew.[13,35] The seasonality of gas savings should also be considered when assessing the persistence of pilot programs.

Maintaining consumer engagement can be a challenge. For IHDs, the initial excitement surrounding installation and new learning can fade. Enhanced billing offerings may fail to be engaging if the information presented over time remains the same. Consumer engagement is important in helping maintain energy savings behaviors and increasing savings over time by urging continual improvement. However, customers may also choose to take *non-behavioral* approaches to reducing their energy use in response to feedback, such as adding insulation to their home. These types of capital improvement approaches will not have to rely on continued consumer engagement with the feedback to yield energy savings.

Ways to continue consumer engagement includes providing sufficiently frequent feedback and capturing customer attention by presenting new information.[35] In tandem with these approaches, the feedback could be presented in an area or medium that is difficult for a consumer to ignore—such as displayed on the home's thermostat or placed within a billing statement. Consumers are more likely to view feedback if it is integrated with other functions and if it is presented in a clear and visually appealing way.[35] Utilities should be prepared to amend their engagement strategies over time, based on what's most effective. For example, in a pilot effort between National Grid and Opower, a "heat map" of the energy report was created that identified those areas of the report that received the most attention from consumers. This can help designers to locate areas where consumers are less engaged and target these for improvement. Analysis of pilot programs has also shown that prompting users to set an energy savings goal can help achieve savings while maintaining or even increasing consumer engagement.[2,36,37]

Additionally, the highly seasonal usage of gas may require a unique engagement strategy that focuses primarily on the transitional fall months and the heating-dominated winter months, with less frequent updates in the summer.

3.4 Driving Gas-Saving Behaviors and Upgrades

Designing feedback that is effective in driving gas-saving behavioral change or capital improvements is still an evolving field. While the body of research on energy savings potential, persistence, and design has been steadily growing, an understanding of *which* behaviors or improvements consumers are making is still in the very early stages. This type of research is complicated by the small dataset for gas feedback and reporting challenges. Behavioral change can be difficult to track, particularly in large numbers. A common method is the use of self reporting, though this requires the consumer to be conscious that they've changed their behavior, which is not always the case.

A recent study on this issue by Opinion Dynamics Corporation (ODC) shed some light on what may be driving gas savings from an indirect gas feedback program.[3] The results are preliminary and the authors caution against deriving conclusions for the broader population; however, as a recent, well-designed, and gas-specific study, it should be highlighted. The ODC report was prepared for the Massachusetts Energy Efficiency Advisory Council to provide an evaluation of behavioral programs in the state, including an enhanced billing gas pilot of about 24,000 households. Behavioral changes and capital improvements (equipment and appliance upgrades) were tracked through self-reporting, and implementation rates were compared between the treatment group of households and a similarly sized control group with similar characteristics. Below are the key findings within the gas pilot.[3]

- The treatment group receiving feedback was more likely to install building envelope[*] and light fixture[†] upgrades than the control group.
    - Of three different types of building envelope upgrades, the measure that was statistically implemented more frequently than in the control group was the installation of attic, ceiling, or wall insulation.[†]
    - Of two different types of light fixture upgrades, the measure that was statistically implemented more frequently than in the control group was upgrades to indoor light fixtures.[†]
- The treatment group receiving feedback implemented a larger average number of energy efficiency measures than the control group.[†]
- Within a set of low-cost measures, the gas pilot treatment group receiving feedback was more likely to install weather stripping/caulking around windows/doors[†] and insulate outlets and/or light switches[†] than the control group.

While these preliminary findings need to be further substantiated and explored through additional research, they can provide an important perspective for feedback designers. If the most likely changes resulting from gas feedback are improvements to the building envelope, can gas feedback be designed to better drive this result? Can alternative methods yield more accurate and consistent results in tracking which behaviors change? Can behavior changes be predicted based on other factors, such as housing type or location? These questions remain outstanding, but may provide a critical piece in designing feedback that more effectively drives gas savings.

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[*] Significantly higher than other treatment group at 95% confidence level.
[†] Significantly higher than other treatment group at 90% confidence level.

4 Integrating Feedback with Controls and Home Area Networks

The future of feedback may be within a Home Area Network (HAN), also sometimes called a home automation network or home energy management system (EMS). The HAN incorporates numerous household devices and provides significantly enhanced control. Generally, a HAN involves appliances, advanced software and network systems, display and feedback devices, and the potential for two-way communication with the utility (Figure 4).[2] In addition to energy management, HAN systems can provide greater control for other home features such as security systems. HAN systems range in size and complexity, from basic systems designed to provide monitoring and control of a single end-use, such as space conditioning (heating and cooling) through a smart thermostat, to a complex automation network that includes electricity, gas, and water devices that communicate with local utilities.

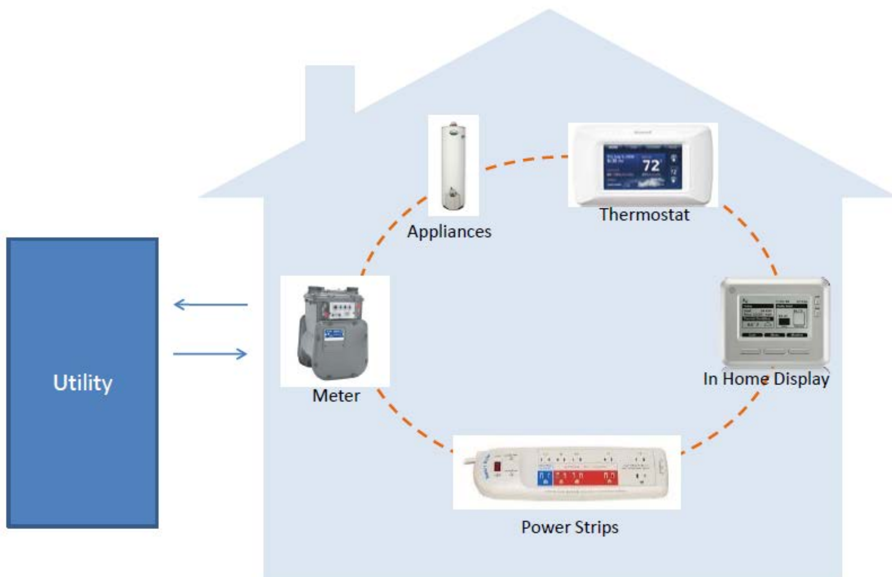

Figure 4. Home Area Network (HAN) for home energy management

The home automation market comprises countless vendors, systems, designs, and features. Vendors include Control4, Tendril, ecobee, Greenswitch, and EnergyHub, among others. Previously, home automation focused on enhanced controls with energy efficiency features just emerging in recent years. As an example, a combined energy management product offering is the Control4 EMS 100, which includes software, a programmable thermostat, and the EC-100 in-home energy controller that communicates with any smart devices on the HAN. In addition to the automation functions, the EMS 100 delivers real-time energy feedback data to both the utility and customer.

By integrating energy use feedback within a system that both informs and provides additional automated controls for the consumer, it may be possible to secure greater energy savings. The availability of settings and controls can shorten the “habit-forming” timeframe of the consumer. They can view the energy feedback, set the control to manage and reduce energy use, and then “forget it,” thereby shortcutting the longer time it typically takes for consumers to form new habits. HAN systems are able to contribute both to consumer comfort by actively engaging them in tailoring their energy environment and to energy savings by avoiding the need for consumers to make continual manual changes.[2]

Although HAN systems have been available for decades, they have not always incorporated energy efficiency features. This, combined with their high initial costs, have limited them to high-end custom homes and technology enthusiasts. Very simple, self-installed systems can range from $200 to $5,000 while complex luxury systems can easily exceed $25,000.[2,38] However, as the potential for HAN systems in the broader market has grown, some vendors have begun to work with utility partners to develop products that are compatible with advanced utility metering hardware (such as ZigBee-enabled communication protocols). Other vendors, such as Control4, continue to focus on the direct-to-consumer market channel. Data on the number of HAN systems is very limited, though market research has estimated that by 2015, there will be a total of 28 million home energy management users worldwide.[39] Data on the impact of adding full HAN controls to feedback programs and the incremental effect on overall savings are extremely limited. They have not been included in many large-scale pilots due to their higher costs and because many of the technological advances in home automation and controls for energy efficiency are still relatively recent.

Although the design of a HAN system for home energy management can vary, advanced thermostats are a key sub-component worth additional discussion as a potential early market entry point for residential gas feedback.

4.1 Thermostats

The thermostat is a practical integration point for feedback since space conditioning often represents the bulk of home energy use. Thermostats are control devices, though they may also be strong early market entry points for residential energy feedback, most especially since majority of gas use is typically space heating.

Beyond programming a customer's space conditioning schedule, some thermostats are also capable of two-way communication with the utility, and because of this similar functionality to smart meters are sometimes called "smart thermostats." However, there is no standard set of criteria that every smart thermostat meets. This has been an area of growing interest for manufacturers. As an example, Honeywell demoed an online energy analysis portal that provides homeowners with the ability to view their disaggregated and historical electricity use, set goals, and schedule alerts.[40] Although this portal is not commercially available right now, it demonstrates the long-term trajectory and potential functionality of the market.

An example of how feedback is being incorporated with the functionality of thermostats can be seen in the Nest thermostat (Figure 5). The Nest is promoted as a user-friendly, learning thermostat. Generally, installation can be completed by the customer. In addition to the conventional temperature sensors, by incorporating activity sensors the Nest can determine when a home is unoccupied and switch to an "auto-away" setting. The Nest is Wi-Fi-enabled to gather weather information and provide users with remote access through computers and mobile devices. Although the primary function of the Nest is for space conditioning control, the thermostat also provides the user with an energy history and identifies the key driver behind the usage (e.g. weather, manual temperature adjustments, auto-away, etc.). However, the detail offered by the energy history is limited and aggregated across the household. Additional information and functionality would need to be added to Nest to make it a true feedback device, but it represents movement in this direction.

Figure 5. Nest thermostat
(Source: Nest, reprinted with permission)

Some advanced thermostats, such as Energy Hub's smart thermostat can retail for as low as $100 while others can cost to up $500.[41] Additional installation costs may also be necessary for more complex systems.

Although smart thermostats are being actively developed and marketed as a pathway to energy savings, the demonstrated savings of advanced thermostats remain unclear. Prior to the introduction of smart thermostats, programmable thermostats represented the advanced technology of the day. Initially, ENERGY STAR developed standards to make programmable thermostats qualifying products. However, mounting levels of research indicated that not only were many programmable thermostats not saving energy, many units were not actually being programmed at all and therefore functioned like conventional, manual thermostats. According to 2009 data from EIA, 47% of households that have programmable thermostats do not set back the thermostat during the day when the house may be unoccupied and 38% do not use setbacks during sleeping hours.[8]

One of the important reasons behind low usage of programmable thermostats is usability. Many people find these units difficult to understand and adjust. Common user complaints included: the units were too complicated to use, buttons/fonts too small, symbols hard to understand, unit was placed in an inaccessible location, difficult to set the date and time, among others.[42] In response to this, ENERGY STAR discontinued the programmable thermostat standard.

The significant usability issues faced by programmable thermostats must be addressed for feedback-enhanced smart thermostats to effectively enter the market and achieve energy savings. Evaluations of smart thermostat usage patterns can help determine if these barriers have been addressed. Additional barriers that will need to be addressed are the relatively high initial costs of these systems and consumer education regarding their benefits.

5 Role of the Smart Gas Grid and Smart Gas Meters

Though largely untapped at present, the growth of the smart gas grid may also offer an early market entry point for residential gas feedback, by enabling non-IHD options, such as text/email alert systems.

Conventional gas meters are most commonly diaphragm meters, which are designed to have two or more chambers formed by movable diaphragms. These chambers alternate between filling and releasing gas, resulting in a steady flow of gas through the meter and into the building. Traditionally, a meter reader is called out on a regular basis to read the meter and determine how much gas has been used. The development of Automatic Meter Reading (AMR) technology in the 1970s changed that by enabling the gas, electric, and water meters to automatically collect and transmit usage and diagnostic data from the meter to the utility. Some AMR technologies still require a meter reader to walk or drive by the meter in order to pick-up the low-power transmission of the meter, but it greatly expedites the process of meter reading. Alternately, fixed network AMR technologies rely on the installation of permanent infrastructure to collect and transmit the meter signals through a network back to the utility without requiring a meter reader. The next technological leap was Advanced Metering Infrastructure (AMI), also called smart metering, which enables two-way communication between the gas meter and the utility. While AMR technology relies on one-way communication of data from the gas meter to the utility, AMI enables the utility to send data to the meter. In 2010 smart gas meters were estimated to account for about 4.1% of total U.S. gas meters.[43]

Providing energy use feedback does not *require* a smart meter. Many of the direct feedback devices that provide data on electric usage can simply be connected to the circuit breaker in the home and do not have to intimately interact with the meter itself. However, there are very few direct feedback devices that offer the ability to monitor gas usage and many of these are limited to prototype designs or are only available outside the United States. Some of these designs are able to operate with conventional meters, such as the prototype GasSense monitoring system, while others require a specific type of smart meter, such as EnergyAware's PowerTab SMI which must communicate with a meter that uses Zigbee Smart Energy as its wireless protocol.[44,45]

Gas AMI could provide a unique form of indirect feedback—customer usage alerts or notifications—where the consumer could set a usage threshold or a series of thresholds that would trigger an alert to be sent via email or mobile text. For example, if a consumer usually uses 200 therms in December, they may elect to receive an alert when their monthly usage exceeds 225 therms. Multiple thresholds could be set and could even be unique to each month of the year to adjust for seasonal expectations. This type of indirect gas feedback speaks directly to customer financial interests, while also communicating information on usage patterns that encourage conservation. Although AMI could be paired with direct feedback, this type of indirect feedback could be offered at lower cost to the consumer. The body of research on this type of feedback system is limited, but it may be possible to draw parallels from lessons learned in pay-as-you-go programs and use similar notification systems.

It is important to note that although AMI is viewed by many as the next-generation of metering, there are still a sizable number of conventional gas meters in the United States, which means that there is still a large portion of the market that will require feedback devices that can work with conventional gas meters. Hardware and software is still being actively developed for compatibility with conventional and AMR systems as evidenced by Grid Insight, a vendor that is currently in the beta testing phase of hardware that could be integrated in other products and communicate using the radio signals already transmitted by AMR systems.[46] Some vendors predict that AMR infrastructure for gas will remain in place longer than for electric, where issues such as load control and demand response have largely driven the switch to AMI.[46]

Providing direct gas feedback is a challenge, though there appear to be some small developments that are compatible with conventional AMR and/or smart AMI systems. However, a key remaining issue that remains unresolved is the designation of a wireless protocol for communication between the utility, smart meter, and consumer. Data transfer from the meter to either the utility or the consumer must be reliable and secure. Although there is currently no official standard, the development of interoperability standards is ongoing. The Energy Independence and Security Act (EISA) of 2007 identified the National Institute of Standards and Technology (NIST) as the agency responsible for developing a framework for protocols and model standards for data management related to smart grid devices and systems.[47] However, our report will not cover the detailed technical issues surrounding wireless protocol, other than to say that it is an important issue that will require consideration as energy feedback devices are developed and launched.

6 Total U.S. Energy Savings Potential and Other Benefits

Research to date indicates that gas use could be reduced from about 1%-4% with the effective incorporation of feedback. Although these savings may be modest on a per household basis, the potential cumulative national energy savings is strong. The challenge in maximizing gas savings lies in the design of the feedback program and/or device. A key consideration is the scope of the program offered to utility customers—whether the feedback is offered to a small, targeted group of high consumption households or if the program aims at capturing a larger audience with the understanding that savings will vary across participants. An analytical scenario was developed to gauge potential nationwide energy savings offered by residential gas feedback. In this scenario, participants representing 15% of total gas use in the United States are targeted for feedback, with the assumption that savings average 2.5%, in keeping consistent with past research results. The gas savings under this scenario are based on projected gas consumption data from EIA's Annual Energy Outlook 2011 Reference Case. The savings are divided by census region to illustrate how savings may vary regionally depending on the intensity of gas usage.

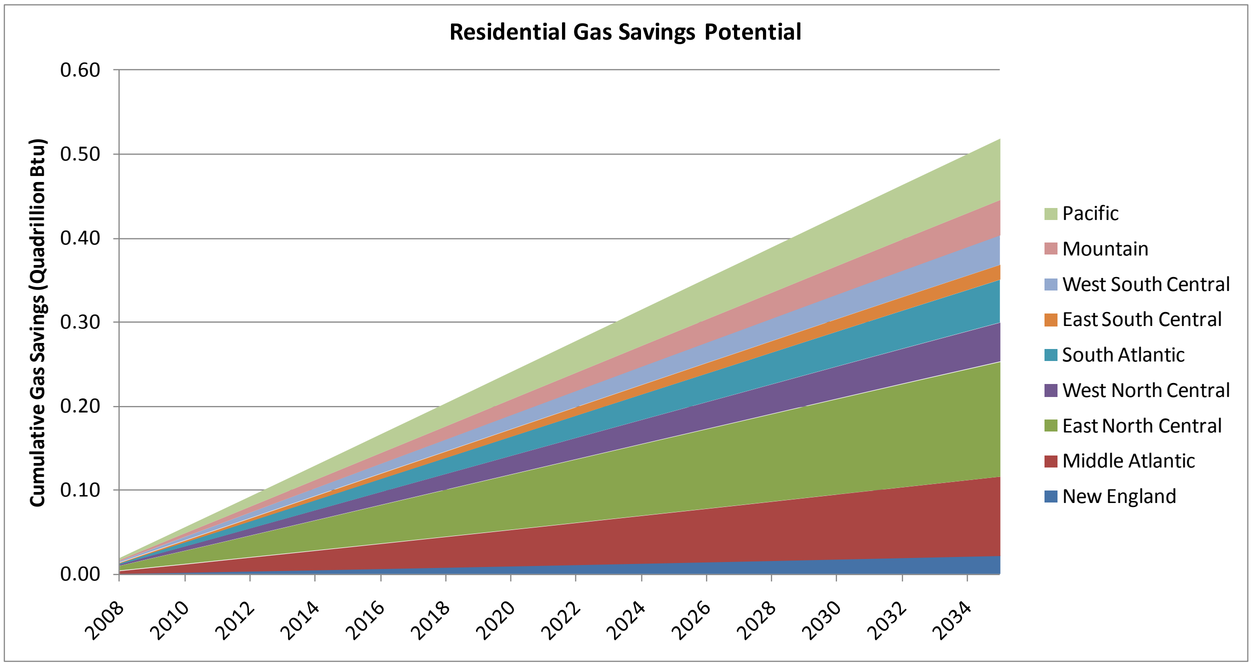

Figure 6. Modeled estimate of U.S. natural gas savings scenario

Some of the largest savings are possible in areas that have heating-dominated climates and largely rely on gas for space heating needs, for example, the East North Central census division (comprising Wisconsin, Illinois, Michigan, Indiana, and Ohio) and the Middle Atlantic (New York, Pennsylvania, and New Jersey) census division. The next largest census for gas savings is the Pacific, where gas use is relatively high due to favorable electric to gas price ratios. Ultimately, these gas savings estimates are intended to be illustrative of the *potential* energy savings from feedback. In reality, the savings will vary across households, regions, and even time.

7 Integrating Gas in Residential Energy Monitoring

7.1 Technical, Design, and Program Challenges

There are a number of challenges to providing residential energy monitoring at large for both electricity and natural gas. Table 2 includes overview of barriers to residential feedback as a whole (for electricity and gas), while Table 3 outlines barriers that are unique to gas feedback.

Table 2. Key Barriers to Residential Energy Feedback (Electric + Gas)

Utility "Hardware Bias" in Energy Efficiency (EE) Programs
• **Issue**: Behavior-based EE is less familiar to many utilities and usually requires ongoing customer engagement, in contrast to the one-time transaction typical of traditional, capital-based EE measures. [5]
• **Solution Opportunities**: Broad sharing of more/better data will mitigate perceived risks of behavior-based EE. Expanded research is needed to provide quantitative, reliable, and vetted data, thereby making EE programs more comfortable with behavior-based measures.
Unclear Energy Savings/Return on Investment
• **Issue**: For many products, rigorous studies quantifying energy savings potential are limited or not available. Longer, multiyear studies are particularly rare, but highly valuable.
• **Solution Opportunities**: Rigorous field studies to prove cost effectiveness using sufficiently large sample sizes, experimental design (control and test groups), over longer time periods. These studies help prove both savings and cost.
Complexity of HEM Products
• **Issue**: Complexity of the device, installation, and/or information presented to the consumer slows the market acceptance of HEM offerings and can add significantly to their cost.
• **Solution Opportunities**: Framework for evaluating user-friendliness of displays, develop feedback devices that do not require professional installation, and field evaluation of "plug and play" devices to assess ease of installation.
Lack of Consumer Awareness
• **Issue**: Many U.S. consumers are not aware of feedback devices available today. HEM devices are relatively young technologically and the market is rapidly developing and changing, which can add to consumer confusion.
• **Solution Opportunities**: This challenge can possibly be addressed through solutions to the other barriers, since those will increase market acceptance and thus boost awareness.
Low Interest in Energy Saving
• **Issue**: Though the cumulative effect of a small average savings can be substantial, on a per household basis, the interest in saving 5% to 15% on utility costs can be relatively low. This is a common problem in EE programs and is not unique to feedback devices.
• **Solution Opportunities**: Leverage existing appliances/functions valued by consumers (security systems, entertainment, etc.), add mobile applications for easy use/access to the HEM device, and make information and/or the display customizable to meet users' needs.

Evaluation, Measurement, and Verification (EM&V) Issues
• **Issue**: Many EM&V protocols rely on engineering-based evaluation, which estimates the performance of a piece of technology *before* it is implemented. But for feedback, the most appropriate EM&V method is an experimental design with control/test groups, which is more quantitatively rigorous, though less familiar to utilities and regulatory commissions.
• **Solution Opportunities**: Generally, feedback pilots are assessed on a case-by-case basis to determine if they qualify for inclusion in an EE program. The development of EM&V protocols for behavior-based measures would help to standardize this process. Some state utility commissions have already chosen to address this, such as the California Public Utility Commission and the Bonneville Power Administration. [37]
Control/Access to Smart Meter Data
• **Issue**: Increased levels of data now available through smart meter infrastructure presents new concerns related to consumer privacy. What types of consumer protections should be considered for smart meter data?
• **Solution Opportunities**: This issue will likely be resolved through regulatory and legal bodies. The National Institute of Standards and Technology (NIST) has been ordered to develop smart grid protocols and standards. NIST has a subgroup devoted exclusively to issues of privacy. Additionally, some states, such as California, Colorado, and New York have taken preliminary stances on consumer privacy protection in relation to utility data.[5]

Table 3. High Priority Barriers Specific to Residential Gas Feedback

Few Commercially Available, Consumer-Initiated Options
• **Issue**: This is a crucial barrier to expanding residential gas monitoring and feedback and is deeply rooted in the other barriers discussed above. There is a substantial lack of commercially available options and even fewer that can be initiated by the consumer. One of the fastest growing options is enhanced billing, which can only be provided by either the utility or a third party operating in cooperation with the utility. This leaves a profound lack of choice in the market for consumers seeking more detailed information on their gas use.
• **Solution Opportunities**: This barrier is somewhat unique in that it will largely be addressed through the solution of the other barriers discussed above. As the research and datasets improve, so will the certainty of energy savings. Continued product development will seek to simplify the design, installation, and operation of HEM products. Utilities and regulators will become more familiar with behavior-based approaches and novel EM&V methods. As a result, it is expected that the market demand for gas feedback devices will grow and that manufacturers, product designers, and utilities will seek to meet it.

Limited Gas-Specific Research and Datasets
• **Issue**: As noted throughout this report, electricity has been the favored energy source for residential monitoring and feedback. Quantitative research and datasets are less available for gas, which means that some of the unique features of gas consumption patterns (seasonality, few appliances, etc.) have been under explored.
• **Solution Opportunities**: Until the research literature reflects a greater quantity and variety of gas studies it will be challenging to design a programmatic approach that maximizes the potential savings of gas feedback. Additionally, some of the existing research was not performed in a systematic or scientific way – making it difficult to apply the lessons learned more broadly. Research and pilot projects should use an experimental design with a representative sample, systematically vary the feedback type/design, and utilize control groups to isolate the effects of different types of feedback.[28]
Disaggregated Gas Flow Monitoring
• **Issue**: Unlike electricity, there has been little development progress on monitoring individual gas lines in a home beyond the meter. Electricity can be monitored at the circuit-level through hardware attached to the electrical panel and at the device-level by attaching small clamps to the electrical wires that monitor the pulses and can determine energy use by the end device. No such low-cost, easy, and safe option exists yet for natural gas.
• **Solution Opportunities**: There are two main avenues for solutions to this issue. Firstly, the development of a novel approach for gas monitoring could address this barrier. For example, researchers at the University of Washington's Ubiquitous Computing Lab have developed GasSense, a low-cost, single-point sensing solution for gas monitoring.[44] GasSense monitors the acoustic response of a gas meter's diaphragm to determine which appliance is calling for gas at any given time. This system is still in the lab-stage of development and more research and development work will be needed to bring such a system to market. Additional research on non-intrusive gas flow monitoring was completed by Tokyo Gas in the mid-1990s though some concerns were raised about the feasibility of moving this technology to the United States. [48] The development of other non-gas-flow methods of data collection may also be under active, though potentially proprietary, development.[49] Secondly, if it's determined that real-time information on gas use is not crucial to driving energy savings, then this becomes a non-issue. It has been suggested that given that there are not the same peak-shifting concerns regarding gas and its heavy seasonality of use, it may not be necessary to provide direct, real-time feedback to consumers. Further research confirming the relative cost effectiveness of these two approaches could provide a quantitative foundation to support or refute this suggestion.

These barriers are seen as true challenges, though perceived challenges can be just as limiting when it comes to market development. Some utilities have cited concerns about implementing behavior-based programs, such as they're too complicated, can't be done in a small territory, they don't know how to design an effective program, or that behavior-based savings are not a reliable EE resource.[50] However, as the barriers outlined in Table 2, and Table 3 are addressed, these perceived barriers are likely to disappear as utilities become more familiar with behavior-based approaches and the supporting research data expands and becomes more robust. Some organizations are taking a more proactive approach, such as the Bonneville Power Administration (BPA). BPA has outlined a strategy for addressing the barriers, which includes three high-level objectives supported by staff efforts and multiyear funding opportunities:[50]

1. Monitor and assess national and regional behavior-based energy efficiency (BBEE) programs and activities, identify and promote use of best practices.
2. Create policies that help build program infrastructure that all Northwest public utilities can use to operate BBEE programs and achieve related energy savings.
3. Collaborate with Northwest public utilities and market partners to implement and evaluate innovative BBEE pilot programs.

7.2 Distribution Channels

Feedback devices are primarily available either direct to consumer or through a utility. The favored distribution channel may depend on the product's characteristics, level of technological maturity, cost, and infrastructure required for support. A single feedback device may be available through multiple distribution channels, though there is often a dominant channel the market favors. Table 4 notes which drivers are impacting the favored distribution channel for a device.

Table 4. Favored Distribution Channels for Feedback Devices

Feedback Device	Favored Channel	Is this a Driver for the Favored Distribution Channel?…			
		Product Characteristics?	Technological Maturity?	Cost?	Infrastructure Needs?
Enhanced Billing	Utility	***Yes*** Often requires utility to permit/ perform data collection	***No*** This form of feedback is relatively mature	***No*** Little to no need for economic support from utility	***Yes*** May need AMI, requires utility cooperation with data collection
In-Home Display	Utility and Direct to Consumer	***No*** Can be installed by consumers or utilities	***Yes*** Relatively young technologically; development is rapid	***Varies*** Costs vary widely, which will affect this driver	***Varies*** Some work with regular meters while others require AMI
Advanced/ Smart Thermostat	Direct-to-Consumer	***Yes*** Can be installed by consumers or utilities; plus consumers prefer freedom of device choice	***Yes*** Somewhat new technologically, but consumers familiar with conventional thermostats	***Varies*** Often higher cost, but may not require utility financial support	***Yes*** Consumers can choose to install an advanced thermostat

Feedback Device	Favored Channel	Is this a Driver for the Favored Distribution Channel?…			
		Product Characteristics?	Technological Maturity?	Cost?	Infrastructure Needs?
Home Area Network (HAN)	Direct-to-Consumer	***Yes*** Detailed installation and variable reqs. based on the home	***Yes*** HANs are still a niche market product with utilities choosing to "wait and see"	***Yes*** Costs are high & variable, unclear how to set a utility rebate	***Varies*** Consumers can have a HAN professionally installed. Some systems may require AMI
Smart Gas Meter Usage Alerts	Utility	***Yes*** Requires a utility to permit/perform data collection	***Yes*** Relatively new technological offering; ongoing development	***Varies*** If AMI is in place, costs could be very low	***Yes*** Requires AMI and utility cooperation with data collection

7.3 High Priority Gas Feedback Options

The original intent of this project was to survey the commercially available options for residential gas monitoring, use lessons from existing research literature to inform gas feedback design, review and discuss the role of controls and automation, and highlight three low-cost gas monitoring and feedback solutions. As the project moved forward we were presented with new and unexpected challenges—primarily, the profound lack of commercially available gas feedback options. This fundamentally limited our ability to compare and contrast a large range of gas feedback options to find the best of the best. After reviewing available products, the body of research in the field, and speaking with many experts on HEM products and development, it was determined that there are three high potential, relatively low-cost options for residential gas feedback—enhanced billing, advanced thermostats, and AMI-driven usage alerts. These options are still in the early stages of market readiness, but represent promising integration points for residential gas feedback.

7.3.1 Priority Gas Option: Enhanced Billing

The market for enhanced residential energy billing has grown tremendously over the past three to five years. Numerous new actors are entering the market and significant developments are continuously being launched, such as mobile applications, online portals, and rewards programs. Most utility efforts have consisted of pilot programs, though there have been some programmatic adoptions of this type of feedback. It is expected that enhanced billing approaches will represent the majority of energy feedback programs, which are estimated to have reached over 5% of U.S. households in 2011.[5]

- **Key Advantages of Enhanced Billing**:
  - Relatively low cost
  - Potential to reach large residential market
  - Customer targeting can achieve greater savings
  - Potential to increase participation in other EE programs
  - Reasonable and growing market of third party implementers.
- **Potential Challenges to Enhanced Billing**:
  - Persistence of savings has not been firmly established
  - Unique M&V requirements (test/control groups)
  - Regulatory uncertainty regarding inclusion in utility EE programs
  - Limited supporting research on applications to natural gas use.

7.3.2 Priority Gas Option: Advanced Thermostats

Smart or advanced thermostats have been an area of increased development, though the definition of "smart" has been applied liberally in some cases. Generally, smart thermostats incorporate an Internet connection that allows users to remotely access the device, and have the potential for two-way communication between the consumer and the utility in the future.

Though not strictly a feedback device, as the central control for the largest gas load in the home—space heating—they are a naturally promising integration point for gas feedback. By leveraging the existing regular use of the thermostat, the incorporation of advanced controls and feedback could be a reliable means of maintaining consumer engagement and having the greatest impact by presenting feedback right at the moment that a consumer is making a decision about gas use (i.e. do I turn my thermostat up or down?).

There have been recent efforts to develop next-generation thermostat designs that show early offerings of feedback, as evidenced by the Nest learning thermostat. Given the recent increased emphasis on user-friendly thermostat design, this is a ripe development environment for advanced thermostats, which could provide users with increased control, energy use feedback, remote access capabilities, and overall energy savings.

- **Key Advantages of Smart Thermostats**
  - Potential to reach large residential market
  - Potentially large energy savings
  - Can incorporate HVAC controls
  - Strong market pull for a more user friendly, better designed thermostat.
- **Potential Challenges to Smart Thermostats**
  - Historical and persistent design challenges to user friendliness
  - Body of research large but inconsistent on energy savings potential
  - New smart thermostat designs require new research efforts regarding savings potential to better gauge their unique features (two-way communication, Wi-Fi capabilities, etc.).

7.3.3 Priority Gas Option: AMI-Driven Usage Alerts

The ability of AMI to provide two-way communication between the gas meter and utility offers unique opportunities to provide gas feedback to consumers. A promising option is an alert system that would activate at certain thresholds—set by the consumer or utility—to notify consumers if their monthly gas usage has exceeded a designated level. This alert could be delivered in both therms and dollars, e.g. "Your December natural gas use is over 200 therms (about $85)." The alert could be paired with recommendations for how to reduce usage or provide other information, such as the customer's historical use.

Utilities have expressed interest in such systems, though it will require larger scale deployment of smart gas meters before reaching wide commercialization.[51,52] While feedback alone is not an economically compelling reason to install AMI, this option could be pursued in areas where gas AMI has already been installed. Recent research by Southern California Gas indicated most residential customers would like to be able to sign-up for alerts that notify them that gas use is high or exceeded some customer-determined threshold and prefer to receive this alert through email.[53] This type of system does not have extensive pilot testing, but is still a promising means of communicating gas use to consumers beyond the post facto monthly bill.

- **Key Advantages of AMI-Driven Usage Alerts**
  - Relatively lower cost
  - Potential to reach large residential market
  - Increase customer satisfaction/reduce customer calls re: high bills
  - Speaks to a key customer motive—saving money.
- **Potential Challenges to AMI-Driven Usage Alerts**
  - Very limited testing of this type of feedback system
  - Gas AMI deployed to a small number of customers to date
  - Unique EM&V requirements (test/control group)

7.4 Cost Comparisons

The cost of behavioral-based EE will vary, but depends strongly on the type of feedback provided and the size and design of the program. As the complexity and frequency of the feedback increases, the cost also typically increases.[2] Providing a customer with real-time, disaggregated feedback with control options will cost significantly more than providing monthly feedback through an enhanced billing program. The program design will determine the use of financial incentives, whether feedback is provided via the Web or paper-based reports, planned community outreach efforts, and other variables that will have inherent cost implications.

Given the stark lack of market-ready options for residential natural gas feedback, the most likely options for behavior-based EE are enhanced billing, advanced thermostats, and AMI-driven usage alerts/notifications. Although these represent the commercially "ripest" options, these measures are still relatively new and costs will change as the market becomes more competitive.

The estimated utility costs for enhanced billing programs are about $0.03/kWh for the first year, in comparison to about $0.30/kWh for a real-time, direct feedback program.[19,35] This cost for enhanced billing programs is consistent with the average cost of $0.025 per kWh saved for electricity energy efficiency programs at large.[54] Given that the average U.S. residential price for electricity in 2010 was $0.098/kWh, it is clear that selecting the appropriate feedback system is critical to its cost-competitiveness.[55]

Advanced thermostats can range in cost from about $100 up to $500 depending on the functionality and optional technological add-ons incorporated. An AMI-driven alert system would range in price depending on the complexity and detail of the information presented to the consumer, the number of consumers involved in the program, and customer's communication preferences (email versus text message). This leads to two primary questions: how can the cost effectiveness of these different feedback options be compared and how will changes in behavior affect energy savings (and, in turn, the cost effectiveness)? Simple payback periods (SPPs) were calculated for a handful of different scenarios for enhanced billing and smart thermostats. The SPP indicates how long it will take for the initial cost of the energy efficiency measure to pay for itself in savings. SPPs are a common, easy-to-understand metric that are often used within utility energy efficiency programs to compare the economic performance of different measures from the consumer's perspective.

Enhanced Billing SPP Scenarios: The SPP for an enhanced billing program was calculated for two sets of initial costs ($10 per participant per year and $15 per participant per year) and three levels of savings (0.77 percent, 1.1 percent, and 2.8 percent). The lowest savings level (0.77 percent) was selected since it was the average annual savings rate of natural gas consumers in a recent National Grid and Opower pilot program that ran from fall 2009 and fall 2010.[3] The mid-level savings rate (1.1 percent) was selected because it represented the average annual savings rate of high consumption end users in the same National Grid and Opower pilot. The largest savings level (2.8%) was selected because it was the savings level observed in a large 2011 study by Ireland's Commission for Energy Regulation for customers that received a monthly bill and energy usage statement. Calculations tables are shown in Appendix A.

Of course, it was expected the most advantageous scenario would be the low-cost, high savings option, but the scenarios indicate the relative spread of SPPs as the two main variables change (Figure 7). SPPs ranged from just over seven months to about two and a half years, indicating that this form of feedback has the potential for attractive payback periods. However, unlike conventional capital EE programs, the cost of this program recurs on an annual basis, which requires that the SPP be stronger than for a one-time, upfront cost program.

The impact of this recurring cost remains an outstanding question. In the first year, program design, roll-out, and revisions could lead to higher overall costs; however, in year two and beyond the costs of maintaining the program may be much lower. This combination of varying costs over multiple years should be considered in overall program cost-effectiveness.

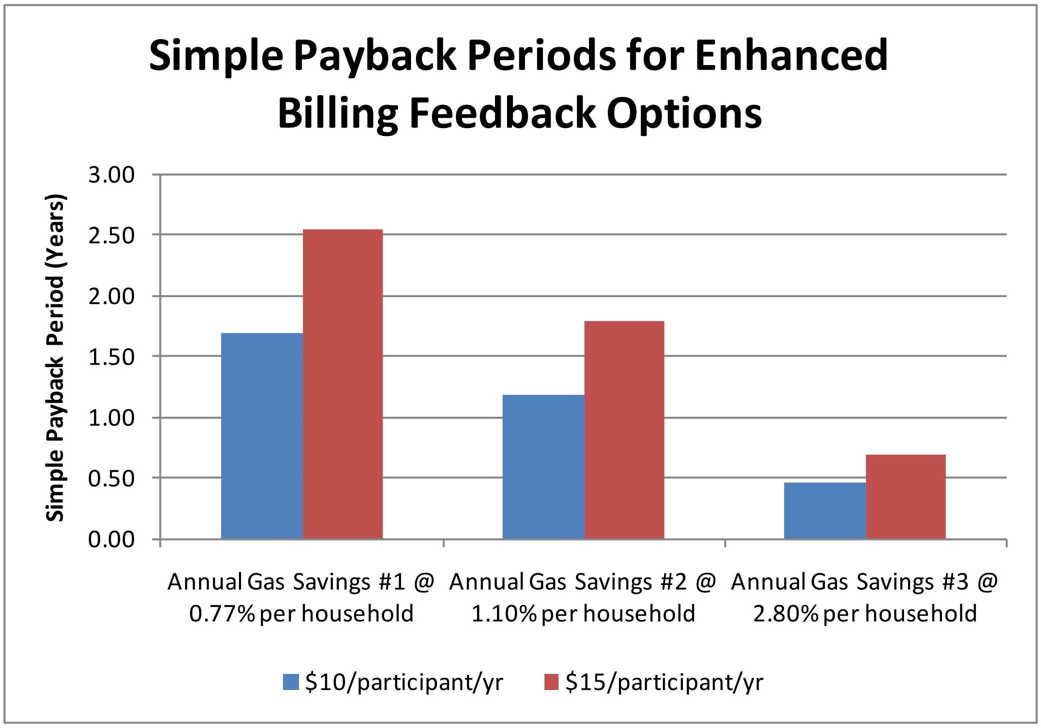

Figure 7. Simple payback periods for three enhanced billing options

Advanced Thermostat SPP Scenarios: The SPP for advanced thermostats was calculated for three initial retail costs ($100, $250, and $500) and two levels of installation cost (professional installation for $80 or do-it-yourself installation for free). The lowest retail cost ($100) was considered to be a reasonable lower-bound estimate for an Internet-connected, programmable thermostat based on current market offerings. The mid-level retail cost ($250) is reflective of design-enhanced offerings that are coming to the market, such as the Nest learning thermostat. The high retail cost ($500) was considered an upper-bound estimate for smart thermostats that are being offered with top-of-the-line functionality, such as offering weather updates or serving as a rotating digital picture frame. Although many of the advanced thermostat offerings require professional installation, there has been some movement towards the development of do-it-yourself (DIY) installations. Therefore, two different installation costs were considered—$80 for a professional installation or free for DIY installations.

The expected annual savings were 66 therms of natural gas and 62.6 kWh of electricity, based on the preliminary results of a small pilot program between National Grid and ecobee testing of their Wi-Fi-enabled programmable thermostat.[56] This equates to roughly 10% of annual household energy use. Although these were preliminary results from a very small sample size, they were used since the piloted thermostat was deemed representative of the type of advanced thermostat proposed here. This savings level was consistent with similar manufacturer market claims, such as the partnership between Honeywell and Opower on their advanced thermostat, which estimates a 30% reduction in HVAC usage. This would be about roughly 15% of the total home energy use.[57]

A portion of the overall energy savings of advanced thermostats is attributable to electric savings from reduced air-conditioning use. Like whole home programs, it is important for utility energy efficiency programs to promote this technology across programs to fully capture the cost effectiveness of this option. Considered on the gas savings alone, the SPPs are less favorable but still reasonably strong.

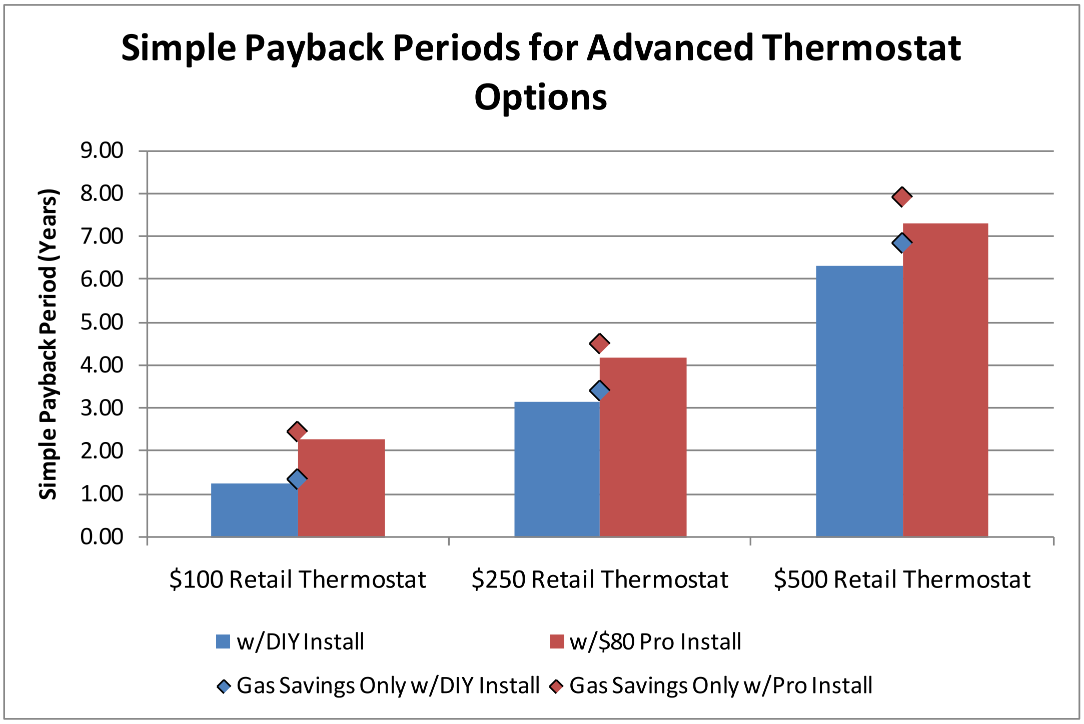

Figure 8. Simple payback periods for three advanced thermostat options

A larger spread across SPPs is seen with advanced thermostats than with enhanced billing, with about six years separating the most expensive scenarios from the most affordable ones. The lower and mid-level scenarios still present reasonably favorable SPPs, since the residential sector will often tolerate payback periods of up to 7 to 10 years for larger energy efficiency upgrades, such as HVAC equipment. However, the high-end scenario pushes the limits of a reasonable SPP for a relatively small appliance upgrade and likely represents an upper-bound limit for future pricing. Of course, these results are dependent on the level of gas savings possible, and if an advanced thermostat design was able to capture a larger amount of savings, then the retail prices could be adjusted accordingly. Full calculation tables are in Appendix B.

There is an alternate way to assess the cost effectiveness of advanced thermostat options. Unlike enhanced billing, which is a service provided by the utility with no upfront financial investment from the customer, advanced thermostats can be customer-initiated EE upgrades. They can be considered in a similar fashion to other one-time capital upgrades, such as a more efficient furnace or increased wall insulation. Such upgrades can be economically evaluated by considering the additional cost they would add to a typical mortgage compared to the annual energy savings they would accrue over time. The same retail costs and savings assumptions were used for this as the SPP analysis above. The mortgage was valued at $250,000 with a 5% annual interest rate for 30 years. The utility energy costs were based on U.S. average prices and U.S. average annual electricity and natural gas use based on the EIA's 2005 Residential Energy Consumption Survey (RECS). As seen in Table 5, the savings from the advanced thermostat outweigh the mortgage addition for each of the three scenarios, meaning that such an investment is cost-effective at $100, $250, and even $500. Full calculation tables are in Appendix C.

Table 5. Monthly Mortgage and Utility Costs for Three Advanced Thermostat Options

Model	Monthly Mortgage and Utility Costs
Building America Benchmark Home	$1,489.09
Home w/$100 Advanced Thermostat	$1,483.02
Home w/$250 Advanced Thermostat	$1,483.83
Home w/$500 Advanced Thermostat	$1,485.19

AMI Usage Alerts SPP Scenarios: Since this feedback option has not received significant study yet, data on costs and savings have not been well-substantiated. Though real-world data is not readily available, such a system has some key similarities to an enhanced billing program. An AMI-driven customer notification system would be initiated by a utility with no upfront customer costs. It would require back-end work on the utility's part to process usage data on a daily basis, compare it to a threshold, and send out the necessary alerts. The cost of providing electronic alerts would be less than the cost of printing and mailing paper reports, though an AMI-based feedback system may require a customer-facing Web portal that could allow the customer to personalize their threshold and communication preferences (e.g. email or text, etc.). Figure 9 shows the SPPs of an AMI-driven alert system that is assumed to achieve roughly the same gas savings as an enhanced billing program but at a 20% lower cost due to the elimination of printing and mailing charges and the nominal cost increases associated with the development of a customer-facing Web portal. Full calculation tables are in Appendix D.

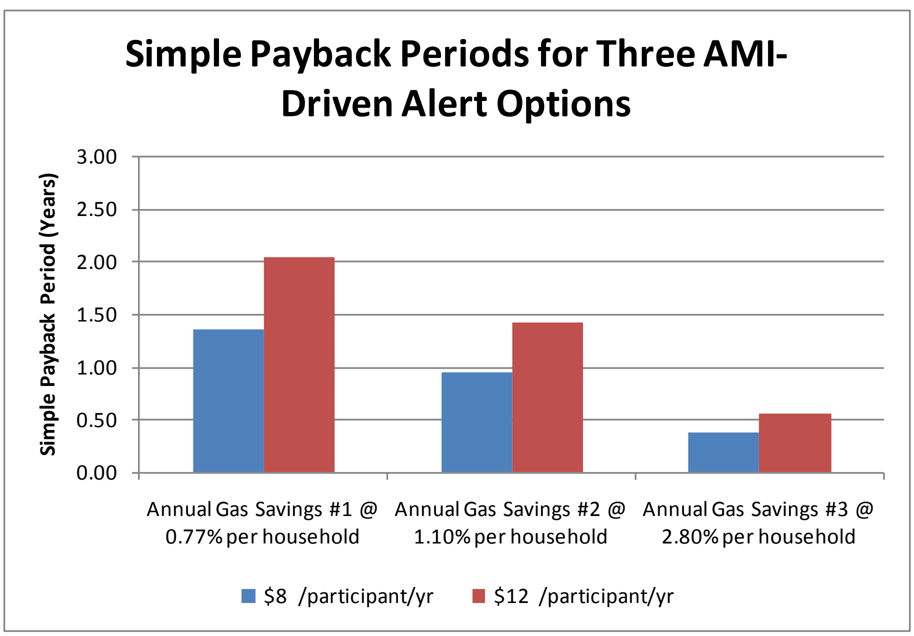

Figure 9. Simple payback periods for three AMI-driven alert feedback options

8 Conclusions and Future Research

Energy feedback has the ability to transform the largely "invisible" use of gas to the visible by providing consumers with a more detailed and holistic understanding of their energy usage patterns. Such feedback offers a great opportunity to achieve energy savings, both for electricity and natural gas. The majority of existing research focuses on electricity, but as gas represents nearly 43% of residential energy use, it is clear that there is untapped potential. Though savings are modest on a per-household basis, the cumulative effect in the residential sector has the potential to be sizable.

The market for feedback is young, but growing, with up to 5% of U.S. households estimated to have received some type of energy feedback in 2011.[5] Although disaggregated residential gas monitoring is not yet commercially cost effective, there are opportunities for natural gas to become more involved in the feedback market. AMI-driven gas usage customer alerts are a promising avenue for leveraging the growing smart gas grid infrastructure, but it is not necessary to wait for full AMI smart meter roll-out to capture feedback-induced gas savings. Enhanced billing relies on statistical disaggregation of utility data based on key variables (house size, age, HVAC equipment, etc.) to provide users with a snapshot of their energy use broken down by end use. Though not strictly feedback devices, advanced thermostats show compelling potential as an integration point for feedback into the primary control system for residential HVAC systems, which is the largest energy end use in nearly all households. These are the strongest market-ready options, though development improvements are still ongoing.

Commercialization of residential gas feedback devices has been intensely limited due to a number of challenges, such as unclear energy savings potential, lack of consumer awareness, complexity of disaggregated gas monitoring, and utility reluctance and unfamiliarity with behavior-based approaches. These barriers are not insurmountable. Some barriers will require concerted, focused efforts (such as unclear energy savings potential), while others are likely to diminish as the market for residential feedback matures (such as low consumer awareness). Potential solutions to these challenges were presented within this report, but it is anticipated that well-crafted research in the future is indispensible to overcoming these obstacles.

Specific future research needs include large enhanced gas billing pilots that employ test and control groups and systematically change the feedback design to determine those features that are critical to achieving gas savings. Features that should be tested for impacts on gas savings include: frequency of reporting (such as increased frequency during the heating-dominated winter season and possibly a single summary report in the summer or fall when retrofits/replacements may occur); targeting of high consumption gas users as compared to a general sample of the population; use of additional alerts/notifications where AMI is available; and access to a Web-based portal. Ideally, pilots should occur for at least two heating seasons, preferably with data from two previous heating seasons that can be used as a baseline. These datasets will also prove valuable in assessing the persistence of feedback-induced gas savings. Additional information on the types of behaviors that consumers change in response to gas feedback would also be valuable to help drive future R&D.

Future research for advanced thermostats should focus on usability testing and establishing energy savings. This research may be performed by utilities, as evidenced by Sacramento Municipal Utility District's (SMUD) intention to launch a thermostat lab where they will recruit consumers to perform usability testing. Energy savings research should focus exclusively on advanced thermostat designs, and consider how behaviors can impact average consumer savings and how incremental design changes may affect overall savings. Incremental design changes may include the use of a touch screen, color display, programming that is question-driven, and other similar alterations. Similarly, the development of a companion Web portal or on-thermostat display that includes historic thermostat usage and settings, and provides additional energy information to consumers should be explored.

Overall, there is a profound lack of gas-oriented feedback research. Until the dataset is larger and more robust, it will be challenging for utilities to design sure-fire feedback programs that will maximize gas savings. Once in place however, the emerging field of behavior-based, feedback-driven energy efficiency shows good potential for gas savings.

Appendix A

Enhanced Billing Simple Payback Period and ROI

Price Inputs

Residential Gas Price (2010$)	11.39	TCF
	1.11	therm
Residential Electric Price (2010$)	0.983	kWh

Average Annual U.S. Residential Gas Use	4655	billion cf
	69.4	million households use gas
	688.86	therms/household

Savings

Annual Gas Savings #1 @ 0.77% per household	5.30	therms
Annual Gas Savings #2 @ 1.10% per household	7.58	therms
Annual Gas Savings #3 @ 2.80% per household	19.29	therms

Costs

Enhanced Billing Option A Initial Cost ($)	10	per person/yr
Enhanced Billing Option B Initial Cost ($)	15	per person/yr

Simple Payback Period (in years)		**ROI (per year)**
Enhanced Billing Option A #1 SPP	1.70	59%
Enhanced Billing Option A #2 SPP	1.19	84%
Enhanced Billing Option A #3 SPP	0.47	214%
Enhanced Billing Option B #1 SPP	2.55	39%
Enhanced Billing Option B #2 SPP	1.78	56%
Enhanced Billing Option B #3 SPP	0.70	143%

Appendix B

Advanced Thermostat Simple Payback Period and ROI

Price Inputs

Residential Gas Price (2010$)	11.39	TCF
	1.11	therm
Residential Electric Price (2010$)	0.0983	kWh

Savings

Annual Gas Savings (per unit)	66	therms
Annual Electric Savings (per unit)	62.6	kWh

Costs

Professional Installation	1	# of installers
Number of hours	2	
Hourly labor rate	$40	
Total	$80	

Smart Thermostat #1 Initial Cost	$100	per unit
Smart Thermostat #1 Pro Install Cost	$80	per unit
Smart Thermostat #2 Initial Cost	$250	per unit
Smart Thermostat #2 Pro Install Cost	$80	per unit
Smart Thermostat #3 Initial Cost	$500	per unit
Smart Thermostat #3 Pro Install Cost	$80	per unit

Simple Payback Period (in years)		Simple ROI (per year)
Smart Thermostat #1 SPP w/Pro Install	2.27	44%
Smart Thermostat #2 SPP w/Pro Install	4.16	24%
Smart Thermostat #3 SPP w/Pro Install	7.31	14%
Smart Thermostat #1 SPP w/DIY Install	1.26	79%
Smart Thermostat #2 SPP w/DIY Install	3.15	32%
Smart Thermostat #3 SPP w/DIY Install	6.30	16%

Appendix C

Advanced Thermostat Monthly Mortgage and Utility Bill Analysis

	US Average	US Average	US Average	US Average
Building Costs	**Benchmark**	**w/Thermost at $100**	**w/Thermostat $250**	**w/Thermostat $500**
Benchmark Mortgage Value	$250,000.00	$250,000.00	$250,000.00	$250,000.00
Energy Saving Premium (Retail Cost of Thermostat)	-	$100.00	$250.00	$500.00
High Performance Mortgage Value	$250,000.00	$250,100.00	$250,250.00	$250,500.00
Annual Interest Rate	5%	5%	5%	5%
Term in Years	30	30	30	30
Annual Payments	$16,262.86	$16,269.36	$16,279.12	$16,295.38
Monthly Payments	$1,355.24	$1,355.78	$1,356.59	$1,357.95

Utility Energy Costs				
Annual Electricity				
kWh (from 2005 RECS)	11,475	11,413	11,413	11,413
$/kWh	0.0983	0.0983	0.0983	0.0983
$ for Electricity	$1,128.03	$1,121.87	$1,121.87	$1,121.87
Annual Gas				
therms (from RECS)	431	365	365	365
$/therm	1.11	1.11	1.11	1.11
$ for Gas	$478.16	$404.96	$404.96	$404.96
$ Total Utility Energy Costs	$1,606.19	$1,526.84	$1,526.84	$1,526.84
Monthly Utility Costs	$133.85	$127.24	$127.24	$127.24

Annual Combined Expenses	$17,869.05	$17,796.20	$17,805.96	$17,822.22
Difference from Benchmark	-	$72.85	$63.09	$46.83
Monthly Combined Expenses	$1,489.09	$1,483.02	$1,483.83	$1,485.19

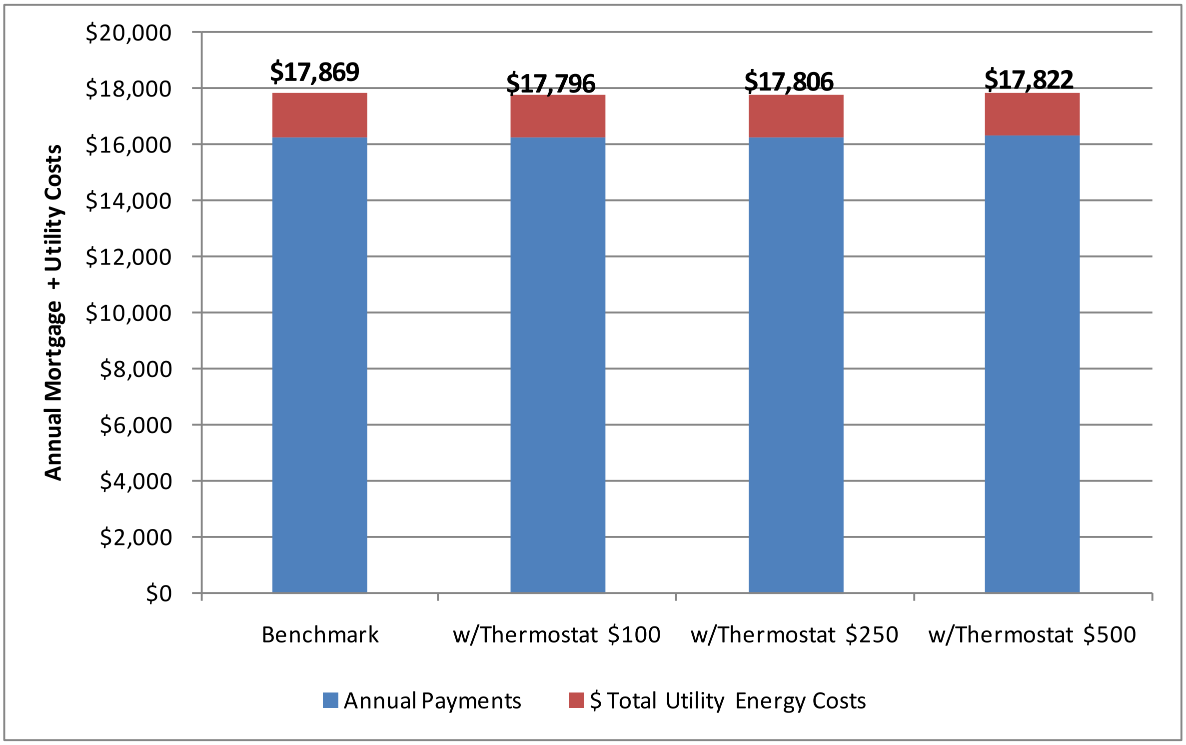

Figure 10. Total impact of three thermostats on homeowner annual mortgage and utility costs compared to a benchmark home

Appendix D

AMI-Driven Use Alert System Simple Payback Period and ROI

Price Inputs

Residential Gas Price (2010$)	11.39	TCF
	1.11	therm
Residential Electric Price (2010$)	0.0983	kWh

Average Annual U.S. Residential Gas Use	4655	billion cf
	69.4	million households use gas
	688.86	therms/household

Savings

Annual Gas Savings #1 @ 0.77% per household	5.30	therms
Annual Gas Savings #2 @ 1.10% per household	7.58	therms
Annual Gas Savings #3 @ 2.80% per household	19.29	therms

Costs

Enhanced Billing Option A Initial Cost ($)	$8	/participant/yr
Enhanced Billing Option B Initial Cost ($)	$12	/participant/yr

Simple Payback Period (in years)		Simple ROI (per year)
Enhanced Billing Option A #1 SPP	1.36	74%
Enhanced Billing Option A #2 SPP	0.95	105%
Enhanced Billing Option A #3 SPP	0.37	267%
Enhanced Billing Option B #1 SPP	2.04	49%
Enhanced Billing Option B #2 SPP	1.43	70%
Enhanced Billing Option B #3 SPP	0.56	178%

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