NSTAR Smart Grid Pilot

Final Technical Report

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On behalf of NSTAR Gas and Electric Corporation

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Preface

Navigant Consulting, Inc. has prepared this evaluation of NSTAR's Smart Grid pilot in fulfillment of reporting requirements for the U.S. Department of Energy's (DOE's) Smart Grid Demonstration grant program. The format of this document follows DOE's Technical Performance Report guidelines (June 17, 2011). Much of the information contained in this report also fulfills requirements and expectations of the Massachusetts Smart Grid Collaborative Technical Subcommittee, as put forth in the Collaborative's *Common Evaluation Framework* (March 23, 2011). For example, the impact tables in Appendix B present findings broken down by demographic subgroup (e.g., low-income, homes with presence of a senior), which is not a DOE requirement.

NSTAR began recruiting participants to the pilot in 2010 and expanded participation throughout 2011 and into the first half of 2012. For purposes of DOE's Smart Grid Demonstration, the official beginning of the 24-month pilot was January 1, 2012. Thus, the billing data used for estimation of energy and peak period load reductions covers the period January 2012 through December 2013.

Executive Summary

NSTAR Electric & Gas Corporation ("the Company", or "NSTAR") developed and implemented a Smart Grid pilot program beginning in 2010 to demonstrate the viability of leveraging existing automated meter reading (AMR) deployments to provide much of the Smart Grid functionality of advanced metering infrastructure (AMI), but without the large capital investment that AMI rollouts typically entail. In particular, a central objective of the Smart Energy Pilot was to enable residential dynamic pricing (time-of-use [TOU] and critical peak rates and rebates) and two-way direct load control (DLC) by continually capturing AMR meter data transmissions and communicating through customer-sited broadband connections in conjunction with a standards-based home area network (HAN).

The pilot program offerings to customers consisted of 1) a set of new rate options and 2) a set of technologies to enable interval metering, provision of enhanced customer information about pricing and electricity consumption, and (for some participants) automated load response. Each of four customer test groups in the pilot received a unique combination of rates and technologies in order to test hypotheses regarding the impact of technology on load reduction, energy consumption, and the interaction of various technologies and rate structures. Table ES-1 presents a summary description of the four test groups, including the number of participants in each group.

Table ES-1. Smart Grid Pilot Customer Test Groups

	Test Group	Description of Test Group[a]	AC Load Control[b]	Number of Participants
1	Enhanced Information	Access to information on energy consumption only; standard rate		1,021
2	Peak Time Rebate	$5 rebate for automated participation in "critical peak" events via NSTAR control of a smart thermostat; standard rate	☑	422
3	TOU Rate plus Critical Peak Pricing (CPP)[c]	TOU rate with CPP; smart thermostat controlled by NSTAR during CPP events	☑	380
4		TOU rate with CPP		894
Total				**2,717**

Source: NSTAR

[a] All groups received an Internet gateway and an in-home energy display.

[b] Air-conditioning (AC) load control refers to remotely raising temperature set-points of programmable communicating thermostats controlling participants' central AC systems.

[c] NSTAR established peak period TOU and CPP rates significantly above NSTAR's standard residential basic service rate in order to provide an effective price incentive for customers to shift usage off-peak. The TOU peak supply price was more than double the standard supplier charges, while the off-peak rate was approximately 60% of the otherwise applicable supply rate. The CPP rate was significantly higher still, at more than ten times the standard supply rate during critical events.

By January 2012 when the 24-month pilot operation period officially began for purposes of the U.S. Department of Energy (DOE) Smart Grid Demonstration project, NSTAR had enrolled approximately 3,600 customers and ultimately installed the enabling Smart Grid equipment at roughly 2,700 homes. As of the end of the pilot, approximately 1,500 customers remained enrolled, or roughly 57% of initial participants.

Evaluation Methods

The data collection and analysis approach was developed to meet the needs and regulatory requirements of both process and impact evaluation. Because of the technology demonstration goals, data collection was enhanced to include information to help understand the performance, reliability, and effectiveness of the Smart Grid technology. Thus, data collection was intended to meet the needs of multiple constituencies, including the DOE, the Massachusetts Department of Public Utilities, and NSTAR itself.

To meet these diverse needs, data collection consisted of three different data sources:

1. **Interval meter data** provided by the pilot technology along with demographic, weather, and other data needed to perform a statistically significant impact evaluation
2. **Survey data** collected from participants at various points in time throughout the pilot and addressing a variety of topic areas including use and acceptance of the technology, experience with installation, and overall views toward the program
3. **Technology data** generated by, or developed to track the performance of, various elements of the technology platform to help better assess the performance of the technology itself

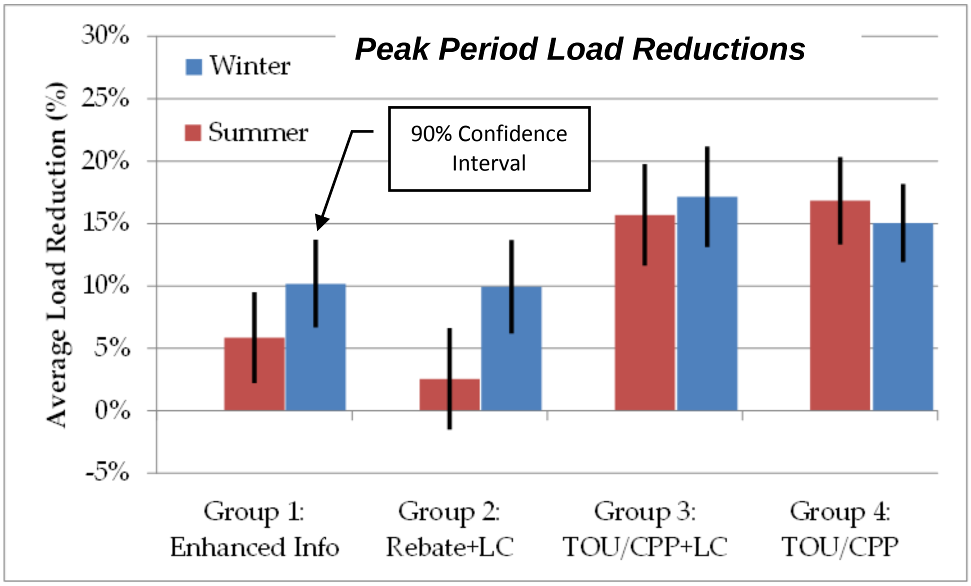
The estimation of the consumption impacts of all four test groups used hourly and/or monthly meter data collected for each participant as well as for the control group. The evaluation treated all of the individual time series as a single panel (or longitudinal) data set; that is, a data set that is both cross-sectional (including many different individuals) and time series (repeated observations for each individual). The consumption impacts of all four groups were then estimated using fixed-effects regression analysis with weather normalization.

Energy and Peak Demand Savings

The purpose of the impact analysis was to quantify changes in energy consumption and peak period demand resulting from participation in each of the four test-group components of the pilot program. Based on participant consumption data from January 2012 through December 2013, major findings of the impact analysis include the following:

» **Peak period load impacts.** Customers on the TOU/CPP rates (Groups 3 and 4) reduced summer peak period loads by approximately 0.2 kilowatts (kW), or about 15% of their average peak period load. Customers on the standard rate also reduced their load during peak hours, but only by approximately half as much as customers on the TOU rate (Figure ES-1).

Figure ES-1.Average Peak Period Load Reductions



Source: Navigant analysis

» **Impacts of critical events.** Customers with automated load control of central air conditioning (Groups 2 and 3) reduced demand by approximately 0.5 kW during events (roughly 20-25%). Customers on the TOU/CPP rate without automated load control reduced consumption by an average of 0.13 kW (9%) during events.

» **Annual energy impacts.** Customers on the TOU/CPP rates reduced their annual energy consumption by approximately 2%, while customers on the standard rates did not show a statistically significant change in consumption. The analysis shows that savings have *decreased* as the pilot progressed, with summer 2012 savings exceeding summer 2013 savings (roughly 2% savings vs. no savings across all participants) and changes in winter consumption moving from a moderate decrease during the first winter (roughly 3%) to a similar increase in the last three months of 2013.

Customer Interest, Energy Impacts, Technology Performance, and Participant Engagement

Several broad themes emerged from the evaluation, based on the specific findings of the impact evaluation and a review of pilot program processes, technology performance, and customer viewpoints. **Key takeaways from the pilot** with respect to customer interest, energy impacts, technology performance, and participant engagement are as follows:

1. **Smart Grid offerings may appeal to only a limited segment of the population—principally educated, affluent, and technologically savvy customers—**absent long-term education efforts and innovative marketing approaches to pique the interest of the broader customer base. Customer interest in the pilot was relatively strong initially, with response rates to NSTAR's direct mail and email marketing efforts of 4% and 7%, respectively, compared to the 2% to 4%

response rates typically seen in Smart Grid program recruitment.[1] While the overall response rate was high, customers expressing interest and enrolling in the pilot were primarily highly educated, affluent households, often with an expressed or demonstrated interest in technology. Despite concerted efforts by NSTAR to market all customers in the pilot territory, low-income customers did not enroll in high numbers, as evidenced by only about one percent of participants being on the R2 rate and roughly four percent reporting income below 60% of the median level for their household size.

2. **Pilot impacts on energy consumption were consistent with industry experience in several respects** (*e.g.*, peak period reductions from TOU rates and load control), **but were inconclusive with regard to whether the pilot's provision of energy usage information enables significant reductions in overall energy consumption.** The pilot's technology and rate offerings were designed to enable three types of reduced consumption: 1) peak period load reductions, 2) load curtailments during critical events, and 3) overall reduction in energy consumption (monthly/seasonally/annually). Consistent with industry experience, the pilot successfully demonstrated peak period reductions, particularly for customers on TOU rates. NSTAR specifically designed peak rates to be significantly higher than off-peak rates in order that participants could reduce their electricity bills by shifting load away from peak hours.[2] Load curtailment during critical events was also successful, particularly where long-established DLC of central air conditioners was employed.[3] Less certain is whether the Smart Grid's provision of access to energy consumption information successfully encourages and enables customers to save energy over the long term. Energy savings was minimal (2% on average for those on TOU rates, and a statistically insignificant change for others), with all groups showing a marked decline in savings after the first nine months of the pilot.

3. **The pilot demonstrated that the technology architecture is capable of AMI-like features through the collection of interval meter data, but that it is not yet viable for the widespread provision of customer information and dynamic rate tariffs.** While the pilot generally demonstrated the capability to deliver on these objectives for many customers, most of the time, the lack of reliability remains a major functional limitation. The following are among the significant reliability issues that must first be addressed before a similar system is deployed on a large scale as an alternative to revenue-grade metering:

   a. *Usability of the technologies*, from the thermostat that was difficult to install, to the accessibility of customer data, which was not available on mobile applications;

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[1] Smart grid marketing response rates are based on market research conducted by Navigant for the NSTAR Smart Grid Pilot Implementation and Marketing Plan, March 2010 (see Appendix C).

[2] Over the past decade, many utilities have developed TOU and CPP rates with much larger peak- to off-peak price differentials than in previous years. See Schare, S., "TOU Rates as TOU Rates As If Prices Mattered: Reviving an Industry Standard for Today's Utility Environment," *American Council for an Energy-Efficient Economy (ACEEE) Summer Study*, August 2008.

[3] The pilot was among a small minority of demand response programs in its use of customer broadband to communicate load control signals to participants. However, the achievement of consistent load reductions from direct load control, typically via radio frequency or very-high-frequency (VHF) paging, is well established in the industry.

b. *Data intermittency* from HAN system disconnections and temporary failure of back-end systems, both of which led to gaps in meter data that rendered TOU rates incomplete and resulted in defaults to the flat rate;

c. *Complexity and inconsistency of meter data validation/estimation process*, which caused data gaps and mis-alignment of intervals, resulting in differences in monthly consumption estimates between the interval data from the pilot architecture and the monthly drive-by reads from NSTAR's standard meter reading procedures.

Advances in technology since the initial pilot Soft Launch in 2010—such as wireless gateways using IP, extended on-site storage of information, and mobile phone apps—suggest that at least some of the issues raised by the pilot may be substantially resolved and that a similar approach to reading the AMR meters but leveraging these newer technologies might be more effective, and possibly lower cost.

4. **Participant perspectives on the pilot were generally positive, but the trend of diminishing interest over time raises questions about the long-term impacts of a future offering, especially if provided to all customers on an opt-out basis.** The positive customer reviews of the pilot are a testament to the strong delivery and positive messaging that NSTAR put forth from initial marketing to final closeout of the pilot. However, this is offset by the decline in enrollment by more than one-third over less than two years, and the decline in participant engagement (even among those who remained in the pilot, as evidenced by declining energy impacts and reduced use of the web portal and in-home displays). The implication is that a program requiring sustained engagement may not be for all customers; even those initially enthusiastic may lose interest over time.

Implications for the Future

Taken collectively, the above takeaways have several broad **implications for the future of a possible customer-facing Smart Grid offering** at NSTAR based on AMR meters and customer broadband:

1. **The pilot achieved its "technology validation" objective, including verification that "smart meter" functionality can be achieved without deployment of an advanced metering infrastructure. The general pilot architecture approach, after improvements in technology and data management, can be an effective, low-cost way for NSTAR or other utilities with AMR meters to enable energy information and TOU rates for customers who want it,** without investing in new metering infrastructure for all customers.

   a. **The residential sector is limited as a source of reducing peak load costs to lower costs for all ratepayers.** As a group, residential customers are not the driver of peak loads within NSTAR's service territory. The ISO New England system peak occurs between 1pm and 5pm, before many residential customers return from work outside the home. This is part of the reason that residential customers account for only about 38% of NSTAR summer peak load,[4] and it implies that targeting the residential sector en masse

[4] *Source:* NSTAR and Massachusetts Residential Appliance Saturation Survey (RASS), prepared by Opinion Dynamics Corp. for NSTAR and four other Massachusetts utilities, April 2009. The RASS study found a central AC saturation of 32%, a figure that NSTAR estimates has now reached 38%.

could be a high-cost/low-impact approach—especially if many customers do not actively respond to the technology and rate offering.

b. **Only a narrow segment of the population is likely to participate or contribute to savings.** The pilot demonstrated that interest among customers is predominantly among more affluent and educated customers, with the relatively few low-income participants showing an interest or ability to conserve energy. These demographic groups represent only a small share of the population. In addition, NSTAR survey research revealed that nearly half of customers who did not respond to the pilot offering would not be persuaded regardless of what NSTAR offered. Even the most subscribed TOU rates in the country have attracted no more than half of the residential population, and DLC programs only about 25-30% of eligible customers.

c. **Savings will come from larger customers with discretionary loads.** NSTAR's vision is to track technological progress and when appropriate deploy a more robust version of the pilot architecture. Target markets would be customers who express interest in reducing and shifting loads and those with large discretionary loads—particularly those with central air conditioning (roughly 38% of NSTAR's residential customer base) or pool pumps, who have the greatest opportunity to change their energy usage patterns.

2. **The market offering must communicate to customers that they have an important role to play in ensuring the system functions as designed.** Customers have a reciprocal role in that NSTAR will need customers to help maintain the operability of the in-home devices and broadband communications in order for NSTAR to provide usage information and to bill customers on dynamic rates.

3. **A successful offering of dynamic rates and visibility into customer usage information will require an aggressive and intelligent marketing effort to reach customers and engage them to act over a sustained period of time.** The pilot demonstrated that only a relatively narrow segment of the population tends to be interested in the technology and rate offerings embodied in the pilot, and many of these customers lost interest during the course of their participation. Keeping customers engaged after the initial few months or first year of a Smart Grid offering will likely require the incorporation of apps for mobile devices where energy information is more readily accessible and occasional push messaging and event notifications can engage customers without their having to initiate the engagement.[5] To make a similar program a success, NSTAR is in a position to draw on its long history as an energy efficiency program administrator, leveraging innovative marketing approaches to reach the targeted customer base.

A decision to invest in a future rollout of similar Smart Grid architecture and program offerings should be assessed based on the costs relative to the achievable benefits. An important consideration will be who bears the costs and to whom the benefits accrue—to NSTAR, its participating customers, all NSTAR ratepayers, or all electricity consumers in the region.

[5] Some participants asked for mobile apps via the pre-pilot and mid-point surveys, but the pilot technology suite had already been established.

1 Scope

NSTAR Electric & Gas Corporation ("the Company" or "NSTAR") developed and implemented a Smart Grid pilot program beginning in 2010 to demonstrate the viability of leveraging existing automated meter reading (AMR) deployments to provide much of the Smart Grid functionality of advanced metering infrastructure (AMI), but without the large capital investment that AMI rollouts typically entail.[6] In particular, a central objective o f the pilot was to enable residential dynamic pricing (time-of-use [TOU] and critical peak rates and rebates) and two-way direct load control (DLC) by continually capturing AMR meter data transmissions and communicating through customer-sited broadband connections in conjunction with a standards-based home area network (HAN). This enabled recording of interval consumption data and transfer of data to NSTAR via a two-way communications pathway, which was also used for sending load control signals and measuring demand response load impacts.

By January 2012 when the 24-month pilot operation period officially began for purposes of the U.S. Department of Energy (DOE) Smart Grid Demonstration project, NSTAR had enrolled approximately 3,600 customers and ultimately installed the enabling Smart Grid equipment at roughly 2,700 homes. As of the end of the pilot, approximately 1,500 customers remained enrolled, or roughly 57% of initial participants.[7] The pilot sampling design, including alternative rates and enabling technologies, allows for data useful to utilities across the country regarding the interaction of rates and technology to yield optimal levels of load reduction and customer acceptance.

In developing this pilot plan, the Company adhered to the following principles:

- **Leverage recent technology investments.** AMR meters were recently deployed throughout the Company's service territory. The cost savings and other benefits of the deployment help improve customer service and provide other operational efficiencies. The Smart Grid pilot employs broadband technology that can utilize the existing infrastructure to provide two-way communication and interval metering more economically than via investment in AMI.
- **Maintain flexibility for future Smart Grid technology.** The pilot was designed to retain flexibility to potentially integrate with other future Smart Grid technology. The in-home communications hardware and load control equipment use a common, standards-based, nonproprietary (Internet Protocol [IP] and ZigBee) HAN protocol that are compatible with foreseeable alternatives to the proposed Smart Grid architecture. Thus, if the pilot rate structures and technology functionality proved to be worthy of a more widespread deployment, the

[6] In its 2008 report to Congress on advanced metering, the Federal Energy Regulatory Commission (FERC) cautioned regulators and utilities to protect against functioning, non-depreciated assets (such as AMR investments) from becoming obsolete. See FERC, *2008 Assessment of Demand Response and Advanced Metering, Staff Report*, December 2008, p. 21. U.S. utilities have already invested in tens of millions of AMR meters, accounting for approximately 25% of all meters nationwide and 80% of meters in the Northeast. Source: Dr. Howard Scott, *The Scott Report: Worldwide Deployments of Automated Metering Services*, May 2009.

[7] Enrolled customer counts are recorded in a Tendril data file "showRegUsers." The final showRegUsers file dated November 30, 2013 (prior to the beginning of de-enrollment in December 2013) listed 1,549 customers enrolled.

Company could then select from among the latest IP and HAN technology offerings to enable the Smart Grid of the future.

1.1 Objectives

Specific objectives for the pilot included the following:

- **Validate technology objectives,** including the verification that two-way communications, "smart meters," and embedded automated load management can be achieved by using currently deployed AMR infrastructure in conjunction with technology from the preferred vendor and customers' broadband Internet service.
- **Identify customer perceptions and views on pilot offerings.** Customer views were obtained by reviewing technical data on load reductions and critical event overrides, through call center records, and via evaluation surveys conducted at several phases of the pilot.
- **Provide sound technical, economic, and marketing information** that can be used to inform the Company's future Smart Grid investment decisions. As part of its pilot, the Company gathered data in order to be able to answer a variety of research questions addressing program designs, rate structures, technology offerings, and implementation approaches.
- **Meet load reduction targets,** which included reduction of usage during the peak period by a minimum of 5% for participating customers.
- **Assess the impact on low-income customers** and the manner in which this customer group used the information to modify energy usage, if any. Various participant demographic data, including income, were analyzed in the pilot evaluation in order to inform if and to what extent low- income participants used this information to modify energy usage.[8]

1.2 Recipient Team Overview

Key members of the Smart Grid project team included the following:

NSTAR. Several organizations of the Company have been actively engaged in this project, including Engineering, Customer Care, Accounting, Information Technology, Corporate Relations, and more. Much of the work to implement the project was performed by NSTAR's contracting partners, as described below.

Tendril Networks. Tendril delivered its hardware solution to NSTAR according to the final rollout plan. A major role for Tendril was to work with NSTAR, both remotely and on-site, to establish the back-office system integration. Data protocols were refined to ensure that AMR data was successfully converted to a nonproprietary IP that can be communicated via customers' broadband connections to Tendril servers. From there, the data format was modified to ensure compatibility with NSTAR Customer Information Systems (CIS) and billing systems such that NSTAR could use the new interval data (as opposed to monthly single-point reads) to calculate TOU-based bills.

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[8] As of the time of this report, NSTAR is in the process of conducting focus groups with low-income participants to further inform the findings for this segment.

Tendril also served as the implementation contractor assisting in developing the overall customer value propositions and associated messages and literature formats for customer recruitment, enrollment, and installation processes. Tendril and its subcontractor oversaw the scheduling and execution of equipment installation at participants' homes, tracking contacts with customers who agreed to participate and reporting back to NSTAR in order that program managers and marketing staff could monitor progress. The Tendril team also arranged for on-site visits to install the equipment where necessary and to educate customers about the program, use of the equipment, and common actions that may be taken to reduce consumption in general and during peak periods or critical peak events. Where appropriate, the Tendril team also ensured that in-home displays were receiving meter and cost data and that customers had access to the web portal to view more detailed information and could adjust thermostat settings (for those participants receiving smart thermostats).

Navigant Consulting, Inc. (Navigant) had the role of evaluating the program's impacts, technical viability, and processes. Impact Evaluation addresses the changes in total energy consumption, peak period loads, and customer bills resulting from participation in the program. Changes in total energy consumption were calculated by comparing meter data from the various participant groups to data from a control group. Changes in peak demand were estimated using statistical regression modeling and comparing the expected peak usage with the actual peak usage based on interval meter data. Technology Assessment addresses the reliability and customer acceptance of the various technologies associated with the Smart Grid architecture. Process Evaluation encompasses a review of how well the Company is administering the program and how customers perceive the program.

2 Technical Approach and Pilot Program Description

The pilot program offerings to customers consisted of 1) a set of new rate options and 2) a set of technologies to enable interval metering, provision of enhanced customer information about pricing and electricity consumption, and (for some participants) automated load response. Each of four customer test groups in the pilot, as described below, received a unique combination of rates and technologies in order to test hypotheses regarding the impact of technology on load reduction, energy consumption and the interaction of various technologies and rate structures. Table 2-1 presents a summary description of the four test groups, including the number of participants in each group.[9]

Table 2-1. Smart Grid Pilot Customer Test Groups

	Test Group	Description of Test Group[a]	AC Load Control[b]	Number of Participants
1	Enhanced Information	Access to information on energy consumption only; standard rate		1,021
2	Peak Time Rebate	$5 rebate for automated participation in "critical peak" events via NSTAR control of a smart thermostat; standard rate	☑	422
3	TOU Rate plus Critical Peak Pricing (CPP)[c]	TOU rate with CPP; smart thermostat controlled by NSTAR during CPP events	☑	380
4		TOU rate with CPP		894
Total				**2,717**

Source: NSTAR

[a] All groups received an Internet gateway and an in-home energy display. See subsections below for a more detailed description of the rates and equipment provided to the various test groups.

[b] Air conditioning (AC) load control refers to remotely raising temperature set-points of programmable communicating thermostats controlling participants' central AC systems.

[c] NSTAR established peak period TOU and CPP rates significantly above NSTAR's standard residential basic service rate in order to provide an effective price incentive for customers to shift usage off-peak. The TOU peak supply price was more than double the standard supplier charges, while the off-peak rate was approximately 60% of the otherwise applicable supply rate. The CPP rate was significantly higher still, at more than ten times the standard supply rate during critical events.

The first two subsections below present the alternative rate structures and technology options used in the experimental design. The third subsection provides detail on the various data collection approaches used to understand and evaluate the results of the pilot.

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[9] NSTAR's initial goals were to attract approximately 700 participants to each of the four groups. However, participation in Groups 2 and 3 required that customers have a one-zone central air conditioning system and that they be willing to replace their thermostat with the pilot thermostat. Consequently, since many participants did not have central air conditioning, many were assigned to Groups 1 or 4, resulting in higher participation levels for these groups.

2.1 *Alternative Rate Structures*

In place of the standard electricity rate, most participants in the pilot received service under one of the following two new rate designs:

1. A new TOU rate with CPP for events called by NSTAR
2. A critical peak rebate overlaid on the standard applicable rate, with a pre-established rebate amount awarded to customers who utilized automated thermostat controls or an automated AC load control switch to reduce load during critical peak events

There was also one customer segment that received a base suite of in-home technology but stayed on their otherwise applicable standard rate, which allowed NSTAR to assess the achievable load reductions from a technology-only option that did not require customers to change rates.

2.1.1 Time-of-Use Rate with Critical Peak Pricing

Table 2-2 presents an example of the total electricity rate for TOU, including delivery charges and the variable electricity supply price for participants on the TOU with CPP rates. For customers on the TOU with CPP rate structure, the peak supply price was more than double the standard supplier charges, and the CPP rate was roughly ten times the standard charges. The off-peak rate provided roughly a 40% discount off the standard charges. Note that the rate differential applied to the supplier charge portion of the bill; the delivery portion of the bill remained unchanged for customers taking service under this rate.

Table 2-2. Illustrative TOU and CPP Rate Periods and Prices

Illustrative TOU and CPP Rate Periods and Prices												
Period	Summer Period (June - September)	Winter Period (October - May)	Standard Supplier Charges ($/kWh)		Approximate Supply Price Ratio (Relative to Standard)		Illustrative Supply Price ($/kWh)		Illustrative Delivery Charges ($/kWh)		Total Electricity Price ($/kWh)
Critical Peak	As called by NSTAR		$0.08	x	10.62 :1	=	$0.82	+	$0.08	=	$0.90
On-peak	Noon to 5pm non-holiday weekdays	4pm to 9pm non-holiday weekdays	$0.08	x	2.23 : 1	=	$0.17	+	$0.08	=	$0.25
Off-peak	All other times during the period		$0.08	x	0.60 : 1	=	$0.05	+	$0.08	=	$0.13

Note: Actual supplier charges and total prices were recalculated periodically throughout the program in order to maintain the relative price differentials for each period and ensure revenue neutrality (pilot rates vs. standard rates) based on then-current supply costs. The "Total Electricity Price" and "Approximate Price Ratios" presented here applied to customers on the standard rate.

Source: NSTAR

2.1.2 Critical Peak Rebate

As compared to the TOU/CPP rate, the critical peak rebate was a no risk alternative intended to address peak demand by providing a financial incentive for customers to reduce load during critical events called by NSTAR. Supplier charges under this rate were according to each participant's standard applicable rate; however, when a critical event was in effect, participants were eligible for a rebate. All customers participating in the critical peak rebate offering were required to have central air conditioning and were provided a smart thermostat that enabled automated load control by adjusting AC temperature during events.

Participants agreed to allow a temperature increase of between 1 and 6 degrees (the amount varied by event, as determined by NSTAR), and they had the option to override the setting. All participants who did not override the load control setting during a given event received a $5 rebate for that event. Rebates were cumulative and were reflected as a reduction on the customer's monthly bill. Customers who overrode the temperature setting (i.e., lowered the temperature during the event) did not receive the rebate for that event but were eligible for rebates during subsequent events.

2.2 *Smart Grid Technology*

The technology architecture was designed to leverage existing, deployed AMR meters by connecting these meters to NSTAR and the relevant NSTAR internal processes through a set of in-home, cloud-based, and back-office technologies. In this way, the AMR meters were intended to provide AMI-like capabilities—such as the ability to provide billing information for CPP programs as described above or providing interval consumption data to participants—but without the cost of a complete AMI infrastructure deployment.

The technology deployed to provide these capabilities is shown in Figure 2-1. The architecture consisted of several pieces of in-home technology that communicated with each other wirelessly—including the customer's AMR meter—and which then connected to a cloud-based technology platform via customer-provided broadband. The cloud-based technology platform in turn connected to NSTAR via a secure Internet connection and was integrated with several of NSTAR's back-office systems to provide the required capabilities for the Demonstration. The in-home equipment and technology platform were provided by Tendril.

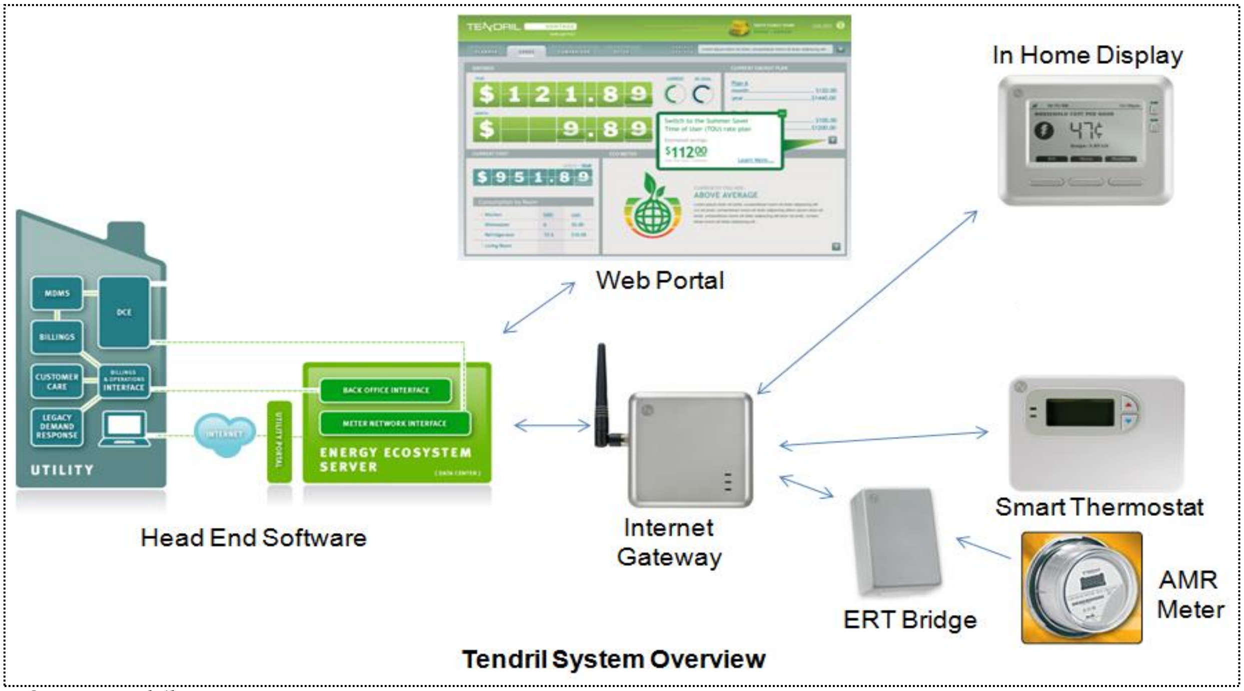
This technology infrastructure was intended to establish a reliable backhaul communications pathway from the meter to NSTAR's internal systems and allow meter reading resolution suitable for TOU and CPP rate plans. The deployed equipment also enabled automated load control of central air conditioning and provided customer information via in-home displays and an Internet-based web portal.

The technology shown in the figure can be divided into the following functional categories:

- **Customer-facing technology:** These are elements that allowed direct communication with pilot participants and provided consumption, pricing, and other information to the participants. These elements were the focus of much of the customer survey work performed in the evaluation.
- **In-home infrastructure:** These are elements that enabled the communication pathways within the home via ZigBee low-power radio connectivity and provided communication, via the customer- provided broadband, to the cloud-based platform capabilities and the NSTAR back-office systems.
- **Cloud-based platform:** Provided the central control and management functionality for the pilot system

» **Utility back-office systems:** NSTAR systems that were integrated to provide the necessary functionality to run the pilot

Figure 2-1. Components of the Smart Grid Technology Platform



Source: Tendril

The customer-facing technology consisted of the following three elements:

» **Web portal:** The *Tendril Vantage* is a browser-based Internet portal that enabled monitoring, management, and control of energy consumption on smart ZigBee-enabled devices in the home. Among its features, the web portal allowed customers to view and manage household energy consumption, compare consumption to other households with similar demographics, and receive messages from NSTAR.

» **In-home energy display (IHD):** The display is a digital wireless (ZigBee protocol) device that showed real-time power demand, billing-period electricity consumption and cost, the current TOU electricity price or critical event status (if applicable), and other related information. The display was used by customers to help identify measures to lower consumption, and it served as an additional communications vehicle for NSTAR to inform customers of critical events.

» **Smart thermostat:** Participants who received a wireless (ZigBee protocol) smart thermostat were able to program temperature set-points either manually or via a user interface on the Internet. At the onset of a critical event, NSTAR sent a signal to increase the temperature setting on thermostats by either 3 or 5 degrees. (The amount varied by event.) Any changes made to thermostat settings supersede the previous load control signal.

The other in-home infrastructure consisted of the following elements:

- **AMR meter**: The customer's automated meter reading meter—already deployed at the customer site prior to the pilot—measures customer consumption and transmits the readings via Encoder Receiver Transmitter (ERT)[10] radio signal at frequent intervals so that they can be picked up by drive-by utility trucks for monthly readings.
- **ERT bridge**: This element was able to read the ERT signal from the AMR meter to get household consumption data, and translate that signal into ZigBee radio signal to communicate with the other in-home devices, which all communicate via the ZigBee protocol.
- **Internet gateway**: All participating homes were equipped with an Internet gateway connected to a wireless (ZigBee protocol) Home Area Network (HAN). This gateway transmitted consumption data from the meter to NSTAR via the ERT bridge and allowed communication back to in-home energy displays.

These technologies constituted the Smart Grid from the **customer perspective**. They provided feedback on energy consumption (via an in-home display or a web portal) and offered participants the convenience of remotely controlling household temperature. The automated response to critical events was intended to allow for greater load reductions and bill savings.

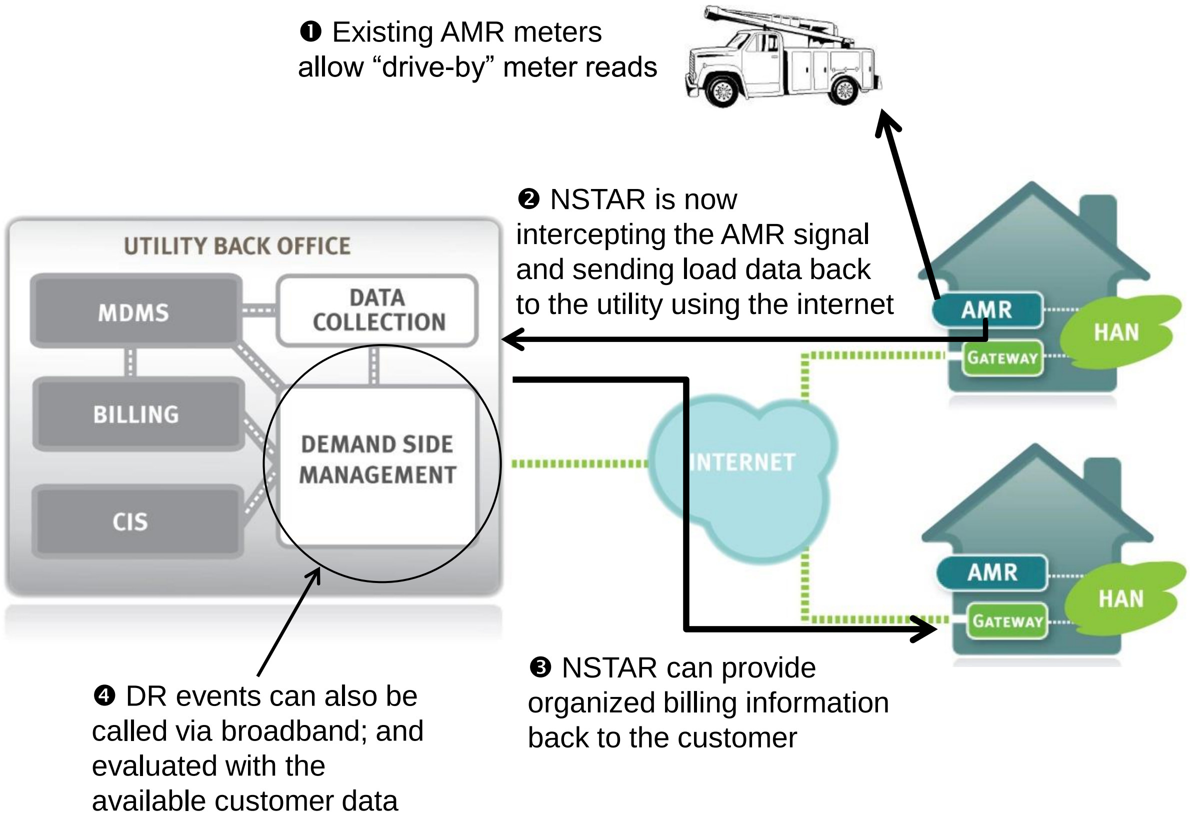
The utility head-end and back-office elements consisted of the following elements, also shown in Figure 2-1.

- **Tendril Energy Ecosystem Server**: Provided the central control and management functionality for the Tendril system, including Internet connectivity to the participant household equipment and to the NSTAR back-office systems via secure connection. It also performed such functions as enrolling and tracking status of pilot participants, collecting consumption data, and managing demand events.
- **Utility Back-Office Systems**: These are production systems as well as pilot-specific systems at NSTAR that were integrated to perform necessary functions for the pilot, including using pilot data for billing and managing participant calls at the call center.

[10] ERT is low-power radio operating in the 900-megahertz (MHz) ILM band and designed specifically for drive-by meter reading applications. ERT is a trademark of Itron, Inc.

A more utility-centric view of this functionality is shown in Figure 2-2, which shows the various communication pathways between the utility and the home. The Tendril platform provided the capability of utilizing the customer's existing Internet connection as the communications backhaul.

Figure 2-2. Communications Pathway to and from the Customer Home



Source: Tendril, adapted by Navigant

As shown in Figure 2-2 (see numbered items):

1. The AMR meters transmit ERT radio signals that allow meters to be read by trucks driving by.
2. Alternatively, using this new platform, the meter readings were gathered continuously and transmitted to NSTAR via customer broadband and secure Internet connection. In addition, since the wireless meter readings are transmitted much more frequently (from 8- to 30-second intervals) than trucks typically drive by (once per month), these time-stamped wireless readings could track the meter consumption readings with much more time granularity.
3. The broadband connection also provided the pathway for NSTAR to communicate directly to the customer via secure Internet connection, and provided consumption, bill estimation, or event notification to the participants.
4. The technology was used to issue demand response (DR) control signals to smart thermostats for those participants in one of the load control groups.

This technology architecture was intended to allow NSTAR's existing AMR meters to provide many of the key capabilities delivered by the newest AMI systems, without undergoing the cost and disruption of upgrading to a new AMI system and retiring the AMR assets before the end of their useful life.

2.3 *Data Collection*

The data collection and analysis approach was developed to meet the needs and regulatory requirements of both process and impact evaluation. Because of the technology demonstration goals, data collection was enhanced to include information to help understand the performance, reliability, and effectiveness of the Smart Grid technology. Thus, data collection was intended to meet the needs of multiple constituencies.

- **DOE,** as part of its Smart Grid Demonstration grant funding of the pilot, required development of a Metrics and Benefits Plan for the pilot, which established a variety of data types to be collected as well as agreed analyses of various aspects of the technology and program operation to assess effectiveness of the original pilot goals.
- **The Massachusetts Department of Public Utilities (DPU)** requires a regulatory evaluation of the program to conform to the guidance of the Massachusetts Smart Grid Collaborative Technical Subcommittee's Common Evaluation Framework.
- **NSTAR** seeks to understand the effectiveness of these new technologies, and what the potential is for using them in its broader service territory to provide greater capabilities to its customers and its internal operations at lower costs than other types of investment might require.

To meet these diverse needs, data collection consisted of three different data sources:

1. **Interval meter data** provided by the pilot technology along with demographic, weather, and other data needed to perform a statistically significant impact evaluation
2. **Survey data** collected from participants targeting different pilot areas at various points in time throughout the pilot, and interview data with program managers and technologists responsible for various aspects of the pilot
3. **Technology data** generated by, or developed to track the performance of, various elements of the technology platform to help better assess the performance of the technology itself

The first two of these efforts are traditional in evaluation of demand-side management (DSM) programs for energy efficiency or DR, so the target meter/billing data for impact evaluation and survey data for process evaluation were very well understood at the outset. The third item, data generated by the technology itself, is a relatively new area without established methodologies and standards. This technology data has provided a richer set of information than has been traditionally been available in demand-side and pricing program evaluation.

2.3.1 Impact Data Collection

The technology platform was used to provide 15-minute interval data that was converted to hourly and used in both peak load and energy impact assessment. Interval data from a limited set of load control customers was also collected to serve as part of the control group. Weather, demographic, and other data needed to perform the impact evaluation were also collected.

2.3.2 Survey Data Collection

NSTAR obtained customer feedback using surveys that covered a variety of topic areas, including use and acceptance of the technology, experience with installation, and overall views toward the program. NSTAR incorporated a standard question set contained in the Common Evaluation Framework (see above) and also customized the surveys by adding questions of particular interest and relevance to its pilot program. Customer acceptance and satisfaction in the program were solicited at several points in the pilot, to provide NSTAR with feedback on the pilot's progress and to characterize participants' final views. Table 2-3 lists each of the survey efforts.

Table 2-3. Customer Survey Efforts

Survey Effort	Number of Completes
Pre-pilot survey, administered immediately following sign-up	2,027
Post-installation survey, administered immediately after technology was installed in participants' homes	1,341
Decline-to-participate survey of customers receiving marketing materials but who did not respond	60
Post-event survey, administered after each of five events	334
Midpoint survey conducted at the end of 2011*	353
Dropout survey of participants who dropped out of the pilot	120
End of pilot survey	305
Low-income survey of low-income customers, primarily non-participants	302

* At the time of the midpoint survey, most respondents had been in the pilot for at least two months, and many for more than six months. For purposes of DOE's Smart Grid Demonstration, the pilot did not officially begin its 24-month duration until January 1, 2012.

Source: Navigant survey data

2.3.3 Technology Data Collection

One of the new, and key, aspects of Smart Grid technologies is that they promise to provide a much greater level of data and information than has been previously available. Analysis of this information can help to better understand and manage the power delivery system and customer-sited systems and activity as well as to inform customer communications. One of the key questions when planning for the technology assessment was whether, and to what degree, information generated by the technology itself could be made available for meeting the evaluation objectives of assessing reliability, understanding customer acceptance, and understanding other operational benefits or limitations of the technology. Among the data elements available for the evaluation were the following:

- Interval data in various stages of processing
- Installer data information

» HAN equipment responses to events

While some information originally sought was difficult (or not possible) to obtain, the information that was provided yields insights beyond those traditionally possible without the data and information generated by the technology. These insights are elaborated in Section 5, Technology Assessment.

2.4 *Analysis of Energy Savings Benefits*

The combination of time-variable rates and enabling technologies allows for testing of various hypotheses regarding the energy savings impact of individual rate structures and technologies. For example, Test Groups 3 and 4(TOU/CPP rates) can be compared to the control group to assess the impact of a TOU rate on peak period consumption as well as the impact of the high-priced critical peak event relative to normal peak hours. Comparing Test Groups 2 and 3 then allows for measurement of how a critical peak *rebate* influences consumption relative to a critical peak *price*.

Control groups served as benchmarks for purposes of estimating load impacts. The analysis employed the following control groups (Table 2-4), each selected to best serve the intended purpose.

Table 2-4. Control Group Specification

Control Group	Purpose in Evaluation	Rationale
Existing interval-metered load research sample*	Peak load and time-of-day impacts	Evaluation requires interval data from prior years in order to assess time-varying impacts adjusted for weather, economic, and other macro factors.
Monthly bill customers*	Annual, seasonal, and monthly impacts	Monthly billing data is readily available and allows for a large control group; interval data is not needed for impacts at monthly or lower granularity.
Participants' own interval data	Impacts of load control and CPP events	Customers are their own best-matched control group. Since events occur a finite number of times for relatively short durations, participants' own interval data from non-event days and hours constitute a strong basis for comparison.

*The evaluation used a sub-sample of each control group population to serve as the comparison group, based on matching of energy consumption patterns with the participant group.

Source: Navigant

The estimation of the consumption impacts of all four test groups required hourly meter data collected for each participant as well as for the control group. The evaluation team consolidated the individual time series into a single panel (or longitudinal) data set; that is, a data set that is both cross-sectional (including many different individuals) and time series (repeated observations for each individual). The consumption impacts of all four groups were then estimated using fixed-effects regression analysis with weather normalization. For more detail on the analytic methods, see Appendix A.

3 Impact Assessment

The purpose of the impact analysis was to quantify changes in energy consumption and peak demand resulting from participation in each of the four test-group components of the pilot program. The pilot design was intended to affect both the amount of energy consumed and the timing of consumption (on-peak or off-peak). A specific objective was to achieve the 5% savings goal of the Green Communities Act, which NSTAR defined as applying to the summer peak periods from June through September on non-holiday weekdays between noon and 5 p.m.[11] Other impact metrics included seasonal and annual energy savings, and load reductions during critical events, both with and without a CPP price in effect and with and without load control of air conditioners.

Based on participant consumption data from January 2012 through December 2013, major findings of the impact analysis include the following:

- **Peak load impacts.** Customers on the TOU/CPP rates(Groups 3 and 4) reduced summer peak loads by approximately 0.2 kilowatts(kW), or about 15% of their average peak period consumption. Customers on the standard rate also reduced their consumption during peak hours, but only by approximately half as much as customers on the TOU rate.
- **Impacts of critical events.** Customers with automated load control of central AC (Groups 2 and 3) reduced demand by approximately 0.5 kW during events (roughly 20-25%).Customers on the TOU/CPP rate without automated load control reduced consumption by an average of 0.13 kW (9%) during events.
- **Annual energy impacts.**
    - Customers on the TOU/CPP rates reduced their annual energy consumption by approximately 2%. Customers on the standard rates showed about a 1% *increase* in annual consumption, although these latter impacts are not statistically different from zero at a 90% level of confidence.
    - Savings appear to have decreased as the pilot progressed, with summer 2012 savings exceeding summer 2013 savings (roughly 2% savings vs. no savings). Winter months showed a similar pattern, with a modest savings in January through May 2012 becoming a modest increase by fall 2012.
- **Bill impacts.** Customers on TOU/CPP rates saved the most on their energy bills, averaging approximately $60 in annual savings, or about 4% of their electric bill. Customers on the standard rates did not experience a significant change in bills compared to what they would have been absent participation in the pilot.

The remainder of this section will discuss the impact findings in greater detail, covering each of the four topic areas above. Navigant also estimated impacts by several demographic characteristics, including

[11] *NSTAR Smart Grid Pilot Plan Filing*, submitted to the Massachusetts DPU, March 31, 2009.

low-income, high-income, low-usage, high-usage, presence of a senior citizen, small homes, and large homes. Appendix B contains detailed results for each demographic subgroup.

3.1 Peak Period Load Impacts

Pilot participants in Groups 3 and 4 were placed on a TOU rate, in which customers were charged a higher rate during the peak period and a lower rate during the off-peak period (all non-peak hours). The peak period is defined as non-holiday weekdays from 12-5 p.m. in the summer (June to September) and 4-9 p.m. in the winter (October to May). The rate is intended to encourage participants to shift a portion of their peak period load to the off-peak period. The peak period and time-of-day impact analysis quantified the amount of load shifting that occurred in response to the pilot.

Navigant found that peak period load reductions are greatest for participants on the TOU rate. Participants on the TOU rate (Groups 3 and 4) reduced their peak demand by between 16% and 18%, depending on the Group and season. Participants on the flat rate (Groups 1 and 2) reduced their peak demand by between 3% and 11%.[12]

Table 3-1 provides the average peak period reductions for summer and winter for each pilot group.[13] Figure 3-1 displays this data with 90% confidence intervals.

Table 3-1. Average Peak Period Load Reduction, by Group and Season

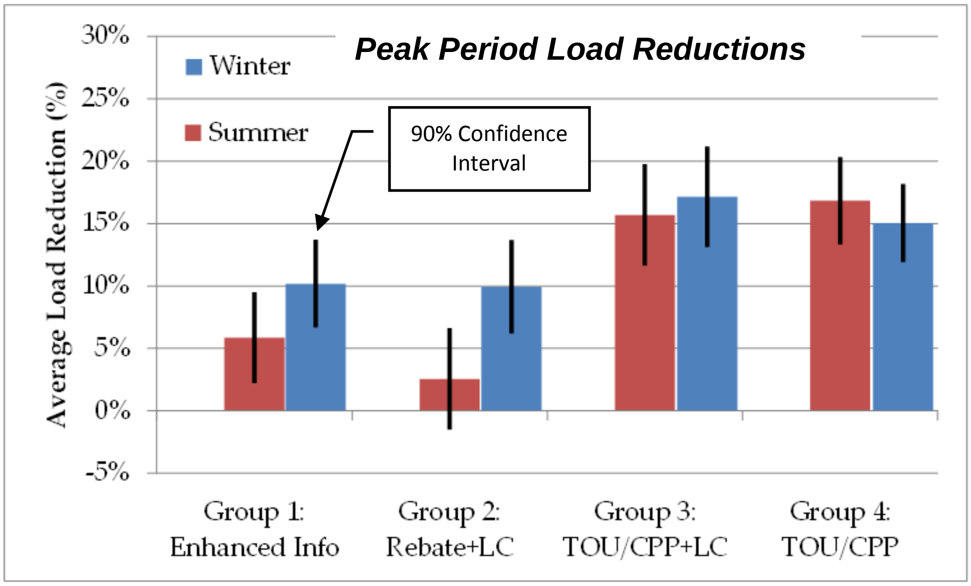
Pilot Group		Peak Period Demand Reduction, January 2012 - December 2013			
		Summer Weekdays, 12-5 pm		Winter Weekdays, 4-9 pm	
		%	kW	%	kW
1	Enhanced Information	6%	0.06	11%	0.09
2	Peak Time Rebate + LC	3%	0.04	10%	0.11
3	TOU/CPP + LC	16%	0.21	18%	0.18
4	TOU/CPP	17%	0.17	16%	0.14

Source: Navigant analysis

[12] The average summer peak demand reduction across all participants was 10.6% of load, as weighted according to the Group assignments of the 2,717 original participants presented in Table 2-1.

[13] Navigant did not include event days in the analysis of peak period load reductions and dropped observations where the interval length was less than 45 minutes or more than 75 minutes, since the model was based on hourly data. Demand reductions were calculated as the difference in load between pilot participants and matched control customers from NSTAR's load research sample.

Figure 3-1. Average Peak Period Load Reductions, by Group and Season

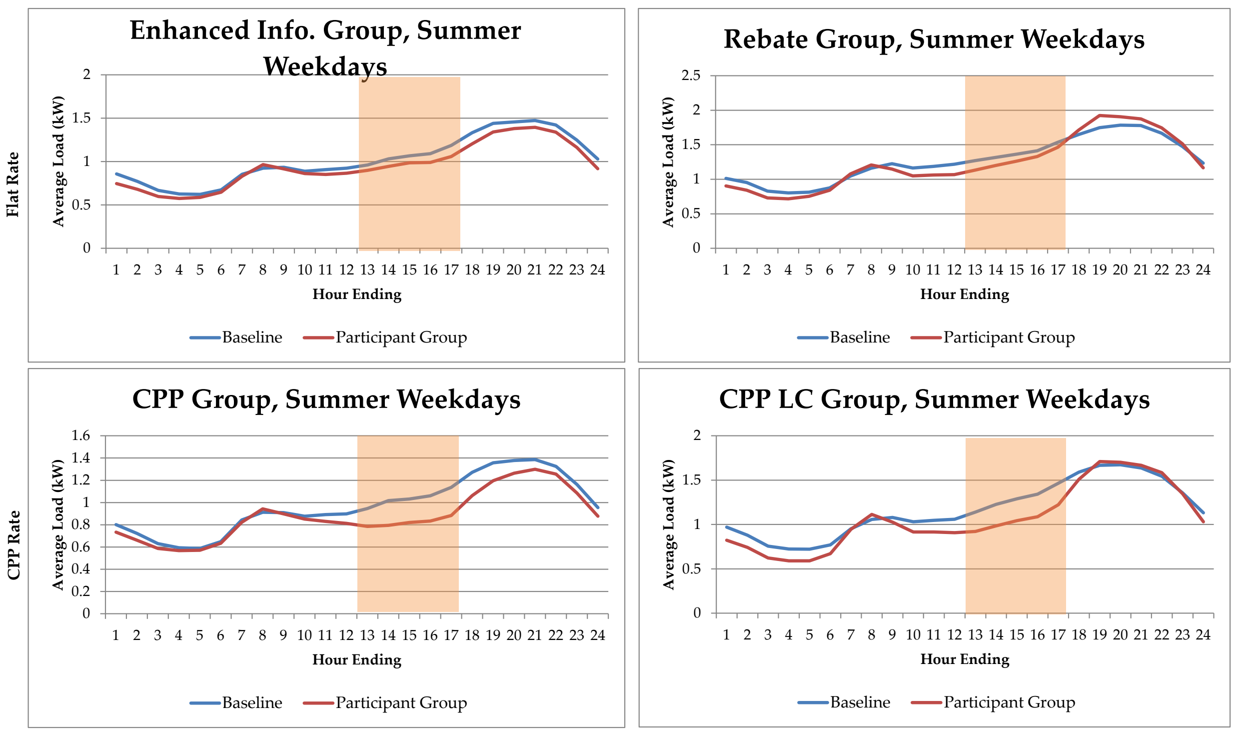


Source: Navigant analysis

Figure 3-2 and Figure 3-3 display the average weekday load curves (excluding event days) and baselines for summer (June–September) and winter (October–May), respectively. The lower red line represents the average load for pilot participants and the higher blue line represents the baseline, based on the load for matched controls. The difference between the participant load and the baseline is determined by the participation variables and indicates the predicted impact of the pilot according to Navigant's regression modeling.

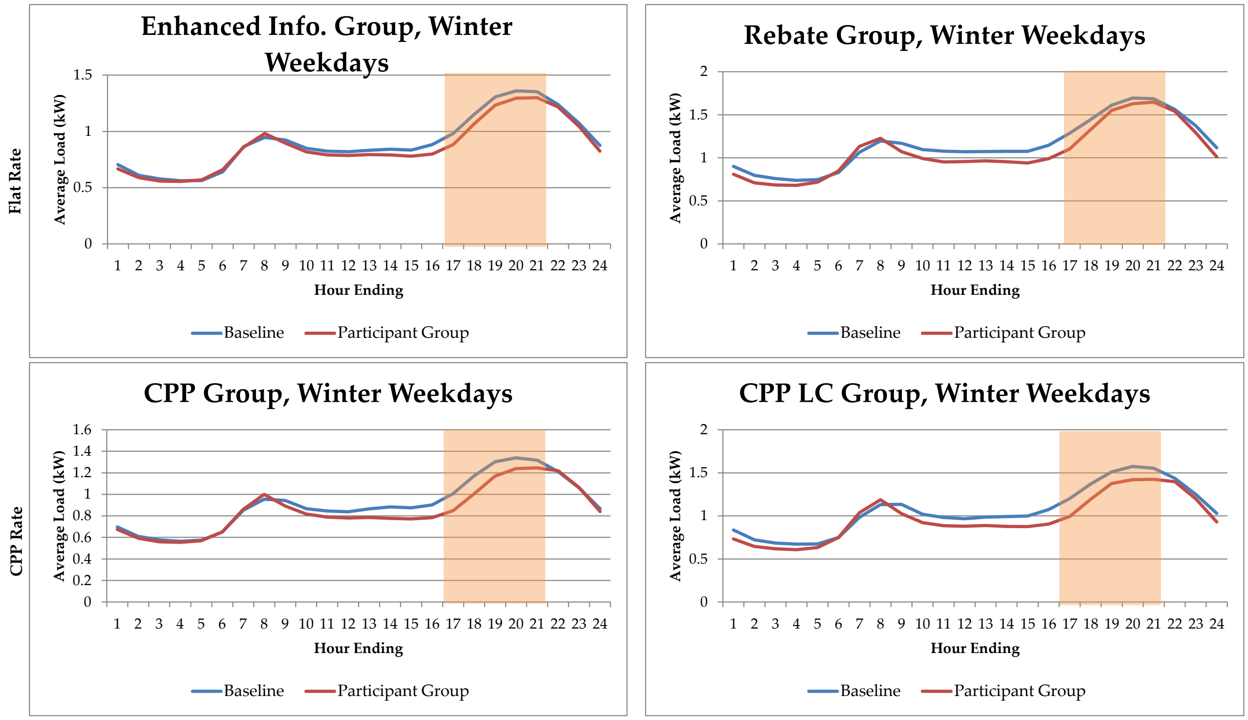
Although the winter peak period is defined as 4-9 p.m., load reductions also occur during the afternoon hours (11 a.m.-4 p.m.) for all groups. This could indicate that pilot participants do not adjust their thermostat settings according to the winter peak period, instead relying on settings tailored to the summer peak period from 12–5 p.m.

Figure 3-2. Average Load Curves and Baselines, Summer Non-Event Weekdays



Source: Navigant analysis

Figure 3-3. Average Load Curves and Baselines, Winter Non-Event Weekdays



Source: Navigant analysis

Navigant also tested for differences in peak load reductions in various demographic subgroups. Results of this analysis are provided in Appendix B.

3.2 *Event Impacts*

NSTAR called seven load control and CPP events during summer 2012 and eight events during summer 2013, for a total of 15 events during the pilot period. The events varied between either three or five hours in length, with the temperature offset varying between 3 and 5 degrees. Table 3-2 summarizes the load control and CPP events.

Table 3-2. Summary of Pilot Load Control and CPP Events

Event Date	Temperature Offset	Temperature (°F)				
		12-1 p.m.	1-2 p.m.	2-3 p.m.	3-4 p.m.	4-5 p.m.
21-Jun-12	3 degrees	90	90	91	92	93
22-Jun-12	3 degrees	90	92	93	92	93
17-Jul-12	3 degrees	92	92	92	94	94
18-Jul-12	3 degrees	85	85	82	78	75
3-Aug-12	3 degrees	-	-	91	92	92
8-Aug-12	5 degrees	82	83	82	83	85
31-Aug-12	5 degrees	-	-	87	88	88
25-Jun-13	5 degrees	87	89	89	90	90
26-Jun-13	3 degrees	79	79	78	78	76
11-Jul-13	3 degrees	75	78	79	80	81
16-Jul-13	3 degrees	-	-	87	87	86
17-Jul-13	5 degrees	85	91	92	92	89
18-Jul-13	3 degrees	86	85	84	83	83
19-Jul-13	3 degrees	-	-	96	96	96
22-Aug-13	5 degrees	-	-	84	81	80

Source: Navigant analysis of National Oceanic and Atmospheric Administration data

3.2.1 Average Event Impact

Event impacts vary widely across groups. Participants with load control (Groups 2 and 3) had the largest reductions—approximately 20-25% of load, or about 0.5 kW. Participants on the TOU/CPP rate without load control (Group 4) realized modest load reductions of nearly 10% (0.13 kW), whereas, participants in the Enhanced Information group (Group 1) produced no discernible load reductions.[14] The results indicate that:

- Automated load control of air conditioners (Group 2) results in more than double the load reductions of customers on a CPP rate (Groups 4) unpaired with load control technology;
- Load control with a CPP rate to encourage additional load reductions (Group 3) provides a modest but discernible increase in load reduction relative to customers with load control only (Group 2).

[14] The average reduction during events across all participants was 9.7% of load, as weighted according to the Group assignments of the 2,717 original participants presented in Table 2-1.

Table 3-3 provides the average load reduction across all events, according to pilot group and event duration/temperature offset.[15] The groups with load control achieved larger load reductions during the three-hour events compared to the five-hour events, and average reductions were larger for events with a 5 degree temperature offset compared to a 3-degree temperature offset.
Figure 3-4 displays the average load reductions with the 90% confidence interval for each group.[16]

Table 3-3. Average Event Load Reduction, by Pilot Group and Event Type

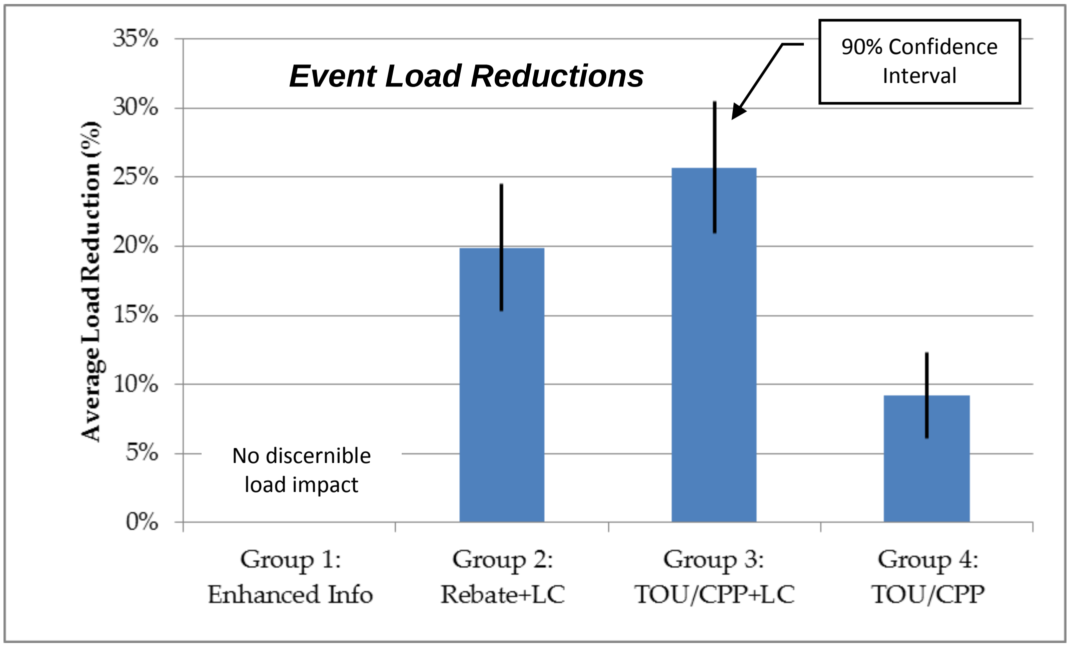
		Average Event Reductions, %				
		All	3hr, 3deg	3hr, 5deg	5hr, 3deg	5hr, 5deg
1	Enhanced Information	No discernible load impact				
2	Peak Time Rebate + LC	20%	22%	26%	19%	21%
3	TOU/CPP + LC	26%	28%	30%	24%	27%
4	TOU/CPP	9%	11%		9%	

Source: Navigant analysis.

[15]Only 1,277 participants had sufficient data to be included in the analysis. Navigant dropped observations where the interval length was less than 45 minutes or more than 75 minutes, since the model was based on hourly data. Accounts were completely excluded from the analysis if they were missing 25% or more of event-day observations.

[16] On average, participants in all groups had higher load on event days compared to non-event days. For the Enhanced Information group (Group 1), the regression analysis was unable to attribute the entirety of the increased load on event days to more extreme weather, resulting in a model estimation of a 5% increase in load as a result of pilot participation. However, this finding is likely because many of the AMR meters currently in use have a relatively low resolution that only registers a change in consumption for each kilowatt-hour that a customer has used. As a result, the hourly load values obtained from the meters and used in the impact analysis are discrete integer values, and many are zeroes for customers with demand of less than one kilowatt. For Group 1 participants, which tend to be low-usage customers with no discernible change in consumption during events (see load shapes below), there are more zero values than for other groups, and there is a significant decline in the number of zero values on hotter event days (when usage is higher) compared to non-event days. This difference in zero values is a likely cause for the model to inadequately control for weather, resulting in the appearance of the pilot increasing customer usage during events.

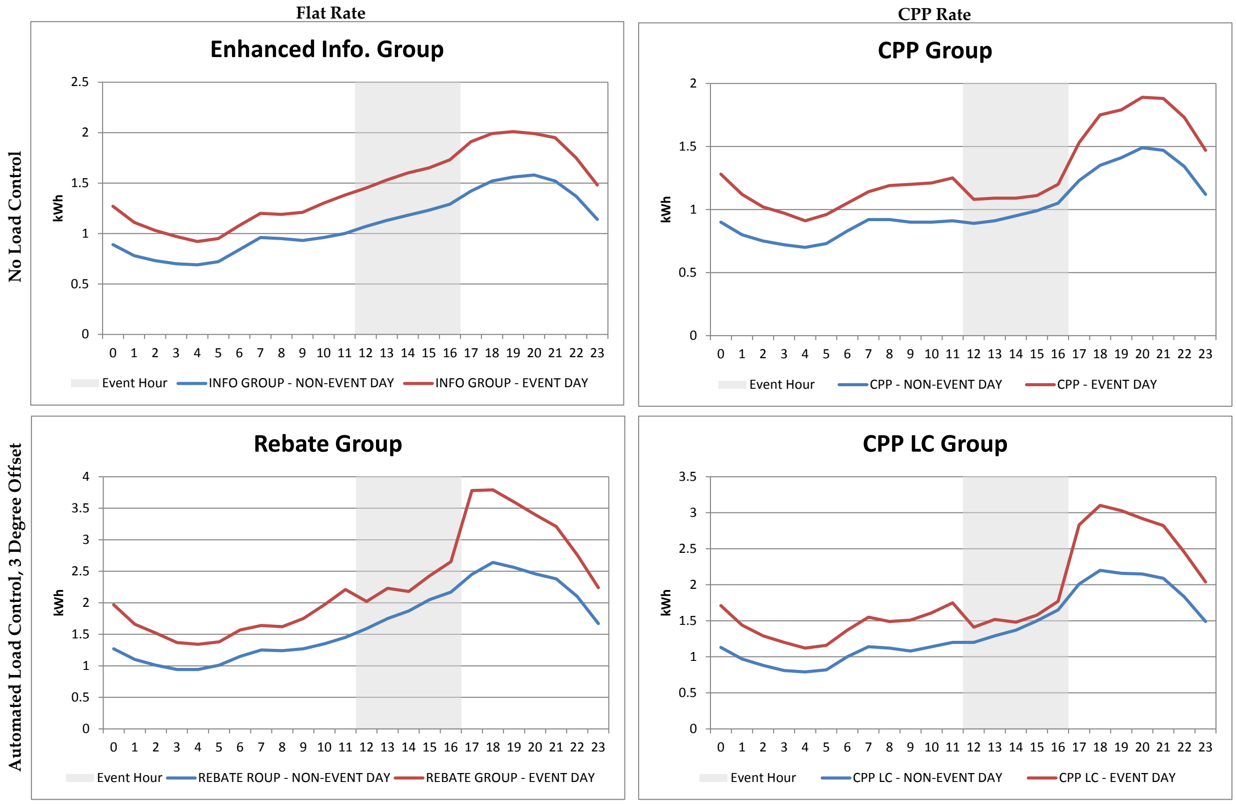
Figure 3-4. Average Load Reductions During Events



Source: Navigant analysis

The event impacts for Groups 2, 3, and 4, as well as the lack of impact for Group 1 are illustrated in Figure 3-5, which displays the average hourly load curves for the five-hour events on event days and the corresponding non-event days. The gray highlighted area indicates event hours; the higher, solid red line indicates the average load for participants on the event days, and the lower blue line indicates the average hourly load on non-event days. The difference between the average non-event day (blue) and average event-day load (red) is the average difference before adjusting for weather. The event days were hotter on average, but Navigant's regression models include parameters to control for the variations in weather conditions and isolate the impact of the event.

Figure 3-5. Average Usage, Five-Hour Events



Source: Navigant analysis

Customers with load control (Groups 2 and 3). The hourly load curves displayed in Figure 3-5 indicate that customers with automated load control demonstrated a sudden drop in their load at the start of the event. Reduced load persisted throughout the event, although the reduction decreased as the event progressed. Snapback occurred immediately after the event period for the customers with automated load control and was larger for the events with a 5 degree offset than for events with a 3 degree offset.

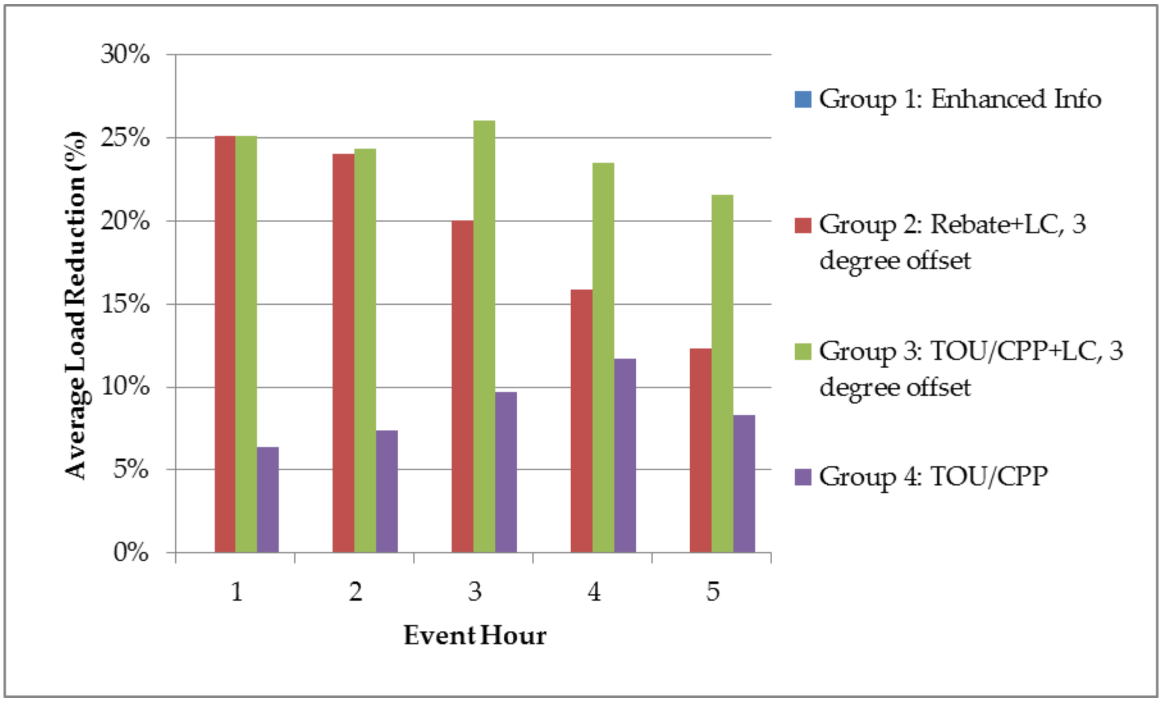
CPP customers (Group 4). Load reductions during events and snapback immediately after also occurred for the CPP group, but were smaller in magnitude than the effects for customers with load control.

Enhanced Information participants (Group 1). Unlike Groups 2 through 4, the Enhanced Information group exhibited no discernible change in load at the start of events or at any time during the events.

3.2.2 Impacts by Event Hour

Estimated load impacts vary slightly by hour of the event, as shown in Figure 3-6, but **most of the hourly impacts are not statistically significantly different from the average event impact at the 90% confidence level.** For participants in the Rebate with Load Control group (Group 2), impacts fade as the event progresses, for all event types. At the time of installation, Tendril technology was not capable of ramping the curtailment, for example, by increasing the thermostat set-point by one degree per hour. Instead, the thermostat set-point was increased at the start of the event and remained constant for the event duration. The result is that load impacts are largest in the first hours of the event and then start to fade as more homes reach the set-point and the air conditioners begin to run. However, for participants in the CPP with Load Control group (Group 3), impacts persist at nearly the same level as in the first hour of the event. This indicates that participants in this group are taking actions to curtail their load during events in addition to the automated temperature offset. For participants in the CPP group (Group 4), impacts increase throughout the event, then taper off slightly in the last event hour.

Figure 3-6. Average Event Reductions by Hour, Five-Hour Events



Results are based on data from 5-hour events with 3-degree offset; Group 1 did not demonstrate a discernible load impact.

Source: Navigant analysis

3.3 *Energy Impacts*

While the previous set of results addressed reduced consumption during peak periods, another major purpose of the pilot program was to encourage energy conservation during all hours through increased information about energy consumption, provided by the in-home display and the web portal. The energy impact analysis described below presents estimated changes in energy usage because of pilot participation.

Navigant found that participants on the TOU rates (Groups 3 and 4) realized energy savings of nearly 2% on average, while the standard rate participants in Groups 1 and 2 saw little change in consumption or an increase in usage (Table 3-4).[17] All of the results have sufficient statistical uncertainty around the estimates to limit generalizations about whether and how much the pilot led to changes in consumption.

Table 3-4. Annual Energy Savings, by Group

Pilot Group		Annual Reduction in Electricity Consumption	
		%	kWh
1	Enhanced Information	-0.3%	-21
2	Peak Time Rebate + LC	-2.5%	-244
3	TOU/CPP + LC	1.7%	157
4	TOU/CPP	1.8%	148

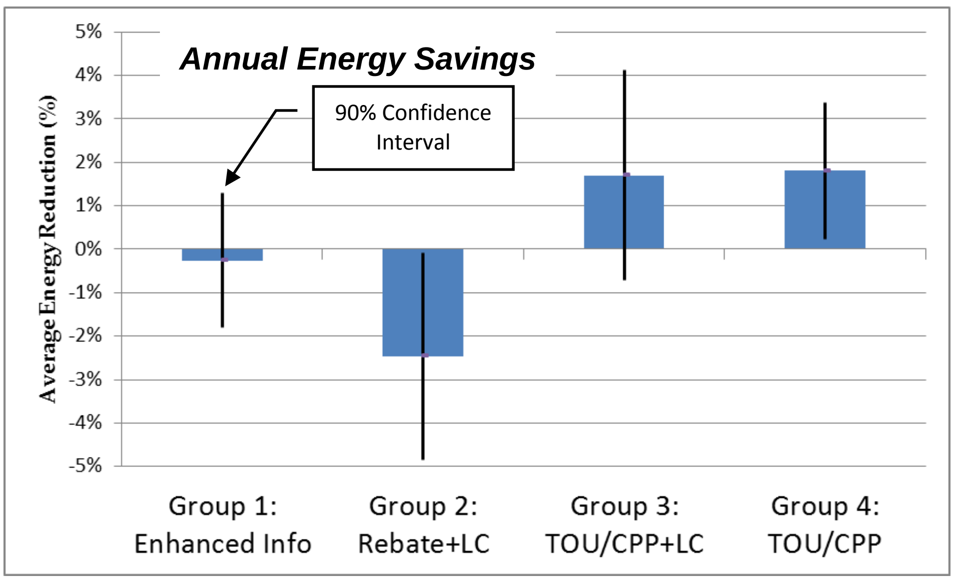
Negative savings imply an increase in consumption.
Source: Navigant analysis

[17] Average annual energy savings across all participants was 0.3% of consumption, as weighted according to the Group assignments of the 2,717 original participants presented in Table 2-1.

Figure 3-7 displays the average energy impacts with the 90% confidence interval for each group. The relatively wide confidence intervals (crossing or coming close to the zero line that implies no change in consumption) is driven by two factors:

- The low number of monthly bills available for analysis. At most, there were only eight summer billing periods and 16 winter periods; and
- The fact that the point estimates of energy savings are relatively small—between 0 and 2.5% savings. This suggests that even a model that can estimate energy savings to within 2% of total consumption will still show an uncertainty band roughly as large as the savings estimate itself.[18]

Figure 3-7. Annual Energy Savings

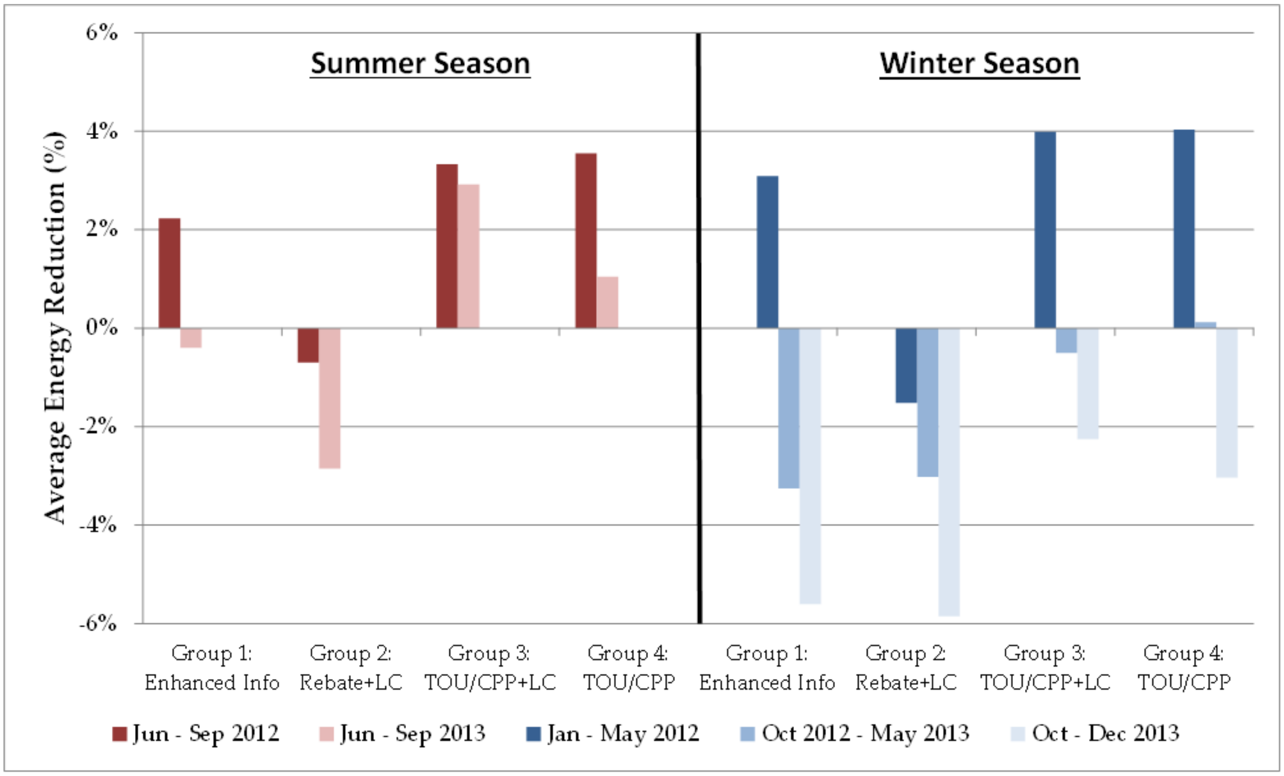


Source: Navigant analysis

[18] Estimation of energy savings from "behavior" programs, such as the Smart Energy Pilot typically utilizes sample sizes in the tens of thousands in order to achieve more precise estimates of impacts.

Energy savings were similar for the summer and winter seasons (see Appendix B for seasonal findings). However, savings declined over time, with significant savings in the first winter (January to May 2012) and summer (June to September 2012), but diminished savings for the remainder of the pilot. The TOU groups (Groups 3 and 4) sustained energy savings in the second summer (albeit at a lower level), but all groups showed greater consumption in the final winter months (October to December 2013) relative to their predicted usage in the absence of the pilot. Figure 3-8 shows the average energy impacts for the two summers and three (portions of) winters of the pilot period.

Figure 3-8. Average Energy Reductions Over the Course of the Pilot



Source: Navigant analysis

3.4 Bill Impacts

Energy reductions and customer rebates from pilot participation hold the opportunity for customers to save on their monthly electricity bills. On average, customers in the TOU groups (Groups 3 and 4) saved the most on their bills, reducing their annual electricity expenditures by more than 4% compared to their expected usage under the standard rate in the absence of the pilot. These bill savings reflect a combination of the customers' roughly 2% reduction in energy consumption (see Section 3.3 above) and their roughly 15% reduction in load during the peak periods when TOU rates are highest (see Section 3.1).[19]These results are averaged across all participants on TOU rates; inevitably, some customers will save more and some less. It is expected that some customers would pay more under TOU rates, particularly those that tend to have high consumption during peak hours and are unable (or unwilling) to shift load off-peak.

Customers in the Enhanced Information group (Group 1) saw little change in their bills (reflecting little change in energy consumption, as discussed in Section 3.3). Bills for Rebate group participants increased by less than 1%, reflecting participants' increase in energy consumption, partially offset by CPP event rebates averaging approximately $30 per year. Table 3-5 presents the bill savings amounts and percentage savings by pilot group, and Figure 3-9 illustrates the relative savings across groups.[20] Bill impacts were similar for the summer and winter seasons (see Appendix B for seasonal findings).

Table 3-5. Seasonal Bill Impacts

Group		Annual Bill Impacts*	
		%	$
1	Enhanced Information	0.3%	$4.51
2	Peak Time Rebate + LC	0.6%	$9.60
3	TOU/CPP + LC	-4.4%	$(67.99)
4	TOU/CPP	-4.1%	$(55.68)

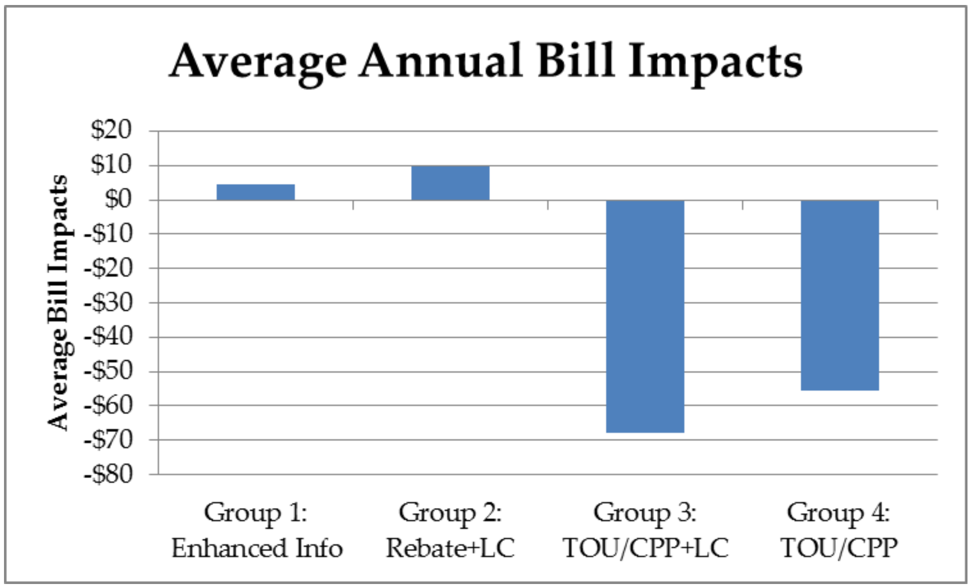
* Negative values indicate decreased bills, corresponding to bill savings.

Source: Navigant analysis

[19] NSTAR designed its TOU/CPP rate such that an average residential customer on the rate would see no change in their annual bills if they continued to consume energy in the same amounts and with the same load shape. The true bill savings from load shifting and energy conservation may be somewhat higher or lower than estimated here because pilot participants' usage prior to the pilot did not necessarily match average customers' usage from the baseline year that was used in setting the bill-neutral rate tiers.

[20] The cost of the program and its possible impact on rates is not reflected in this bill impact analysis. Discrepancies between the energy savings percentage from Section 3.3 above and the bill savings percentage for each group are a result of several factors, including: 1) some customers were excluded from the bill savings analysis due to arrears balances in their billing data; and 2) the fixed component of monthly bills does not vary with energy consumption, which means that—all things equal—a given percentage reduction in consumption yields a slightly lower percentage reduction in bills.

Figure 3-9. Average Bill Impacts by Pilot Group



Negative values indicate decreased bills, corresponding to bill savings
Source: Navigant analysis

3.5 DOE Metrics and Benefits Reporting

In addition to energy and bill savings, NSTAR's Metrics and Benefits Reporting Plan for the DOE identified the possibility of deferred investments in generation capacity and the distribution system. For the reasons described below, the pilot did not lead to any deferred investment, although the technology and rate offering demonstrated the possibility that a future, larger scale rollout could achieve some level of investment deferral if participation and benefit levels were significant enough.

3.5.1 Deferred Generation Investments

At the level of the independent system operation, the New England ISO, generation capacity is required to meet projected system peak demand with a reserve margin. Since peak loads typically last only a few hours and there is a sharp drop-off in peak loads across the top 40 or so hours of the year, any program that can reduce loads significantly for three to five hours for five to ten occurrences per summer can theoretically contribute to deferral of generation capacity.

The Smart Energy Pilot's CPP rates (Groups 3 and 4) and AC load control (Groups 2 and 3) appear able to provide the load reductions necessary to assist in deferral of generation capacity. At the participation levels of the pilot, however, the load reductions are not significant enough to affect ISO planning. Even at full enrollment prior to customer dropouts, the roughly 800 load control participants were able to contribute approximately 400 kW of peak load reduction (at roughly 0.5 kW per participant) and the nearly 900 CPP participants in Group 4 were able to provide 120 kW. Thus, in total, the potential contribution of the pilot to peak load reduction was just ½ megawatt—not enough to be considered on a system that exceeds 25,000 MW in peak demand.

3.5.2 Deferred Distribution Investments

While NSTAR is not responsible for generation planning, the utility must ensure that the distribution system can meet the future requirements for supplying power to customers. As the loads at substations and other distribution system assets reach their limits, NSTAR must invest in system upgrades or manage power flows and demand in order to maintain functioning of the system. There are examples where U.S. utilities have utilized demand response to help manage distribution system assets, most notably Con Edison's Distribution Load Relief Program. In NSTAR's case, however, two limitations prevent the pilot from contributing to deferral of distribution system investments:

1. *The magnitude of the load reductions is too small*—whether the reductions from critical events or the peak period reductions from TOU rates. At less than 1 MW, the impacts are too small to affect NSTAR's capital plans.
2. *Load reductions need to be location specific to address the needs of the distribution system.* Unlike generation planning, distribution system planning requires capacity or load management to be callable at specific locations on the grid, where local contingencies drive investment needs. Thus, reductions from Smart Grid must be concentrated in pockets of need and must have the operational flexibility to meet the specific temporal needs of each asset for which the Smart Grid might help defer investment.

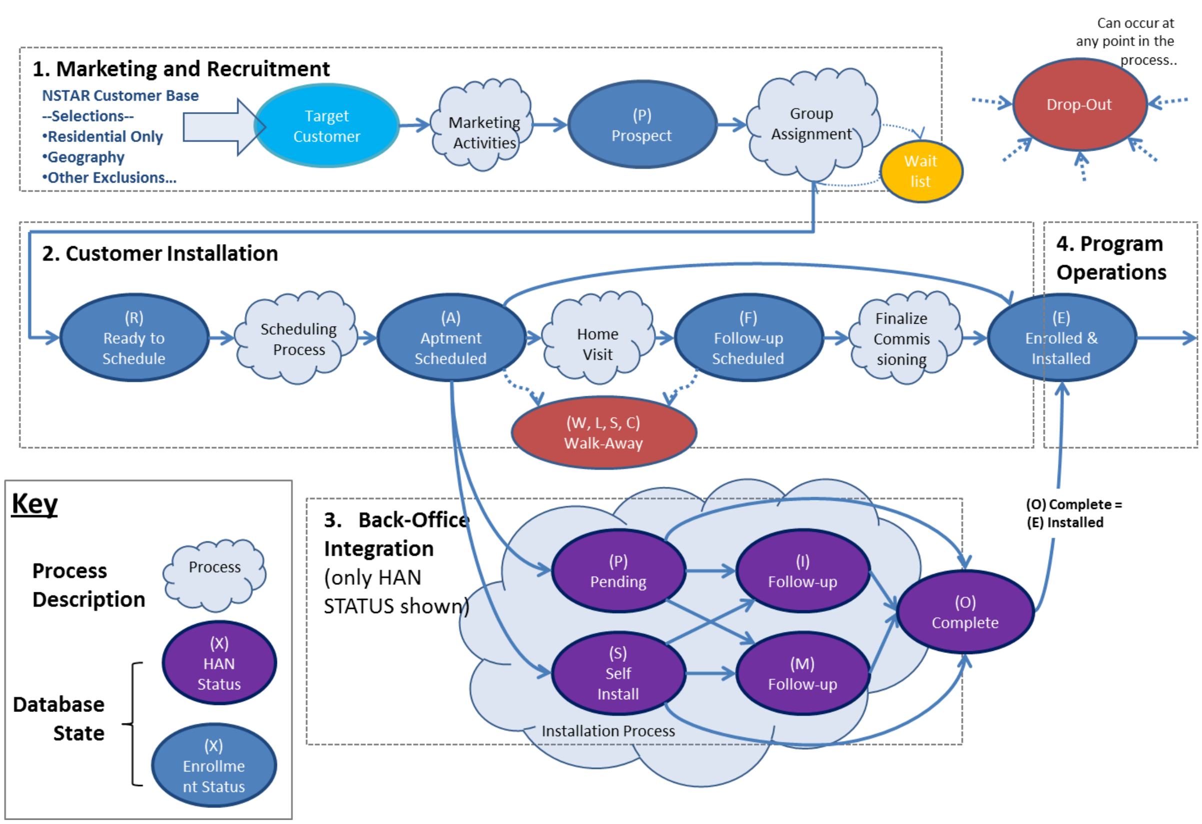
4 Program Processes

The energy savings described in the previous section are the tangible outcome of the pilot's impact on customers' energy consumption. How the pilot design and execution enabled these energy savings is the subject of this section on pilot program processes, which is presented according to four major activities:

1. Marketing and Recruitment
2. Customer Installation
3. Back-Office Integration
4. Program Operations

The first three of these processes were critical for successfully enrolling the required number of customers and getting systems and processes in place. The fourth, Program Operations, represents the program with customers enrolled and participating in program activities, including alternate rates, and technology-enhanced information based on their enrollment group. Figure 4-1 illustrates these program processes.

Figure 4-1. Processes to Ramp-Up Program



Source: Navigant illustration: based on "Tendril Solution Design Specification NSTAR N Files v2 4 4.pdf"

Each of the four major program processes is discussed in the four respective subsections below.

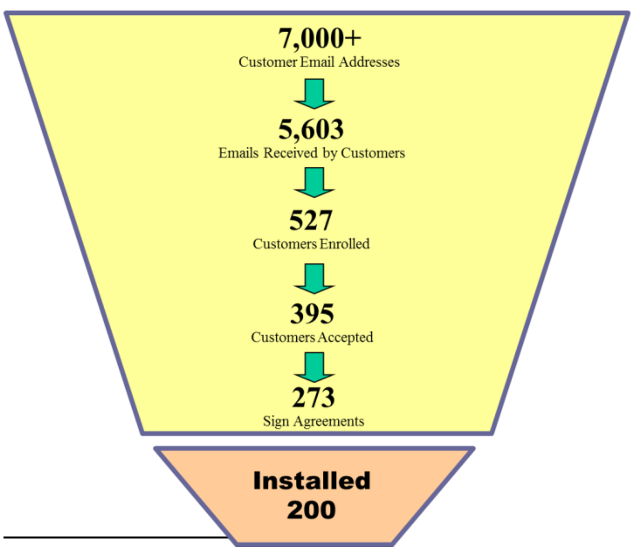
4.1 *Marketing and Recruitment*

NSTAR developed a two-step plan to flush out technology and process issues, gain initial insight, and minimize deployment risk prior to scaling up recruiting and installations for the pilot itself. The first step involved installation at NSTAR employee homes, and the second involved a limited deployment ("Soft Launch" at a small number of customer homes).

» **Employee test installations.** A small number of employees—less than 50— were recruited, and the technology was installed and commissioned at their homes. The installation experience and performance of the system were carefully monitored by the pilot project team and participating employees were interviewed about the experience. The step provided initial insights into the functioning of the technology, the format of the energy information provided by the system, and overall participant experience. One of the key takeaways from the employee test installations was that, due to complexities with self-installations, it was preferable to have a qualified technician install and register the Tendril devices to maximize the installation success rate.

» **"Soft Launch."** With this experience in hand, NSTAR expanded to a limited "Soft Launch" within the customer base to understand the additional complexities that came with actual customer deployment. This process allowed testing of the actual recruiting process, as well as a limited-scale installation and commissioning of equipment. Figure 4-2 details the recruiting process including stages of offer and response, culminating in 200 installations.

Figure 4-2. "Soft Launch" Recruiting Process



Of the emails actually received by customers, almost 10% found the program attractive enough to enroll (527), and 75% of those customers (395) were accepted into the program[21] after the qualification process.[22] Approximately 70% of these accepted customers actually signed the participation agreements (273). Finally, 200 customers eventually had equipment installed. Customers may have dropped off after signing the agreement, after home inspections and qualifications to make sure the equipment could be used within their homes (e.g., for those customers assigned to the rebate group, determination that program thermostats were compatible with their heating, ventilation, and air conditioning [HVAC] system), or due to lack of

[21] Because NSTAR was trying to limit the size of the initial Soft Launch to approximately 250 customers, NSTAR did not initially allow all 527 participants into the program. However, those customers who enrolled but were not initially accepted were put on a waitlist and contacted again once the pilot advanced to full deployment.

[22] Customers were disqualified if they indicated during enrollment that they did not have broadband Internet, that they were moving within six months, or if they were not currently in NSTAR's pilot eligibility database.

response to attempts to schedule the installation appointment. Fifty-one percent of customers accepted into the trial resulted in actual equipment installation.

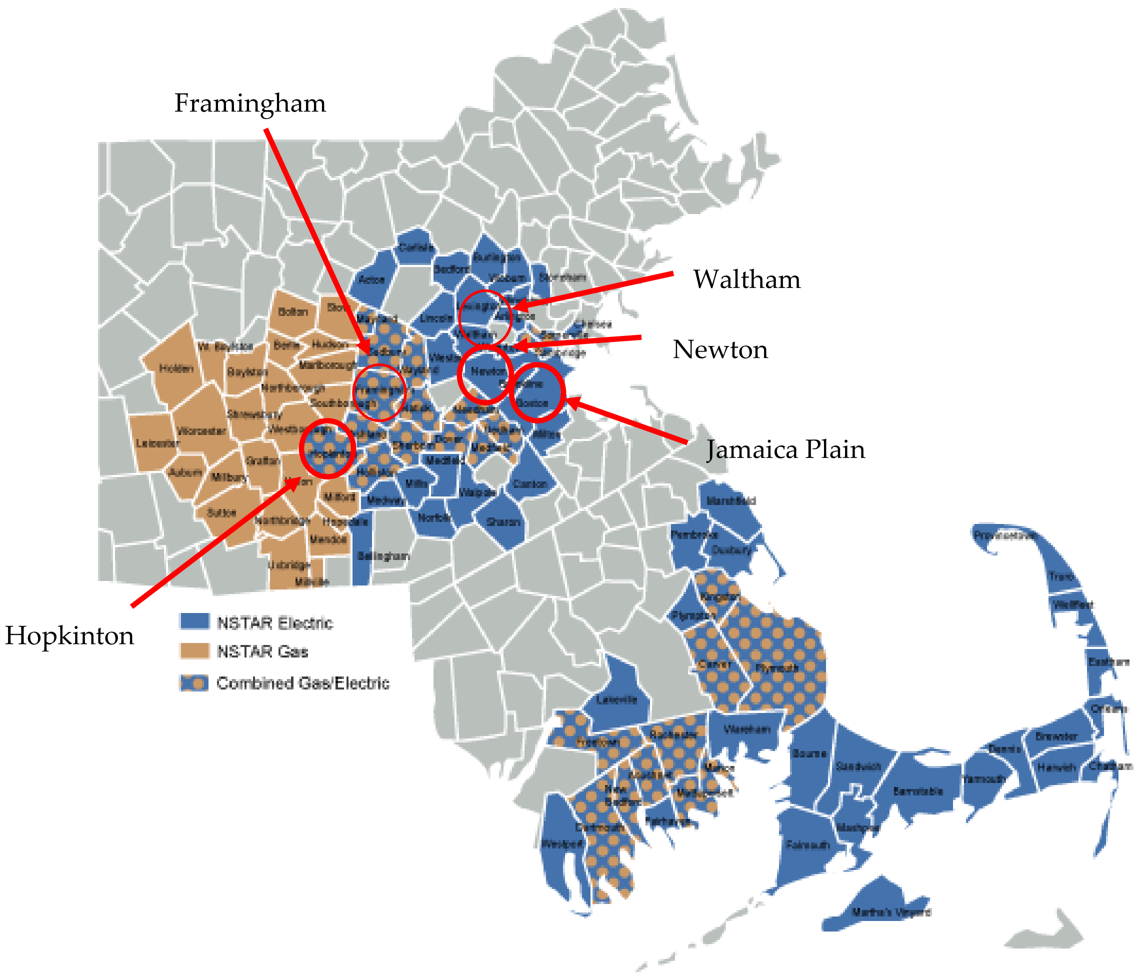
The “Soft Launch” process provided a valuable preview of the issues and challenges involved with rolling out the pilot to scale. One key learning from the Soft Launch was that, given the diversity of HVAC system configurations in the region, Programmable Controllable Thermostats (PCTs) were difficult to install and had a low rate of installation success. The PCT required a certain wiring configuration, which was not always available in a given home and depended on a variety of factors. In order to mitigate the impact of this for the full launch, Tendril and NSTAR introduced a newer generation PCT that allowed the same pilot functionality, but was compatible with a wider range of home wiring configurations, thus increasing the success rate.

NSTAR was also able to make improvements to the enrollment process as a result of the Soft Launch to increase the success rate. Namely, the Company identified process improvements in the enrollment sequence so that customers experienced the shortest delay possible from the time of enrollment to the time of first contact for installation scheduling. In addition, during the Soft Launch NSTAR noted higher than anticipated drop-off in the period between ”enrollment” and ”acceptance.” During the Soft Launch, enrollment was a two-step process: 1) customer enrollment and 2) after acceptance into the program, the customer was required to reply to a second email to complete an acceptance form. In order to improve the success rate for the full launch, NSTAR consolidated this into one step, so that the acceptance form was completed during the initial enrollment process.

4.1.1 Target Geography

The pilot geography initially encompassed three specific communities within NSTAR's service territory, offering high density of broadband connectivity and the ability to reach a diverse set of customer demographics and construction types. These communities, identified in Figure 4-3, included two primarily middle- to upper-middle-income suburban areas (Newton and Hopkinton) and one Boston neighborhood, Jamaica Plain, which has historically been a mixed-income neighborhood and was included with the hope of increasing the diversity of the participant pool and home type. The pilot geography was ultimately expanded to include Waltham and Framingham, in order to meet the pilot's enrollment targets after the initial marketing campaign (see Section 4.1.3, Customer Enrollment below).

Figure 4-3. NSTAR Service Territory and Targeted Communities



4.1.2 Marketing to Customers

NSTAR recruited customers using a variety of channels, including direct mailings, postcards, and several waves of emails to customers in the targeted communities. Recruitment was targeted to help ensure that customers invited to participate were eligible and lived within one of the designated communities. Consequently, mass media, such as radio and television, were not used. Rather, the marketing campaign consisted of direct mail and email to those customers meeting the initial eligibility criteria. Bill messages and inserts were also used, as was local newspaper advertising, where appropriate. The marketing and recruitment material described how the pilot program would help NSTAR to develop a "Smart Grid" that will improve the reliability and lower the cost of electricity supply. A more complete description of NSTAR recruitment efforts is contained in *The NSTAR Smart Energy Pilot Marketing and Recruitment Plan* (Appendix C).

In addressing the customer value proposition, NSTAR emphasized specific benefits, including the following:

- The NSTAR Smart Energy Pilot would put the control in customers' hands, providing them with a home energy management system that delivered information on how they were consuming energy. It could help them make decisions that can add up to real savings.
- The system was a $400 value that customers receive for signing up.
- The system could help customers make a real difference for themselves and their community.
- Participation would also help NSTAR better understand how customers consume energy for years to come.

Examples of direct mail and email recruiting pieces to customers can be found in Appendix C, which details the NSTAR Smart Energy Marketing Plan.

Prior to inviting participation, the Company established the recruitment criteria including demographic, geographic, usage identity, and rate information. One specific requirement was that participants had a functioning broadband Internet connection and that they commit to maintaining broadband service for the duration of the pilot program. The broadband connection is essential for the Company to leverage its existing infrastructure investments in AMR meters to obtain interval meter data.

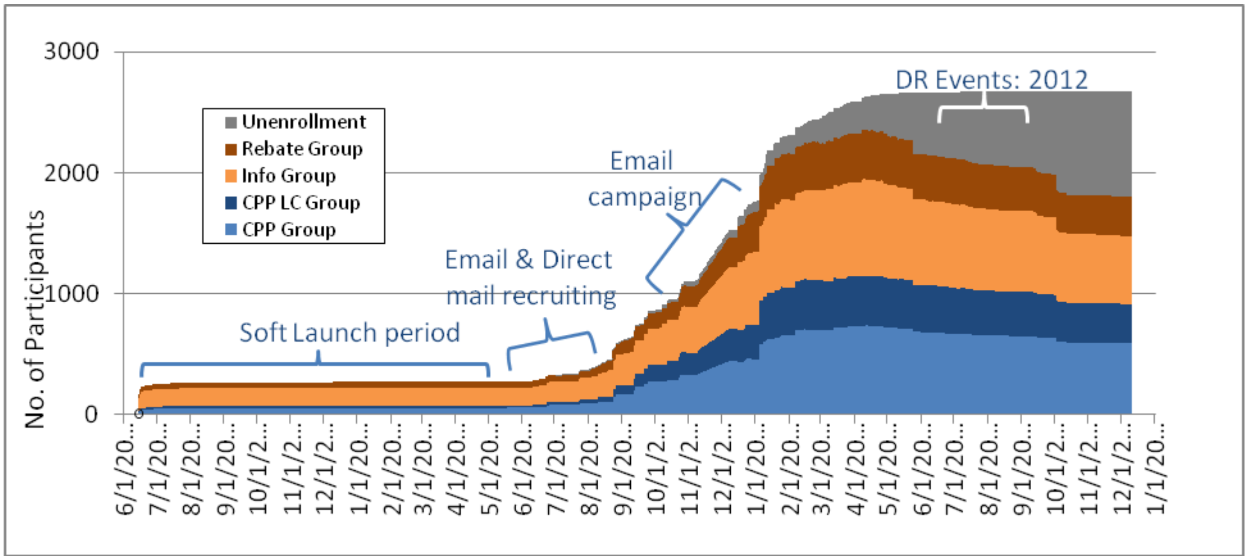
4.1.3 Customer Enrollment

Enrollment rates were relatively high, with response rates to NSTAR's direct mail and email marketing efforts of 4% and 7%, respectively, compared to the 2% to 4% response rates typically seen in Smart Grid program recruitment.[23] However, converting customers from "enrollment" to "installation" was a challenge, as was retaining those customers active in the pilot. Customers were randomly assigned to groups based on a process designed to meet several objectives, such as filling the load control and rebate groups with customers with central air conditioning and offering low-income customers an opportunity to participate in the rebate group. Appendix D provides a detailed overview of the process used to assign interested customers to the four participant groups.

[23] Smart grid marketing response rates are based on market research conducted by Navigant for the NSTAR Smart Grid Pilot Implementation and Marketing Plan, March 2010 (see Appendix C).

The results of NSTAR's program marketing and recruitment efforts can be seen in Figure 4-4, as analyzed using the system enrollment data.

Figure 4-4. Marketing Time Line and Customer Enrollment

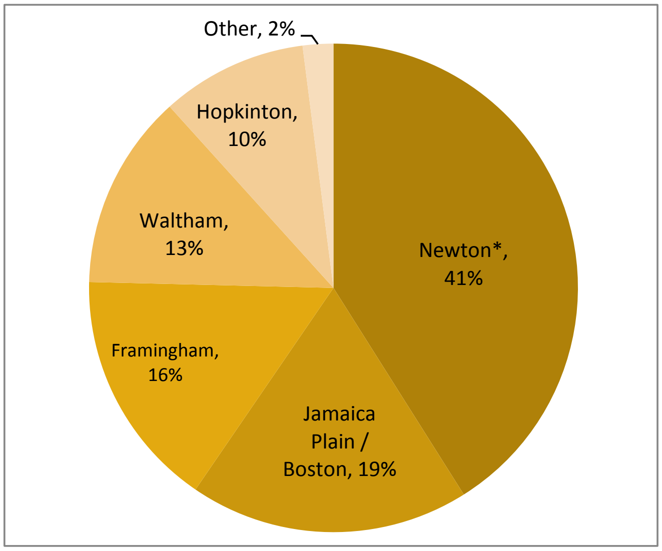


Source: NSTAR data

The different colors show the various treatment groups, and the gray band in the upper right shows program un-enrollments that begin to occur later in 2012. The constant, small number of enrollees in 2010 and much of the first part of 2011 represent participants that started in the "Soft Launch" early enrollment trial in the summer of 2010. The vertical lines overlaying the graph represent different marketing, newsletter and outreach, and demand response events.

Geography of Pilot Participation. Figure 4-5 presents the geographic location of the participants. More than one-third (41%) were located in Newton and surrounding towns; 19% were located in the Jamaica Plain neighborhood of Boston, and the remainder were located in the other suburban areas targeted by the pilot.

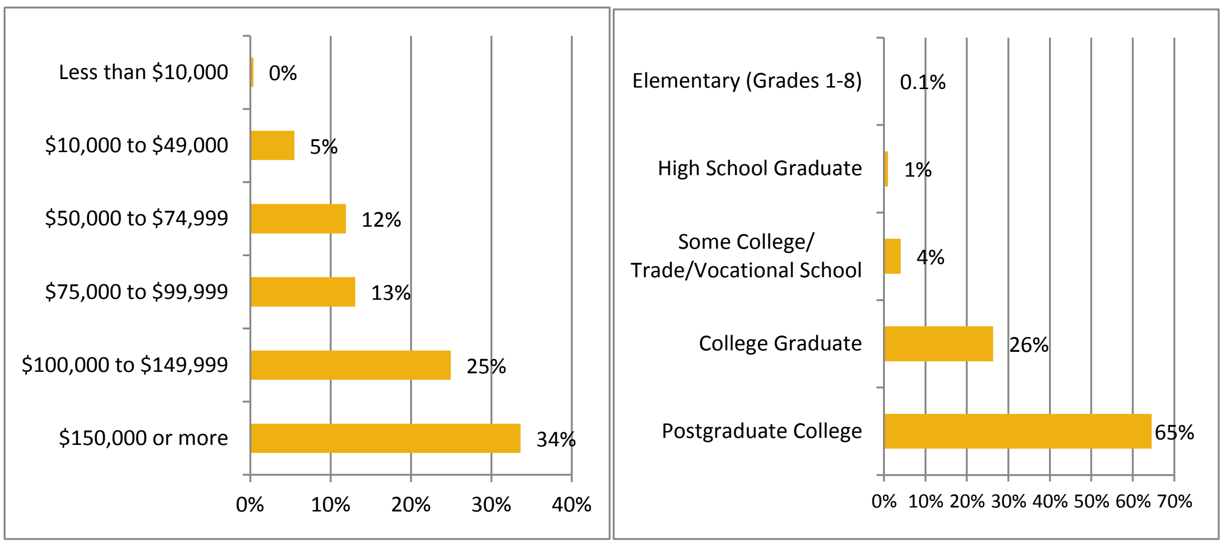
Figure 4-5. Geographic Location of Smart Energy Pilot Participants



Source: Pre-pilot survey, n=2,027.

Income and Education Level of Participants. As demonstrated in Figure 4-6, participants in the pilot tended to have high levels of education and income, with 59% of participants earning more than $100,000 per year, compared to about one-third of utility customers in Massachusetts.[24] Nearly two-thirds of participants had a post-graduate education, and the participant population appears to be technologically savvy, with 43% of participants having three or more computers in the home.

Figure 4-6. Income and Education Levels of Participants



Source: Pre-pilot survey, n=2,027.

Approximately 25% of customers dropped out prior to having equipment installed (mostly due to failure to schedule an appointment) and were never counted in pilot participation figures; and another 30% of those active in the pilot dropped out within a year.

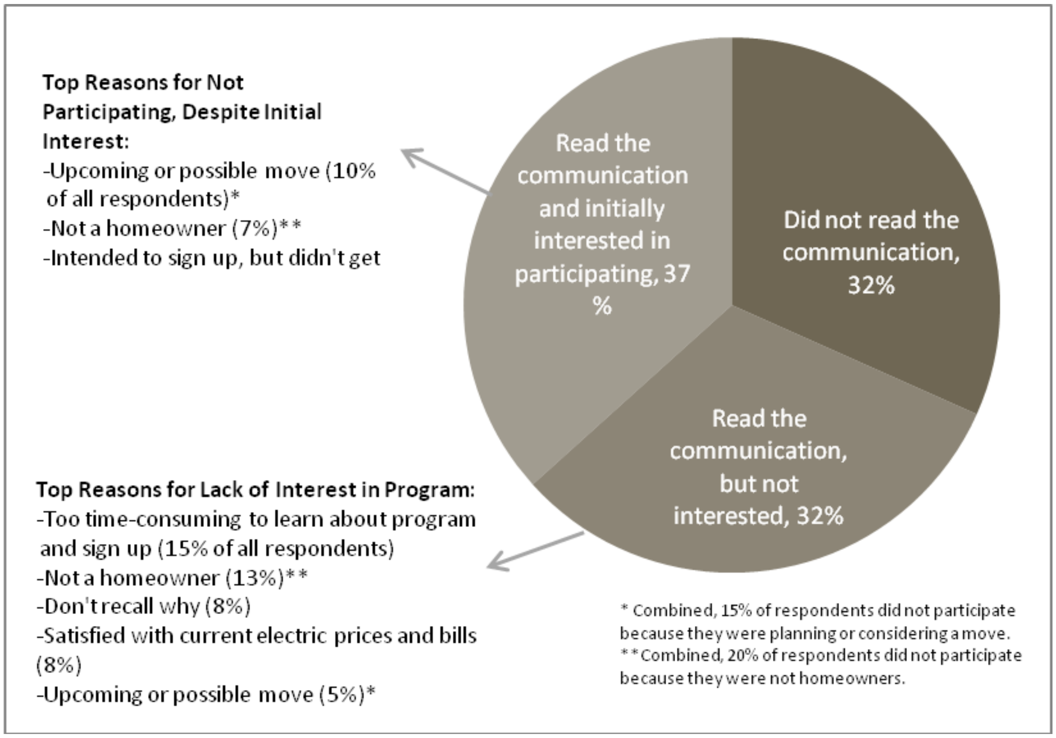
4.1.4 Reasons for Not Participating

Navigant conducted a survey of 213 people who did not respond to solicitation or who declined to participate in the pilot. In this process 153 (or 72%) were not given the whole survey because they did not recall receiving any communication about the pilot. The 60 customers who recalled the communication but declined to participate had a range of reasons for this choice. Sixty-eight percent (68%) of respondents read the communication; however, 29% of those who read it did not recall anything about the program from what they read.[25] Forty-four percent of respondents recalled a message of "Monitoring/smart meter" and 12% recalled "Ability to save money on electric bills." As shown in Figure 4-7 below, the most common reasons for not participating include not being a homeowner, an upcoming or possible move, and a perception that it would take too much time to learn about the program and sign up for it.

[24] Source: Massachusetts Residential Appliance Saturation Survey (RASS), prepared by Opinion Dynamics Corp. for NSTAR and four other Massachusetts utilities, April 2009.

[25] Recipients of the post card were less likely to have read it (53%) compared to direct mail (81%) and email (69%), and there was especially low recall among post card recipients (63% didn't recall anything).

Figure 4-7. Reasons for Declining to Participate



Source: Decline-to-Participate Survey: n=60 respondents who recalled receiving an NSTAR solicitation for the Smart Grid pilot

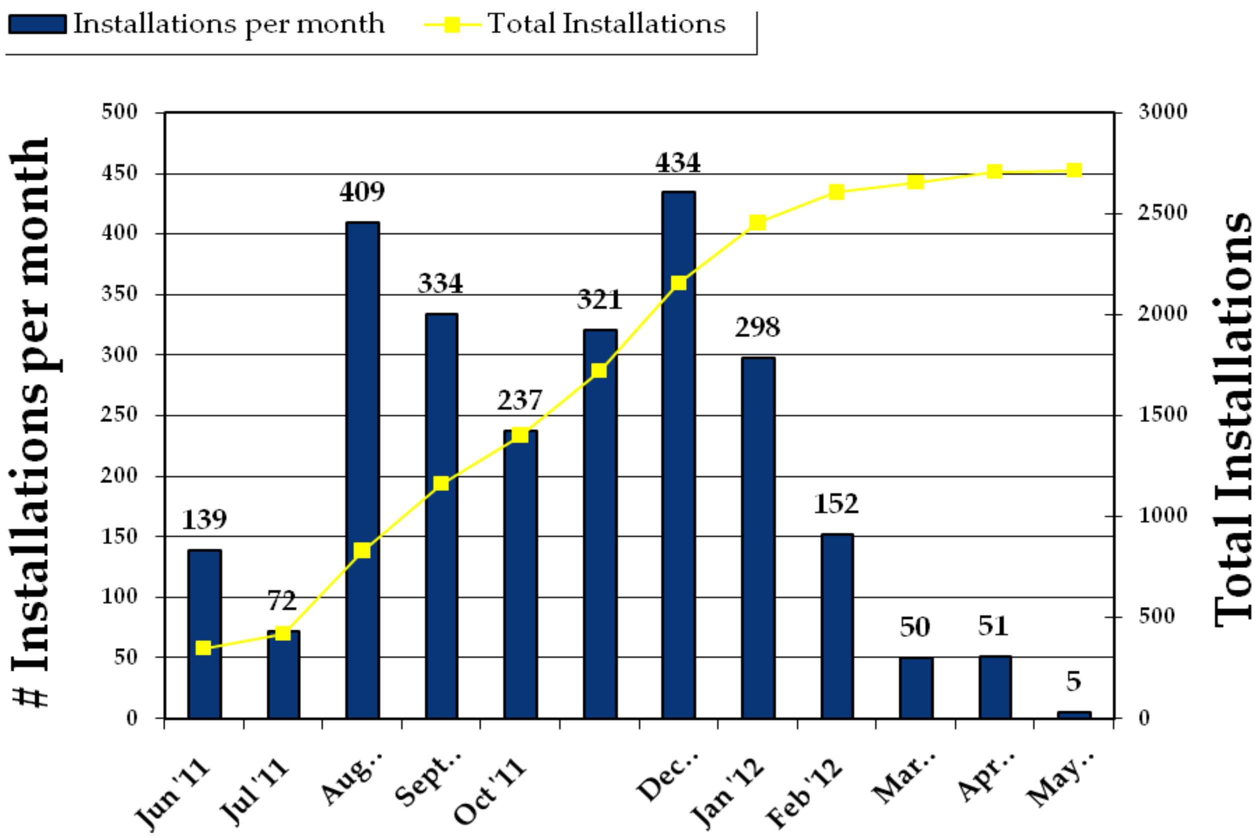
The most common suggestion for improving the program was to open it up to renters (10%), but almost half (46%) of all respondents said there was *nothing* NSTAR could have done to persuade them to sign up.

4.2 *In-Home Equipment Installation*

Once NSTAR had recruited customers to the pilot customers, the Company—through its technology vendor Tendril and a local installation contractor—scheduled and completed installation of the Smart Grid equipment in participant homes. During the installation process, the installer educated customers about the program, use of the equipment, and the actions they could take to reduce consumption in general and during peak periods or critical peak events. The installation technicians also ensured that customers had access to the web portal to view more detailed information and to adjust thermostat settings (for those participants receiving smart thermostats).

The initial installations occurred among the "Soft Launch" participants in 2010. When the full pilot ramp-up was underway in mid- to late 2011, NSTAR was conducting approximately 300 installations per month (Figure 4-8). By May 2012, NSTAR had completed all pilot installations, having outfitted more than 2,700 customers with Smart Grid equipment.

Figure 4-8. Equipment Installations by Month



Source: NSTAR Internal Smart Grid Update Briefing, November 19, 2012

4.2.1 Installation Challenges

A number of issues created delays in the installation process and cancellation of some enrollments. NSTAR and its partners addressed these issues during the course of the installation process, to varying degrees of success. Among the issues were the following:

Installation Processes

» **Delays between enrollment and installation.** In some cases, there was more than a week between a customer's enrollment in the program and scheduling of the installation, resulting in customers losing interest in the program, and causing scheduling difficulties for the installers. To help resolve this issue, NSTAR used smaller marketing "bursts" that allowed a more continuous flow of enrollee names being fed to the installer process, reducing the large installation queue that built up after some of the initial marketing efforts.

» **Inefficient hardware inventory management.** The use of multiple storage sites for the in-home devices resulted in inefficient inventory management for installers. As a result, the installation teams performed multiple inventories of the hardware, which was time consuming and at times inaccurate. To remedy this situation, NSTAR's primary vendor engaged a national installer with a logistics person on-site that scanned all hardware as it entered the facility. A more sophisticated inventory control/management system helped to reduce the occurrence hardware losses.

» **Insufficient installation procedures.** Early in the installation process, Tendril and NSTAR noted instances of HANs being offline after the installation was complete. In some cases, this was due to installers not following instructions on the proper placement and configuration of the HAN in order to maximize the success rate of the installations. To address some of these issues, NSTAR implemented additional installation procedures and installers were retrained to ensure they did not install hardware in locations that hindered communication (e.g., basement locations where radio communications were sometimes difficult). The pilot team learned that, in certain instances, communication was being lost with the HAN because customers were inadvertently unplugging the HAN equipment, causing the devices to lose communication with the Tendril and NSTAR back-office. To correct this, NSTAR placed stickers on the gateway devices to warn customers not to unplug them. These measures resulted in a smoother and more efficient installation process with fewer nonfunctioning systems.

» **Slow online data entry system for installers.** Tendril developed a custom online site to help installers input information in real time into the system during installation. However, the installation vendor found the system slow to load, which delayed the installation process. As a result, installers often entered their information at the end of the day, after they may have forgotten some of the information, or transcribed it incorrectly. This resulted in a high level of missing data from installations. To help remedy this, the NSTAR team redesigned the tool for ease of use, including redeploying the tool in phases so the installers could provide feedback and fix things that they felt were not relevant. In addition, the Tendril devices required firmware updates when first connected. This was an automated process, but was often a time consuming process that frustrated installers and customers who were waiting for the devices to update during the installation period. To remedy this, the project team pre-loaded the firmware updates in an effort to minimize the amount of time needed for this process during installation.

Technology Issues

» **Delayed meter communication with the In-Home Display.** In some cases it took several hours before the in-home displays successfully communicated with the customers' meters. In those cases where it was not practical for the installation technician to wait for that communication link, the customer was educated on the program, including receiving the education materials, but additional follow-up action (via phone or, in some cases, additional visits) was required in some cases to troubleshoot.

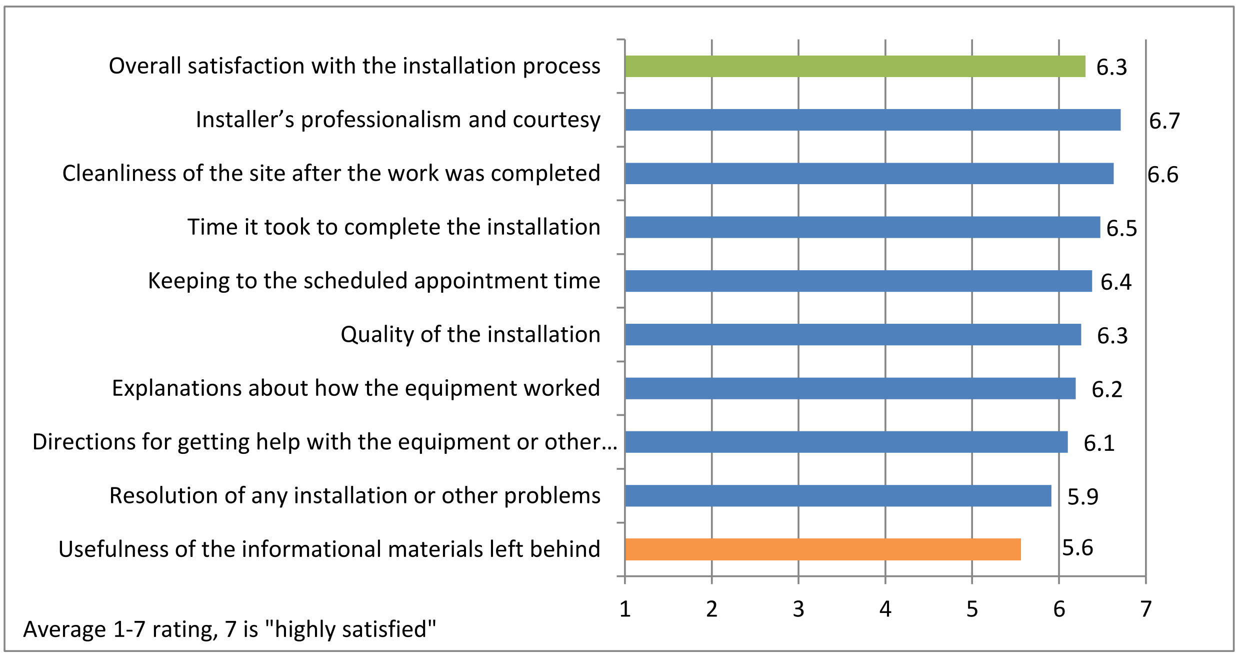
» **Incompatibilities between thermostats and in-home wiring.** During the Soft Launch, NSTAR found a **high number of incompatibilities** between the PCT and the HVAC wiring in many residences. The installation process was modified for those enrollees who were candidates for PCTs so that the initial visit installed and commissioned equipment other than the PCT, and the

HVAC system was assessed for PCT compatibility. If determined to be compatible, a second visit was scheduled to install the PCT.

4.2.2 Participant Views of the Installation Process

Participants were highly satisfied with the overall installation process, with an average rating of 6.3 on a 7-point scale (as shown in Figure 4-9). Satisfaction with the professionalism, cleanliness, and efficiency of the installer is particularly high. The component with the lowest participant satisfaction is the "usefulness of the informational materials left behind," though it still has an overall favorable rating.

Figure 4-9. Participant Satisfaction with Installation Process



Source: Post-installation survey

Thus, despite several challenges in ramping up the installation process, participants were, on average, quite satisfied with their experience. Overall, the enrollment and installation process was successful in getting the targeted number of participants into the pilot.

4.3 Systems Integration and Billing

Two important efforts for making the new technology work included integration with existing NSTAR systems, and appropriate bill calculation and processing.

4.3.1 Integration with Existing Back-End Office Systems

As part of this pilot project, NSTAR had to integrate the AMR meters utilizing the Tendril infrastructure with a number of back-office applications for handling transactions, such as customer enrollments, various customer inquiries related to billing, operation of equipment, and declaration of critical pricing events. NSTAR integrated the AMR/Tendril cloud-based head-end functionality—in some cases this meant merely providing the Tendril system aggregated data--to the following major back-office applications:

- » Customer Information Systems
- » Customer Relationship Management
- » Bill Presentment and Payment
- » Corporate Website
- » Interactive Voice Response
- » A newly developed Smart Grid database application to integrate with the existing billing system and other systems

Significant effort was devoted to end-to-end testing, ensuring availability of accurate and timely meter reads, accurate provisioning of the in-home displays, and customer portal with current and historical data. It was a significant testing effort by NSTAR and Tendril to ensure that customers were billed accurately and on a timely basis, based on the rates established for the Smart Grid pilot. In addition, charges and rebates such as the ones associated with the CPP were tested extensively to ensure they were being calculated properly and presented consistently over the multiple channels available to the customer (i.e., IHD, web portal, and electronic and paper bill). NSTAR also built safeguards into the process and tested extensively to ensure that, in the event of missing or incomplete interval data, the bill would automatically default to bill generation using the otherwise applicable rate and monthly kWh consumption reading as measured by the drive-by metering system.

4.3.2 Bill Calculation, Rendering, and Payment

For customers taking service under the pilot TOU rates, NSTAR calculated the bill using the DPU-approved rates currently in effect at the time of billing and the interval usage data captured by the Tendril in-home technology. Prior to producing a bill, NSTAR's systems compared the total kWh of monthly interval data provided by Tendril to the kWh reading obtained from the drive-by meter reads. If the total consumption of the interval data did not match the total consumption of the drive-by meter reading (outside an acceptable tolerance level; see below), NSTAR produced the bill using the otherwise applicable basic service rate (i.e., if the interval data did not match the drive-by data, NSTAR did not use the interval data for billing but instead billed the customer on the otherwise applicable flat rate).

For most of the pilot, NSTAR billed using the applicable TOU rates whenever the sum of the interval reads was within 2 kWh of the monthly drive-by value; when the discrepancy in the kWh values was more than 2 kWh in a given billing month, NSTAR billed the customer according to the customer's standard rate. In 2013 NSTAR moved to a threshold of 10 kWh per month in order to increase the success rate for billing on the TOU rates. Customers who were actively engaged in the pilot and on the TOU rates often called when they were billed on the flat (rather than the dynamic) rate. By increasing the acceptable tolerance level, NSTAR intended to improve participant satisfaction by using the interval data more frequently.

4.4 Program Operation

Once enrollees had equipment successfully installed, they entered the *operation* phase of the pilot. This was a state where customers had the appropriate equipment for their particular pilot group (e.g., IHDs, PCTs, and gateways) running in their homes; they were on a new rate plan, if applicable; and they had access to their specific energy information via the web portal and IHD. Generally, the program operated as it was intended, and NSTAR made adjustments as needed; however, there were a number of notable challenges faced—and mainly overcome—during operation.

One of the major operational aspects of the pilot was collection of meter data and the billing function, which was discussed in System Integration and Billing above. Other key operations functions included:

1. Customer support services
2. Declaration and initiation of critical peak events
3. Equipment and system maintenance
4. Customer retention

4.4.1 Customer Support Services

Customer Care resources were available to address various customer inquiries related to the operation of customer-facing equipment, billing and payment, and other inquiries**.** These services encompassed a range of activities including operation of a call center, responding to requests to repair malfunctioning equipment, and communicating to participants through targeted mailings and messaging to the in-home displays and web portal. Call center support was provided by both Tendril and NSTAR, depending on the nature of the inquiry. In general, Tendril support was available to respond to equipment- and pilot-related inquiries while NSTAR support was available for billing inquiries.

One of the principal customer issues that arose was the **HAN's going offline.** During program operation, many of the HANs ceased communicating via the Internet. In most cases, this issue was resolved by Tendril instructing customers to power-cycle the ERT bridge "Transport" device (i.e., turning it off and then back on). Initially this was not occurring frequently enough to require a defined process. However, as the pilot progressed and more participants were brought on, this started happening with greater frequency and required a more structured process in order to keep participants engaged and enrolled. Ultimately, the NSTAR support team took over the process of managing the emails to participants, explaining how to get their devices back online. As a result, NSTAR was able to have better visibility into the volume and priority of support cases.

The program's communications and information are one of the primary areas of concern for participants and a common theme among former participants' reasons for dropping out of the program. The most common suggested improvements to the program related to improving communications (mentioned by 18% of participants) and offering better technologies (mentioned by 13% of participants).[26] At 2011 year-end, 69% of participants who recalled receiving any informational materials said that they were

[26] Customer perceptions about the specific technologies (in-home display and web portal) are discussed in Section 5, Technology Assessment.

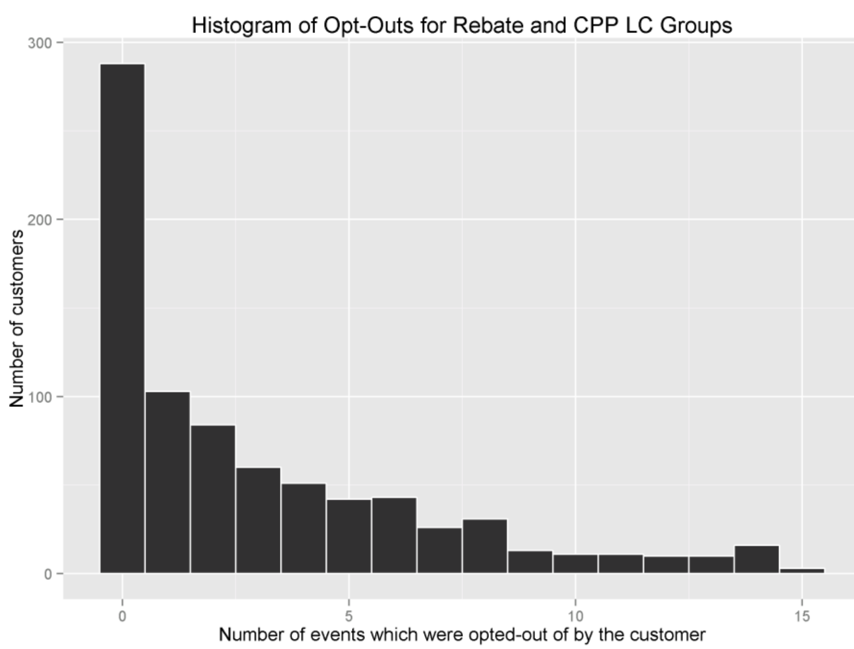
"somewhat helpful." The most common complaint about informational materials was a lack of specifics on how rates would change and the reasons for critical events being called.

4.4.2 Critical Peak Events

NSTAR called seven critical events during summer 2012 and eight events during summer 2013, for a total of 15 events during the pilot period. The events varied between either three hours or five hours in length, with the temperature offset for load control participants varying between three degrees or five degrees. The events were scheduled a day ahead of time, based on weather/temperature forecast and NSTAR's day-ahead load forecast for the next day. Participants in the load control groups (Groups 2 and 3) could opt out using the web portal or via their programmable controllable thermostat.

Nearly two-thirds of participants in the load control groups took advantage of the flexibility to opt out of at least one event, and they opted out of an average of about 2-1/2 events per summer. On a per-event basis, customers opted out of about 15% of the 3-hour events and 23% of the 5-hour events.[27] Many customers opted out of no more than one event per summer, but about one in ten customers opted out of 10 or more events during the course of the pilot, and several opted out of every event (Figure 4-10).

Figure 4-10. Frequency of Event Opt-outs by Participant



Source: Event opt out information reported fromTendfril

The following results are taken from participant surveys that were fielded as part of the Process Evaluation. In post-event surveys fielded immediately after five critical events occurred, nearly all (94%)

[27] Opt-out summary statistics were calculated based on the number of opt-outs and the starting enrollment in Groups 2 and 3. These statistics do not account for the effects of participant attrition.

of participants were aware that an event had occurred, and 84% of those who were aware took energy-saving actions.

Survey Results on Event Notifications. Participants responded that they were notified by both email and the in-home display (49%) or by email only (45%). Nearly all felt that they had received adequate notification of the event (94%). When asked how event notifications could be improved, 78% had no suggestions or felt that the current methods were fine. The most common suggestions for improvement include:

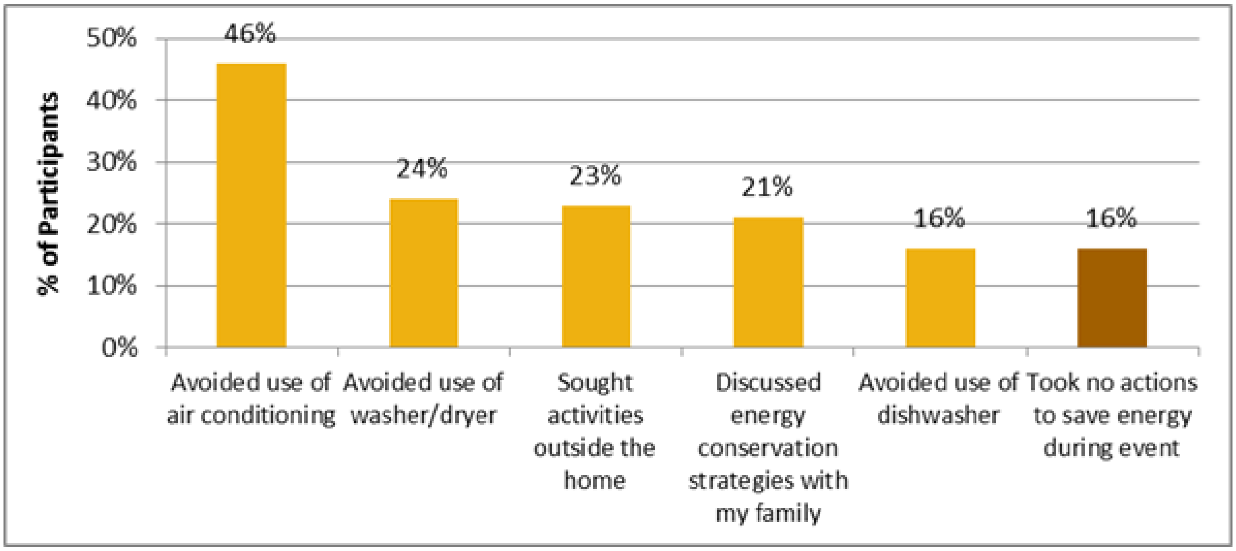
- **Improve email content** (6%): Participants want to see consistent formatting and explicit details on the timing of the event and the rate that they will be charged, and they do not want emails that simply tell them to check their in-home display
- **Provide earlier notification of events** (4%)
- **Improve in-home display/thermostat functionality** (4%): Participants noted problems with accessing messages on the in-home display as well as accepting/acknowledging notifications
- **Send text messages** (3%)
- **Provide better explanation of the need for events** (2%): Several participants wanted to know why events were being called and the typical criteria for event days (e.g., is there a specific temperature threshold that triggers event days?)

Although most participants felt that event notification was adequate, participants were less satisfied with NSTAR's efforts to educate them on how their rates would change during events. In communications, NSTAR did not explicitly state the rate; however, links to the rate tables were included in most newsletters from May-August. In addition, prior to events NSTAR sent an email to participants explaining the price increase and letting them know where in the portal to see the rate they were currently being charged. There was also a link in the portal to the rate table.

In the survey responses, over one-quarter (26%) did *not* feel that they receive adequate education on the rate structure. Many participants on the CPP rate felt that it was much higher than they expected based on NSTAR's communications during the enrollment phase. Suggestions on how to improve customer education about rates focused on transparent comparison between the pilot rates and the standard customer rates, providing the exact rates in email notifications about events, and providing estimates of energy savings from specific actions (e.g., setting their thermostat 3 degrees higher vs. 5 degrees higher). Several participants questioned whether other, non-participating NSTAR customers were paying the same CPP rates, and felt they were being "penalized" for participating in the pilot.

Survey Results on Actions Taken. The most common strategy for reducing electricity consumption during the events was limiting the use of air conditioning: nearly half (46%) of participants increased their thermostat set-point, pre-cooled their home, or turned off their air conditioning altogether during the event. Just 16% of participants said they did not take any actions to save energy during the event, and many of those participants noted that there was no need for them to take action because they were on vacation or at work. Figure 4-11 summarizes the most common actions taken in response to the events.

Figure 4-11. Actions Taken in Response to Critical Peak Events

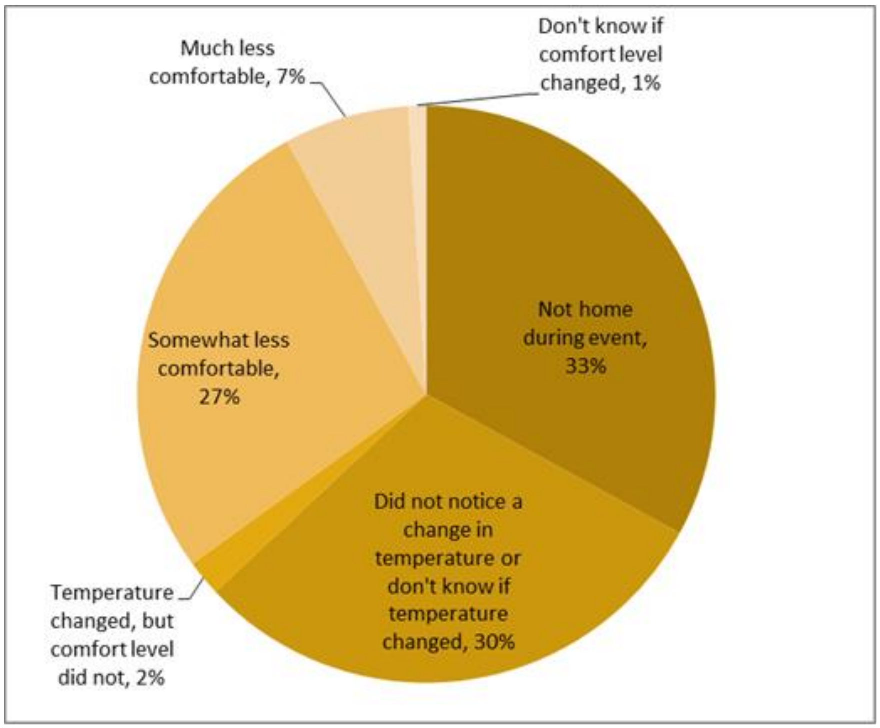


Note: Data are those respondents indicating that they took action in response to critical events. Respondents could indicate more than one action.

Source: Post-event surveys, n = 334

Survey Results on Comfort. Relatively few participants experienced significant discomfort during the critical events. One-third (33%) were not home during the event, and another 30% were home during the event but did not notice a change in temperature. As shown in Figure 4-12, 27% of participants were home during the event and noticed a change in comfort that they considered "somewhat less comfortable" than what they are used to in their homes. Just 7% described the critical event as "much less comfortable."

Figure 4-12. Participants' Perceived Change in Comfort During Critical Events



Source: Post-event surveys, participants who noticed a change in temperature during event only, n=87

4.4.3 Equipment and System Issues and Resolutions

There were several key issues resulting in participant disconnects and/or inability to use some of the HAN equipment. These issues were generally addressed fairly effectively with various process modifications and equipment changes.

Database issues: At various points early in the pilot, the Tendril head-end platform had **database issues**, resulting in outages and unavailability for portal customers. Tendril was able to use a number of database patches and alter the timing of various processes to help resolve some of these issues.

Equipment failure was recognized as a significant issue midway through the pilot. By the end of 2012, 51% of customers indicated equipment stopped working properly at some point in the pilot. As described previously in Section 4.4.1, many of the HANs went "offline," requiring Tendril or NSTAR staff to contact the customer via email to power-cycle equipment off and back on.

Data processing. As part of interval meter data processing, Tendril contracted with an energy management company, Energy ICT (EICT), to do estimation on the raw consumption data that was being pulled from the meters. This process involved "snapping" the time-stamps of the raw data to the 15-minute interval boundaries, and then doing estimation on the data (the Validation, Estimation, and Editing [VEE] process). At various points during operations, secure File Transfer Protocol (SFTP) software stability issues in the head-end caused file transfers to EICT to fail, resulting in meter data to not be correctly processed. Duplicate files were sent to EICT, resulting in apparent meter "spikes," with billing determinant files not transferring or processing. Tendril worked with the SFTP vendor to understand the root causes and developed methods to mitigate this issue, including adding checks to the process to understand if data has stopped flowing. It should be noted that these data spikes were, at worst, a temporary presentation issue on the web portal or in-home display and not a billing issue. As described previously, NSTAR had safeguards in place to ensure that if there was a data integrity issue, that the bill would be calculated using the participants' monthly kWh consumption data collected through NSTAR's typical meter reading process and the participants' otherwise applicable rate.

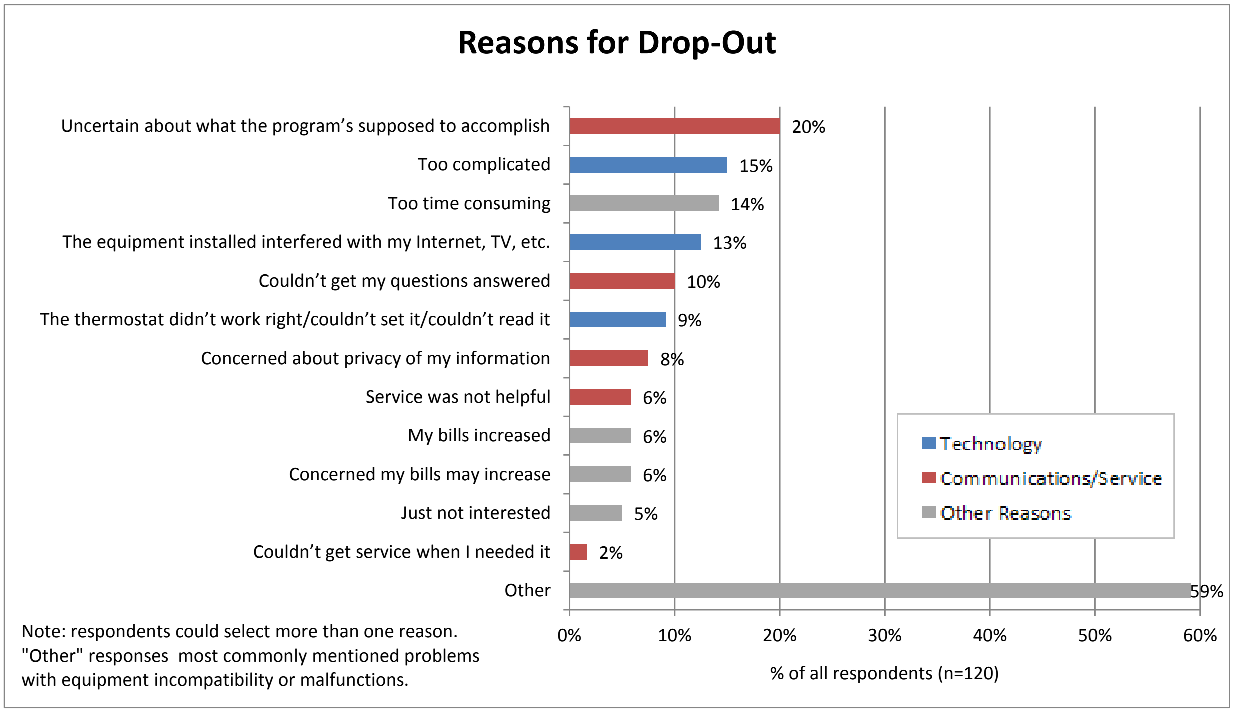
4.4.4 Customer Retention

More than 800 customers or roughly 30% of initial participants had dropped out of the pilot as of December 2012. NSTAR proactively reached out to customers to keep them informed of the pilot benefits and opportunities for savings through various efforts, including sending monthly e-newsletters designed to keep customers engaged, notify them of seasonal rate changes, provide tips and tricks for saving energy, and provide insights for using the pilot equipment.

NSTAR was also responsive to incidents of customer equipment unexpectedly going offline. When communication with the customer equipment could not be established for more than 24 hours, NSTAR sent emails to those customers notifying them of the situation and suggesting that they check for a disconnected gateway or other causes, or that they contact the pilot support team to obtain help identifying and remedying the problem. In many cases the customer self-diagnosed and corrected the issue, or they received the necessary support from NSTAR and came back online. In other cases, NSTAR could not reach the customer; after this non-communication (neither via email, phone, nor the gateway), NSTAR removed the customer from the pilot.

Despite NSTAR's efforts, the survey findings indicate that improved communication, particularly about the purpose of the pilot and its expected benefits, may be worthwhile. The most commonly cited reason for dropping out of the program was that participants were "uncertain what the program was supposed to accomplish." Former participants also cited a number of other communications, service, and technology-related reasons for dropping out of the program, as shown in Figure 4-13.

Figure 4-13. Customer Reasons for Dropout



Source: Dropout survey

5 Technology Assessment

The Technology Assessment reviewed the functionality and effectiveness of the customer-facing elements, and analyzed the pilot architecture performance as an integrated system. **Customer-facing technologies** include the web portal, in-home displays, and smart thermostats, but other equipment was also installed in participants' homes such as communication gateways and ERT bridges to form the complete home area network (HAN). Examination of the customer-facing elements leveraged customer feedback obtained through a series of surveys conducted throughout the pilot period. This information provided customer perspectives on the perceived usefulness and value of these elements.

Examination of the **integrated system performance** was primarily performed using data provided by the Smart Grid technology itself. This review examined system communication success and failure rates, AMR/ERT meter data collection completeness, processing of meter reads, and use of pilot-generated meter data for successful customer billing.

The assessment addressed the following areas:

1. Customer-facing technology
2. System infrastructure
3. Effective functionality of the AMR/HAN/broadband architecture

5.1 Customer-Facing Technology

The customer-facing technology—those elements which actually engaged customers and provided information or interaction—constitute an essential and highly visible component of the pilot technology architecture. Evaluation and assessment of the customer-facing technology includes the following types of equipment installed in a participant's home:

1. Web portal
2. In-home display
3. PCT

5.1.1 Web Portal

The web portal was provided by the Tendril cloud-based platform, and was accessed by the participant using a computer connected to the Internet via the participant's broadband Internet connection. Relevant information from the customer's meter and other in-home equipment, as well as information from NSTAR back-office systems, was collected by the cloud-based head-end platform, and provided to the participant via this path.

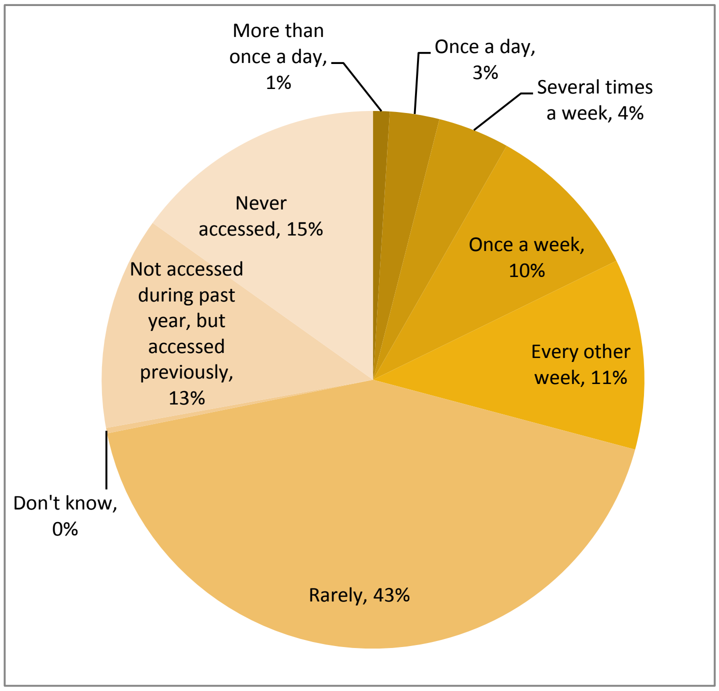
A computer was used to set up and commission HAN devices during installation, and then to view meter readings and other information that was being collected during the operational phase. The user could log onto the web portal interface and access different types of information, including interval data from a past day, current energy usage (updated every 15 minutes as long as information was being transmitted), current electricity price, and projected end-of-month bill. The participant was also able to receive some helpful energy-saving tips based on their usage patterns and other information (Figure 5-1).

Figure 5-1. Web Portal Interface

Source: NSTAR

The web portal was used infrequently by most participants, though most believe it to be useful and would sign up for a similar service if offered again. Most participants accessed the web portal at least once during the pilot (85%), and almost three-quarters (72%) accessed it at least once within the final year of the pilot. Many participants reported accessing the portal more frequently during the first few months of the pilot than they did in the last year (44% of all participants).[28] By the end of the pilot, almost half (43%) reported accessing the portal "rarely", as shown in Figure 5-2. There were no statistically significant differences in frequency of web portal use between the different pilot test groups.

Figure 5-2. Frequency of Using Web Portal in Past Two Years



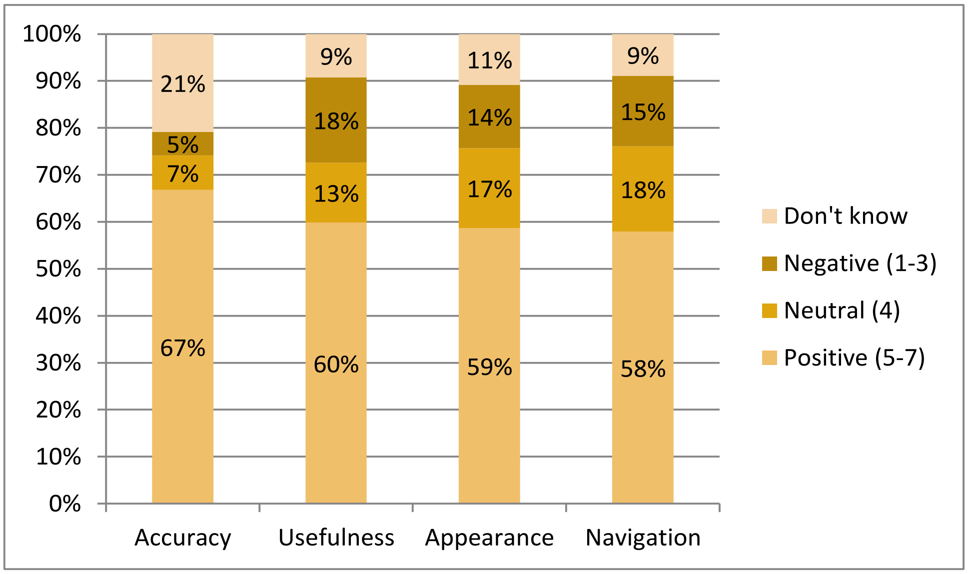
Source: Post-pilot survey of participants, n = 305

There was a small percentage of participants (about 18%) that found the portal useful enough to continue to visit it once per week or more. These participants might be called an *enthusiasts* group, and evidently found value in the information provided on the portal. A much larger group, however (slightly over 70%) used the portal rarely to never, indicating that there was not enough value in it for them to frequent the site. To reach this group with future offerings, it is likely that more compelling site content or engagement would be required.

[28] Comparison of various survey results between the midpoint survey and the post-pilot survey confirm that web portal use declined over the course of the pilot. In the midpoint survey, 19% of all participants used the web portal daily or several times per week, compared to 8% of participants in the post-pilot survey.

Figure 5-3 shows participant reactions to several aspects of the web portal. Web portal users most often rate the data accuracy positively (67% positive); the most negative ratings were for data usefulness (18% negative).

Figure 5-3. Participant Ratings of Web Portal Characteristics



Source: Post-pilot survey of participants, portal users only, n = 259

More than three-quarters (83%) of all participants would sign up for a similar web portal if it were offered again at no cost. Participants in the CPP (88%), Rebate (85%), and CPP-LC (83%) groups were more interested in a future portal offering, relative to the Info group (76%). So, despite infrequent usage, interest in having this functionality remained high, indicating that a future web portal offering might be well received.

5.1.2 In-Home Display

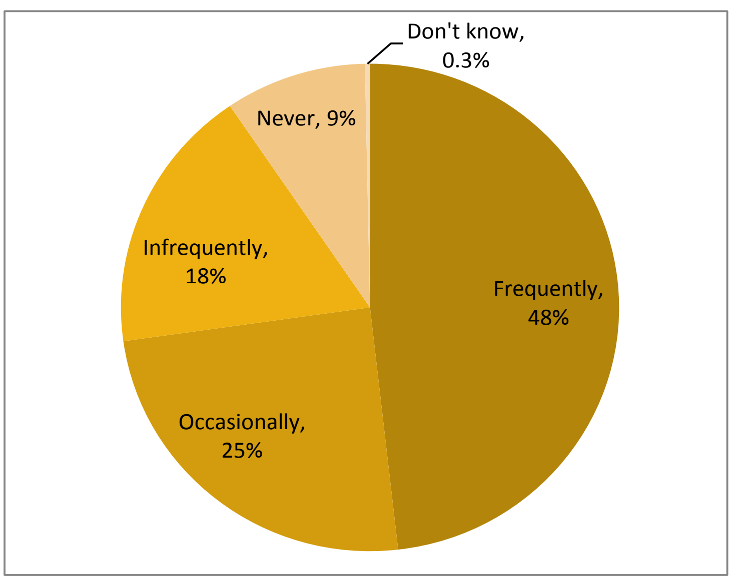
The IHD received a subset of information available on the portal, owing to the smaller screen real-estate available on this device and the functionality offered in the device, but it was designed to be an easily accessible means of conveying key program and consumption information to participants. The IHD was approximately 4 inch by 6 inch by 1 inch device with a small LCD black and white screen, as shown in Figure 5-4. The device was powered from a wall outlet, and connected via the ZigBee wireless HAN connectivity to the Internet gateway.

The participant could access several different screens of information using buttons on the front of the device to move from current price information to end of monthly projected bill based on recent usage.

Figure 5-4. In-Home Display-Different Screen Displays

Nearly half (48%) of participants reported using their in-home display "frequently" and another 25% used it "occasionally", as shown in Figure 5-5; participants reported very similar usage frequency in the midpoint survey, indicating that in-home display use has remained fairly consistent over the duration of the pilot.

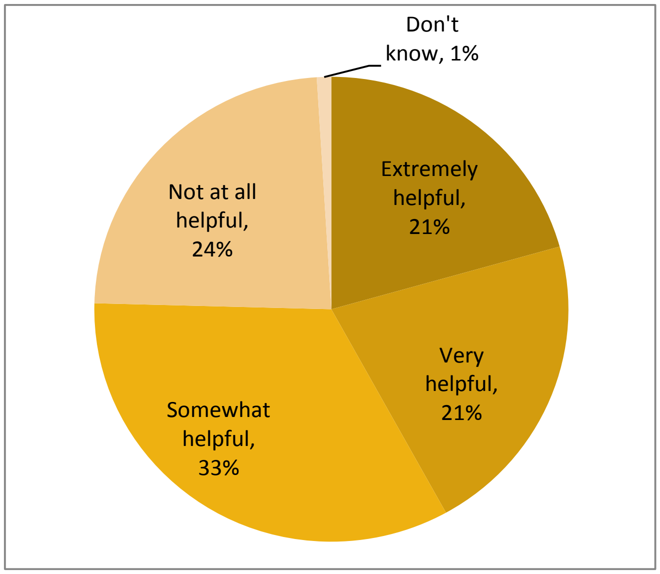
Figure 5-5. Frequency of Using In-Home Display



Source: Post-pilot survey of participants, n = 305

Participants generally thought the in-home display was useful; 42% of participants describe the in-home display as "extremely helpful" or "very helpful" in making decisions about electricity usage. There are no statistically significant differences among treatment groups for this metric.

Figure 5-6. Usefulness of In-Home Display in Making Decisions About Electricity Usage



Source: Post-pilot survey of participants, n = 305

The most common reason for not using the in-home display more frequently was unreliable Internet access or no Internet access at all, cited by 20% of participants; 9% prefer to look at the information on the web portal and another 9% would have preferred a mobile app option. It should be noted that since the initial pilot design and deployment, Tendril had ceased production of an IHD in favor of a more user-friendly mobile app.

The IHD provided more consistent access to the key elements of information for a larger percentage of participants, and use did not decline, as with the portal. As such, the IHD seems to have been a more effective mode of communication to many participants than the portal. It may be that the ease of accessing this key information on the IHD is one reason that portal usage dropped off (although we cannot say for sure), as users were able to get the information they valued from the IHD.

5.1.3 Programmable Communicating Thermostat

As with the IHD, the PCT communicated via ZigBee wireless signal to the gateway, receiving information via the cloud-based head-end platform. The PCT (shown in Figure 5-7) was a principal means to control and manage household energy use over the course of the pilot, and was also essential for NSTAR's execution of automated load control during CPP events.

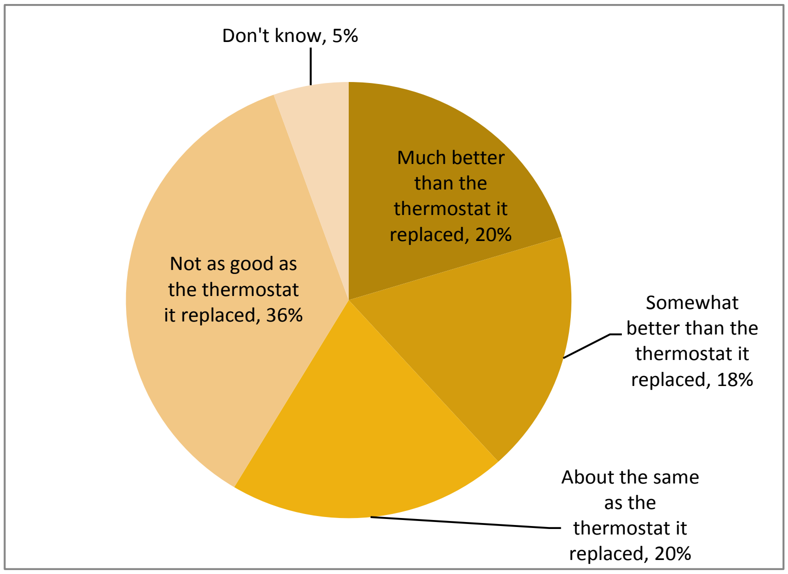
Figure 5-7. Programmable Communicating Thermostat

As mentioned in the Program Process section above, some of the equipment installations were difficult due to thermostat incompatibility with HVAC wiring. In addition, some customers found the thermostats complex to use and had some characteristics that caused participants to report errors in certain circumstances. For example, the thermostats flashed a red light-emitting diode (LED) when they lost connectivity with the HAN and the Internet. Some customers complained about this, and NSTAR addressed the issue by replacing some of the thermostats. NSTAR anticipated that the blinking light on the older-model thermostats would cause many complaints once the HAN was shut off at the end of the pilot. Consequently, NSTAR proactively removed thermostats to help ensure that these customers did not end the pilot with a negative experience.

In addition, partway through the Pilot, a newer thermostat model became available from Tendril and NSTAR began installing this new model instead of the original model. The new model was thought to be simpler to use and was flexible enough to be installed with more home wiring configurations than the original thermostat.

Participant opinions on the thermostat were mixed. Over one-third (36%) of thermostat recipients believe that the pilot thermostat was not as good as the one it replaced, often citing difficulty of use, as indicated in Figure 5-8.

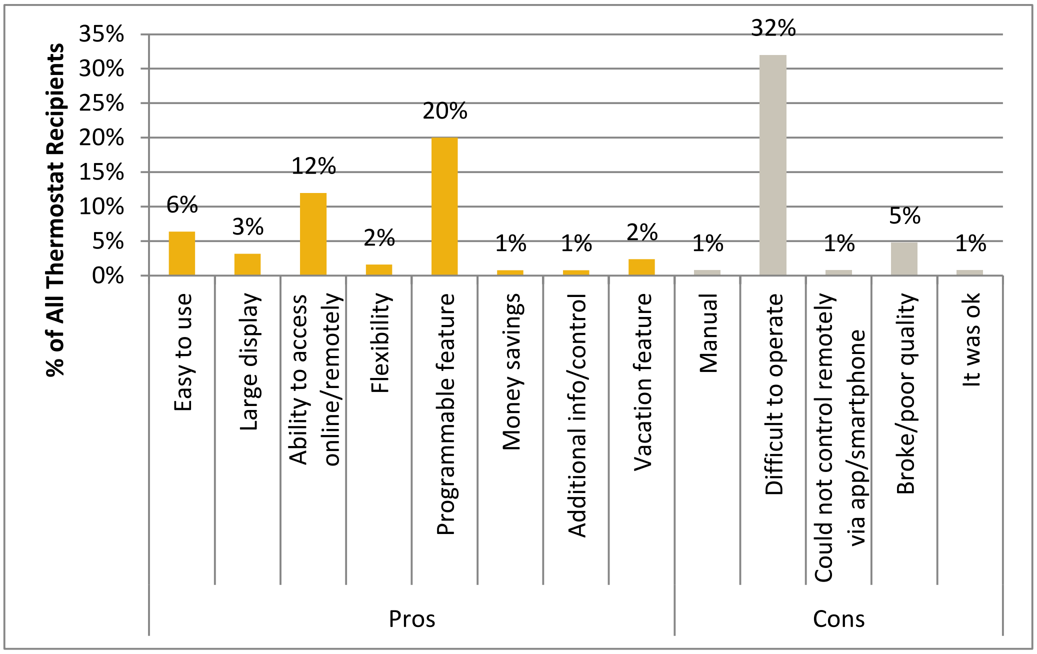
Figure 5-8. Opinions on Pilot Thermostat Relative to Old Thermostat



Source: Post-pilot survey of participants, thermostat recipients only, n = 128

Thermostat recipients who felt that the pilot thermostat was better than their old thermostat most often liked the programmable feature (20% of all thermostat recipients), and 12% liked the ability to access it remotely using the web interface (Figure 5-9).

Figure 5-9. Pros and Cons of the Pilot Thermostat



Source: Post-pilot survey of participants, thermostat recipients only, n = 128

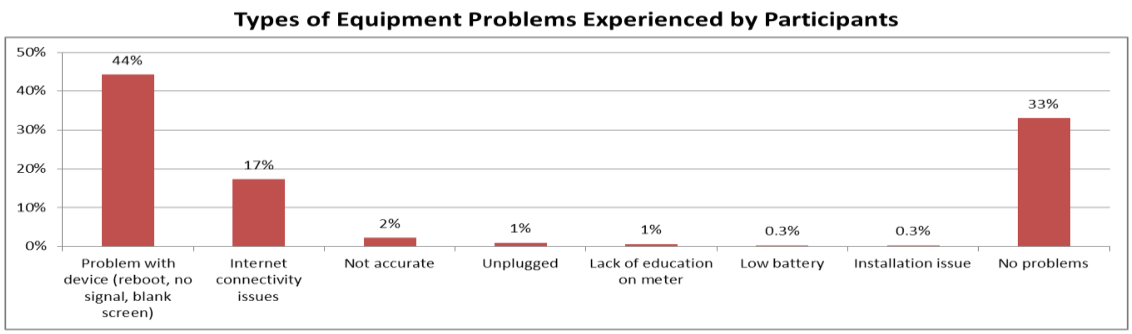
The PCT was a critical piece of technology for actively managing load and energy, and at the same time one of the most complex and expensive to install and also for the participants to operate.

5.1.4 Customer Perspectives on Equipment Performance

Participants responded to midpoint survey questions on the overall impression of the HAN equipment, including the customer-facing elements above but also the other elements including HAN Gateway and the ERT bridge.

One-third of customers responding to a midpoint survey reported no equipment problems. This leaves more than half having experienced some type of equipment problem, with most of these being an apparent problem with the device itself (e.g., need to reboot or blank screen). About one in six customers reported Internet connectivity issues that resulted in nonfunctioning equipment (Figure 5-10).

Figure 5-10. Types of Equipment Problems Experienced by Participants



Source: Navigant survey of pilot participants, n=305.

- Most participants were satisfied with customer service’s resolution of the issue (average of 5.7 on a 7 point satisfaction scale).
- No statistically significant differences among participant groups for these questions.

Addressing device quality issues as well as finding ways to mitigate issues caused by intermittent connectivity losses will be important issues for future programs.

5.2 System Infrastructure

Many pieces of system infrastructure were leveraged to get meter data, event signals, and other information to and from the customer-facing equipment. An overview of this system infrastructure is provided in Section 4.2 above. Some key findings that help provide insights into pilot system operation are presented below, addressing the following topics:

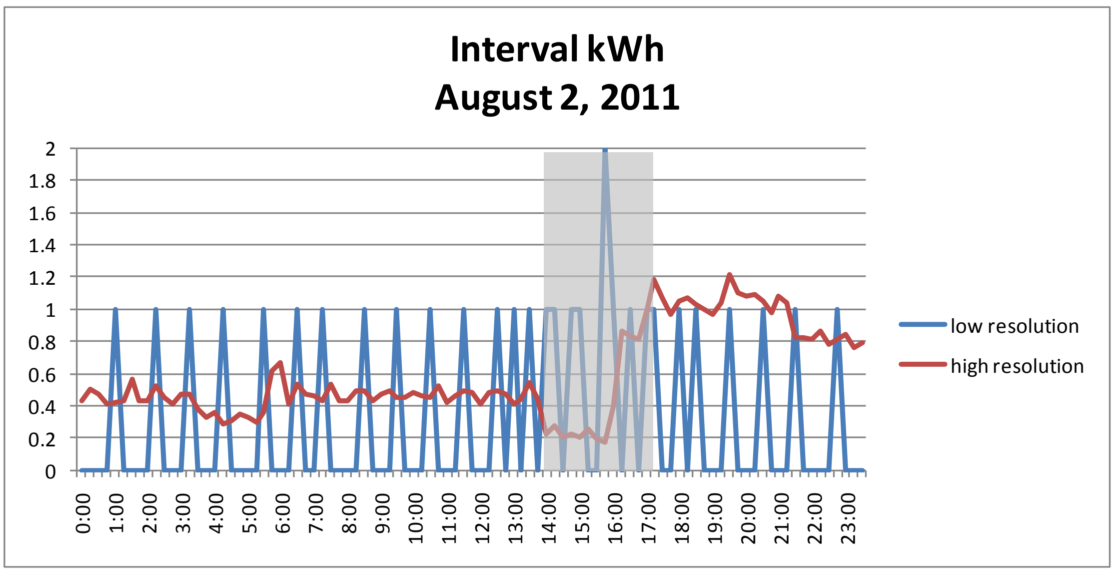
1. AMR meter data resolution
2. Meter data processing
3. Meter data quality as an indicator of system performance
4. Data use in billing analysis
5. Equipment response to events

5.2.1 AMR Meter Data Resolution

The interval consumption data generated by the system provides a number of insights into system operation and issues that occur during operation. The raw interval consumption data collected by the system was available for analysis. One interesting observation in the interval data is that two different types of meters were used in this service area, each with different kWh resolution capabilities.

The high (10 watt-hour) resolution meters tend to show steadily varying consumption as electrical loads switch on and off in the home. The lower (1,000 watt-hour, or 1 kWh) resolution meters, however, do not register increases in consumption until each time the home has used an incremental 1 kWh of electricity; when the average load in a home is less than 1 kW, this means that an hour can pass with no discernible change in the meter reading (Figure 5-11).

Figure 5-11. Relative Resolution of Decawatt-Hour and Kilowatt-Hour Meters



Source: NSTAR and Tendril meter data

These lower resolution meters were also equipped with lower power radios, which presented a challenge at times to for the ERT (Translate) devices to receive the consumption information so it could be transmitted onto the HAN network and collected. In some cases, these lower powered meters were swapped out for a higher powered one and a HAN connection was successfully made. For customers looking to in-home displays or web histories to help understand how small changes in behavior affect electricity usage, the lower resolution data did not reveal the energy consumption impacts as readily, and in some cases underperformed customer expectations.

5.2.2 Meter Data Processing

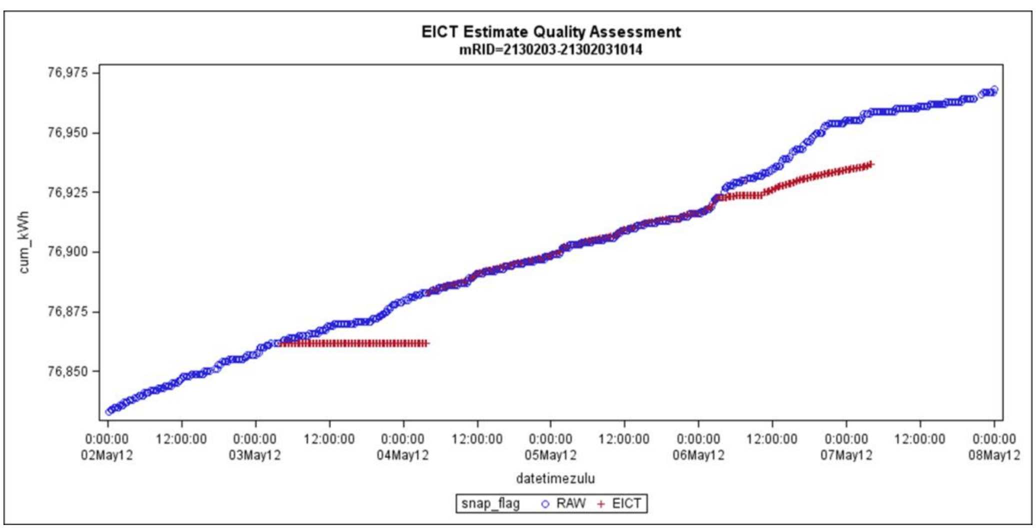
The analysis looked at and leveraged consumption data at different stages of processing. The meter readings taken directly from the meters are referred to here as “raw” data. This data is then “snapped” to 15-minute boundaries, and finally the data is processed through a VEE process to fill in gaps and make it appropriate for billing. These three levels of interval data processing are referred to below, and include:

- "Raw" meter data—readings taken directly off the ERT radio, which are time stamped but not aligned to 15-minute interval boundaries[29]
- "Snapped" interval data—which take the "raw" readings and snaps them to a 15-minute time boundary, creating 15-minute interval data
- "Estimated" interval data—which process the snapped interval data using a VEE algorithm to fill in gaps, address abnormalities, and prepare the data to be used for billing purposes

The Technical Assessment examined data at these various levels of processing to try and understand if the process was working correctly. This examination identified certain abnormalities which did not affect the impact analysis, but they are noteworthy nonetheless.

Figure 5-13 shows some of these abnormalities through a single meter providing data over a period of a day or more, with the snapped interval data in blue and the estimated data in red. The figure shows a fairly constant rate of consumption over several days, seen in blue, but the estimated data diverges from this at two significant points. It is not clear why this happens, but it is likely an error that could be fixed upon examination and modification of the VEE algorithm being used. One possible explanation is that the estimated data was processed initially without the full set of actual data, as shown in blue. If the actual data was received after the estimated data was processed but the estimated data was not then re-processed, a divergence as seen in Figure 2-14 may result.

Figure 5-12. Estimation Abnormality



Source: NSTAR

[29]Recall that the ERT readings are received asynchronously, and don't fall on 15-minute boundaries, but may fall anywhere within a 15-minute interval. These readings are received by the Tendril system, time stamped, and sent to the cloud-based head-end. A post-process is used to take this time-stamped data and "snap" it to 15-minute boundaries, so that it turns into a stream of 15-minute interval data that can be used for TOU billing, etc.

This example illustrates the value of visualizing this information to spot anomalies. The meter data was run through a number of other tests and checks to spot anomalies and in some cases raw data was removed from the impact analysis. It should be noted that these data anomalies would not result in a billing issue to the customer. As described previously, NSTAR had safeguards in place to ensure that if there was a data integrity issue that the bill would be calculated using the participant's monthly kWh consumption data collected through NSTAR's typical meter reading process and the participant's otherwise applicable rate.

5.2.3 Meter Data Quality as an Indicator of System Performance

An objective of the pilot was to understand the degree to which communications using customer broadband was effective in delivering interval meter data to NSTAR that was suitable for billing purposes as well as for impact assessment. To perform this assessment, Navigant examined the meter interval data that was available to the NSTAR utility back-office systems to understand the success rates of the overall interval data collection. This data provided insight into the operation of the system as a whole, including broadband communications, the cloud-based, head-end functionality, the meter interval data estimation process, and the timeframe in which issues occurred. (Note that the analysis does not allow determination of where the problem occurred in the list above, only when.)[30]

The results of this assessment are shown in Figure 5-13, which shows several years of interval data collected and compares interval data at different levels of processing to see what insights can be gained. Using this view, we can see the points at which significant interval data, both snapped and estimated, is missing and can speculate about the reasons.

This figure shows the pilot time line on the horizontal axis, and the number of pilot participants on the vertical axis. Each of the approximately 20,000 vertical lines (too narrow to see each discrete line) represents a single hour interval period during the pilot. The height of each vertical line (to the top of the shaded area, including all four color components) indicates the amount of meter interval data that is theoretically possible to collect for that hour period--all intervals for all participants that have enrolled to that date (including participants who have dropped out by that date). The color categories then break that theoretical maximum number of observations for that hour interval into the following four categories:

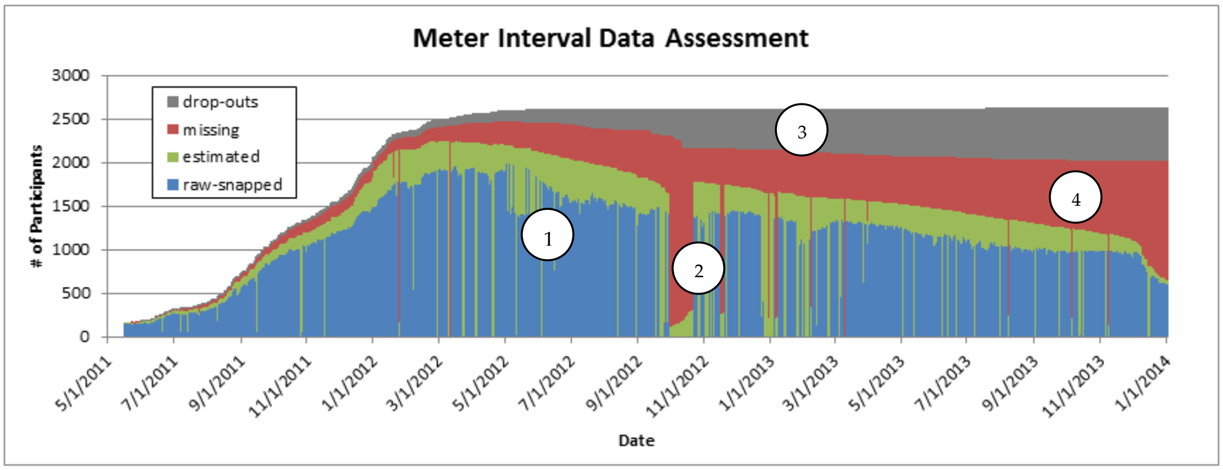
- **Raw-snapped:** As describe above, this is raw interval data collected from the ERT radio readings, but processed to be "snapped" to a 15-minute interval boundary. The raw-snapped data was submitted on a daily basis to an external provider of meter data processing services and VEE processes to perform the estimation process.
- **Estimated:** Interval data after the VEE process is used on the raw-snapped data above to fill in missing intervals and make other estimations based on the nature of the data, to prepare it for billing purposes.
- **Missing:** This is the amount of interval data "missing" for that hour period (not present in the system, but which should be present based on the number of currently enrolled

[30] The Tendril equipment did not provide link-level protocol success rates on the broadband customer connection. As such, Navigant conducted this analysis using the process described here.

customers). Thus, this amount of interval data did not successfully transit the full path from the ERT meter through the HAN equipment, customer broadband and cloud-based head-end, and through the VEE process. The intervals could have been dropped anywhere along that path, or never captured from the meter to begin with; it is not possible to tell from the data.[31]

» **Dropouts:** This is the amount of data that we expect to be missing in that hour time period given the number of participants who have officially dropped out by that date in the pilot.

Figure 5-13. Meter Interval Data Collected During Pilot Operations



Source: Navigant analysis

From this graphic, it is possible to draw a number of insights about the operation of the system. Interesting phenomena are labeled with the numbered bubbles on the figure:

❶ The green vertical stripes (VEE estimated data) indicate that a large percentage (or all) of the raw-snapped data for that block of time was missing. Thus, the ERT readings were apparently not available, and the VEE process had to fill in the missing data with all estimated data. Note that some level of estimation is expected; thus, the horizontal green stripe across the entire diagram is expected. The vertical green strips that span the entire height of the graph, however, represent periods where almost the entire set of interval data for all participants in that period was estimated. This could be because the VEE algorithm required data be estimated for those periods, or, in some cases, could have been due to a communications failure —either the server was down for a brief period, or communications to the cloud-based head-end failed, or some other process failed so that no customer meter data was available for that period.

❷The vertical red stripes (missing data) indicate that no data was available during these periods. In these periods there was some type of system outage and or data transfer process issue that prevented interval data from being collected, and/or properly transferred to or from the VEE

[31] A portion of the missing data is likely attributable to disconnected HAN systems from customers who did not subsequently respond to NSTAR's offers of technical support. After several months of noncommunication, NSTAR removed such customers from the pilot, but the customers would have been listed as participating for a period of several months where billing data was not being transferred.

process. The large vertical red stripe in the October through November of 2012 indicates a sustained failure that prevented appropriate meter data collection and processing for more than a week.

❸The number of dropouts, as accounted for in the program, is shown in the graph to increase over time.

❹The amount of meter interval data being collected after a peak in March of 2012 is seen to steadily decrease over time. The gap between the officially counted dropouts and the number of participant systems actually reporting meter data widens starting in November of 2012, indicating that the official account of dropouts may be missing some participants that have effectively dropped out because the equipment is no longer functioning (possibly unplugged), broadband communications is not working, or some other problem is preventing the collection of interval data.

Looking at the interval data in this way, it is possible to get an idea of the efficacy of system operation as a whole over the entire pilot period. The system was able to provide estimated data, suitable for billing, for much of the pilot period (the exception being the red vertical lines where estimated data dropped out—with one period of major system dropout). There were many short periods throughout the pilot where estimated data filled in for a lack of actual raw data collected from the meters (the vertical green stripes throughout). And finally, the method of counting official dropouts may not account for some participant attrition as indicated by the declining amount of meter data being collected after the peak in the spring of 2012.

5.3 *Effective Functionality of the AMR/HAN/Broadband Architecture*

At the outset of the pilot, it was anticipated that the pilot Smart Meter architecture based on existing AMR meters and installed HANs would provide many of the features and capabilities of a full AMI deployment such as remote upgrades, net metering, and meter diagnostics. Table 5-1 presents a list of the features and capabilities of AMI systems, along with an assessment of how well the AMR/HAN architecture of the pilot performed with regard to each.

Some, but not all, of these system features were demonstrated as part of the pilot, as shown in the figure. The first four features shown were examined in detail as part of the pilot evaluation.

Table 5-1. Comparison of Features: AMI vs. Pilot Architecture

Description	Pilot Architecture with HAN (achieved)	System Feature Comparison
Interval Data	●	15-minute, whole house, interval data for both billing and impact assessment was successfully provided, with some data anomalies, as discussed extensively in the sections above.
Customer Information	●	Information such as household consumption, current electricity price, and projected monthly bill was successfully communicated to customers, with some interruptions and delays.
Direct Load Control	●	Critical events were successful and achieved the load reductions described in the Impact section.
Temperature Setbacks	●	Setbacks were successfully used as the method of shedding load during demand events, again, as described in the Impact section.
Remote Upgrades	●	Firmware upgrades of remote devices were successfully achieved, although not at a scale that provides much certainty about the efficacy of this approach to upgrade to new product features in the future. NSTAR did not attempt to push many firmware upgrades as part of the project in order to limit the amount of re-testing required in a limited duration pilot, and in order to keep the customer's experience as consistent as practical throughout the pilot.
Revenue Protection		The pilot was not designed to test or enable these features.
Net Metering		
Meter Diagnostics		
Remote Disconnect		
Automated Outage Reporting		

Source: Navigant analyses

The findings suggest, despite some of the issues discussed above, that the broadband, HAN, and back-end systems are capable of providing the necessary data transfer for enhanced customer information and for TOU/CPP billing. However, it also indicates that consistency and reliability improvements are needed to ensure that NSTAR can provide customers with the Smart Grid rates and services without having to revert to standard rates when interval data is not available.

Based on the relatively high frequency of customer HANs going offline, any future application of the Smart Grid architecture to outage detection should assess multiple participant homes on the same feeder to eliminate false outage indications that are attributable to individual customers disconnecting.
The observations above merit further analysis prior to wide-scale deployment.

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6 Conclusions

This evaluation of NSTAR's Smart Energy Pilot has provided many individual findings related to the electricity usage impacts, technology performance, and administrative process of NSTAR's offering the Smart Grid technology and rate package to customers. Beyond these details emerge broader learnings that can guide future business and policy decisions related to Smart Grid investments. The following discussion presents key takeaway from the pilot with respect to customer interest, energy and demand impacts, technology performance, and participant engagement.

6.1 *Key Takeaways*

1. **Smart Grid offerings may appeal to only a limited segment of the population—principally educated, affluent, and technologically savvy customers—**absent long-term education efforts and innovative marketing approaches to pique the interest of the broader customer base. Customer interest in the pilot was relatively strong initially, with response rates to NSTAR's direct mail and email marketing efforts of 4% and 7%, respectively, compared to the 2% to 4% response rates typically seen in Smart Grid program recruitment.[32] While the overall response rate was high, customers expressing interest and enrolling in the pilot were primarily highly educated, affluent households, often with an expressed or demonstrated interest in technology. Despite concerted efforts by NSTAR to market to less affluent neighborhoods, low-income customers did not enroll in high numbers, as evidenced by only about one percent of participants being on the R2 rate and roughly four percent reporting income below 60% of the median level for their household size.
2. **Pilot impacts on energy consumption were consistent with industry experience in several respects** (*e.g.*, peak period reductions from TOU rates and load control), **but were inconclusive with regard to whether the pilot's provision of energy usage information enables significant reductions in overall energy consumption.** The pilot's technology and rate offerings were designed to enable three types of reduced consumption: 1) peak period load reductions, 2) load curtailments during critical events, and 3) overall reduction in energy consumption (monthly/seasonally/annually). Consistent with industry experience, the pilot successfully demonstrated peak period reductions, particularly for customers on TOU rates. NSTAR specifically designed peak rates to be significantly higher than off-peak rates in order that participants could reduce their electricity bills by shifting load away from peak hours.[33] Load curtailment during critical events was also successful, particularly where long-established DLC

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[32] Smart grid marketing response rates are based on market research conducted by Navigant for the NSTAR Smart Grid Pilot Implementation and Marketing Plan, March 2010 (see Appendix C)

[33] Over the past decade, many utilities have developed TOU and CPP rates with much larger peak- to off-peak price differentials than in previous years. See Schare, S., "TOU Rates as TOU Rates As If Prices Mattered: Reviving an Industry Standard for Today's Utility Environment," *American Council for an Energy-Efficient Economy (ACEEE) Summer Study*, August 2008.

of central air conditioners was employed.[34] Less certain is whether the Smart Grid's provision of access to energy consumption information successfully encourages and enables customers to save energy over the long term. Energy savings was minimal (2% on average for those on TOU rates, and a statistically insignificant change for others), with all groups showing a marked decline in savings after the first nine months of the pilot.

3. **The pilot demonstrated that the technology architecture is capable of AMI-like features through the collection of interval meter data, but that it is not yet viable for the widespread provision of customer information and dynamic rate tariffs.** While the pilot generally demonstrated the capability to deliver on these objectives for many customers, most of the time, the lack of reliability remains a major functional limitation. The following are among the significant reliability issues that must first be addressed before a similar system is deployed on a large scale as an alternative to revenue-grade metering:

    a. *Usability of the technologies*, from the thermostat that was difficult to install, to the accessibility of customer data, which was not available on mobile applications;

    b. *Data intermittency* from HAN system disconnections and temporary failure of back-end systems, both of which led to gaps in meter data that rendered TOU rates incomplete and resulted in defaults to the flat rate;

    c. *Complexity and inconsistency of meter data validation/estimation process*, which caused data gaps and mis-alignment of intervals, resulting in differences in monthly consumption estimates between the interval data from the pilot architecture and the monthly drive-by reads from NSTAR's standard meter reading procedures.

    Advances in technology since the initial pilot Soft Launch in 2010—such as wireless gateways using IP, extended on-site storage of information, and mobile phone apps—suggest that at least some of the issues raised by the pilot may be substantially resolved and that a similar approach to reading the AMR meters but leveraging these newer technologies might be more effective, and possibly lower cost.

4. **Participant perspectives on the pilot were generally positive, but the trend of diminishing interest over time raises questions about the long-term impacts of a future offering, especially if provided to all customers on an opt-out basis.** The positive customer reviews of the pilot are a testament to the strong delivery and positive messaging that NSTAR put forth from initial marketing to final closeout of the pilot. However, this is offset by the decline in enrollment by more than one-third over less than two years, and the decline in participant engagement (even among those who remained in the pilot, as evidenced by declining energy impacts and reduced use of the web portal and in-home displays). The implication is that a Smart Grid program requiring sustained engagement may not be for all customers; even those initially enthusiastic may lose interest over time.

[34] The pilot was among a small minority of demand response programs in its use of customer broadband to communicate load control signals to participants. However, the achievement of consistent load reductions from direct load control, typically via radio frequency or very-high-frequency (VHF) paging, is well established in the industry.

6.2 *Implications for the Future*

Taken collectively, the above takeaways have several broad implications for the future of a possible customer-facing Smart Grid offering at NSTAR based on AMR meters and customer broadband:

1. **The pilot achieved its "technology validation" objective, including verification that "smart meter" functionality can be achieved without deployment of an advanced metering infrastructure. The general Smart Grid architecture approach, after improvements in technology and data management, can be an effective, low-cost way for NSTAR or other utilities with AMR meters to enable energy information and TOU rates for customers who want it,** without investing in new metering infrastructure for all customers.

   a. **The residential sector is limited as a source of reducing peak load costs to lower costs for all ratepayers.** As a group, residential customers are not the driver of peak loads within NSTAR's service territory. The ISO New England system peak occurs between 1pm and 5pm, before many residential customers return from work outside the home. This is part of the reason that residential customers account for only about 38% of NSTAR summer peak load,[35] and it implies that targeting the residential sector en masse could be a high-cost/low-impact approach—especially if many customers do not actively respond to the technology and rate offering.

   b. **Only a narrow segment of the population likely to participate or contribute to savings.** The pilot demonstrated that interest among customers is predominantly among more affluent and educated customers, with the relatively few low-income participants showing an interest or ability to conserve energy. These demographic groups represent only a small share of the population, and NSTAR survey research revealed that nearly half of customers who did not respond to the pilot offering would not be persuaded regardless of what NSTAR offered. Even the most subscribed TOU rates in the country have attracted no more than half of the residential population, and DLC programs only about 25-30% of eligible customers.

   c. **Savings will come from larger customers with discretionary loads.** NSTAR's vision is to track technological progress and when appropriate deploy a more robust version of the pilot architecture. Target markets would be customers who express interest in reducing and shifting loads and those with large discretionary loads—particularly those with central air conditioning (roughly 38% of NSTAR's residential customer base) or pool pumps, who have the greatest opportunity to change their energy usage patterns.[36]

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[35] Source: NSTAR and Massachusetts Residential Appliance Saturation Survey (RASS), prepared by Opinion Dynamics Corp. for NSTAR and four other Massachusetts utilities, April 2009. The RASS study found a central AC saturation of 32%, a figure that NSTAR estimates has now reached 38%.

[36] The pilot demonstrated that direct load control (DLC) of central air conditioning using customer-sited broadband communications is a viable alternative to the most common forms of A/C load control using paging networks. Impacts were similar to typical DLC programs, accounting for the relatively mild temperatures in NSTAR's service territory. Similar to the pilot architecture, new load control efforts across the country are increasingly using two-way communications—including customer-provided broadband—to improve reliability and identify nonfunctioning equipment.

2. **The market offering must communicate to customers that they have an important role to play in ensuring the system functions as designed.** Customers have a reciprocal role in that NSTAR will need customers to help maintain the operability of the in-home devices and broadband communications in order for NSTAR to provide usage information and bill customers on dynamic rates.
3. **A successful offering of dynamic rates and visibility into customer usage information will require an aggressive and intelligent marketing effort to reach customers and engage them to act over a sustained period of time.** The pilot demonstrated that only a relatively narrow segment of the population tends to be interested in the technology and rate offerings embodied in the pilot, and many of these customers lost interest during the course of their participation. Keeping customers engaged after the initial few months or first year of a Smart Grid offering will likely require the incorporation of apps for mobile devices where energy information is more readily accessible and occasional push messaging and event notifications can engage customers without their having to initiate the engagement.[37] To make a similar program a success, NSTAR will have to draw on its long history as an energy efficiency program administrator, leveraging innovative marketing approaches to reach the targeted customer base.

6.3 Looking Ahead

NSTAR's residential Smart Grid pilot has provided a wealth of data on customer perspectives, technology performance, and programmatic impacts on energy consumption. Collectively, this data can inform corporate and policy decisions whether and how to pursue similar endeavors in the future. The pilot has demonstrated the feasibility and promise of residential Smart Grid technologies, while also revealing their limitations and drawbacks.

In particular, the pilot demonstrated the potential to deliver customer benefits by utilizing existing metering infrastructure and broadband communications, provided that (1) technology offerings continue to develop in order to improve usability and reduce data intermittency (2) education and marketing efforts are robust to be able reach customers and engage them to act over a sustained period of time, and (3) the solution is targeted to those customers most likely to embrace and benefit from alternative rate designs and take action by changing their energy usage behaviors.

A decision to invest in a future rollout of similar Smart Grid architecture and program offerings should be assessed based on the costs relative to the achievable benefits. An important consideration will be who bears the costs and to whom the benefits accrue—to NSTAR, its participating customers, all NSTAR ratepayers, or all electricity consumers in the region.

[37] Some participants asked for mobile apps via the pre-pilot and mid-point surveys, but the pilot technology suite had already been established.