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NSTAR Smart Grid Pilot

Technical Performance Report #1

AMR Based Dynamic Pricing

DE-OE0000292

Prepared for:

U.S. Department of Energy

On behalf of NSTAR Gas and Electric Corporation

NSTAR

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Preface

Navigant has prepared this evaluation of NSTAR's Smart Grid pilot in fulfillment of reporting requirements for the U.S. Department of Energy's (DOE) Smart Grid Demonstration grant program. The format of this document follows DOE's Technical Performance Report (TPR) guidelines (June 17, 2011). Much of the information contained in this report also fulfills requirements and expectations of the Massachusetts Smart Grid Collaborative, 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 sub-group (e.g., low income, homes with presence of a senior, etc.), which is not a DOE requirement. The final pilot evaluation report, expected in early 2014, will include all relevant reporting requirements from the Collaborative Framework.

As an interim evaluation report, this TPR is based on less data and fewer survey responses than will be available at the end of the pilot. In particular, the billing data used for estimation of energy and peak demand savings covers the period January 2012 through September 2012; thus, complete data is not available for either a full winter or summer season, and there is only nine months' worth of data overall, compared to the 24 months that will be available for the final evaluation report. As a consequence, there is a relatively high degree of uncertainty in the energy (kWh) and peak period demand (kW) savings estimates, reflected in the report by 90% confidence intervals on the impact results. The seasonal energy savings estimates are particularly affected by these data limitations since they are based on at most five monthly energy consumption values for each participant, whereas the peak period demand analysis utilizes hourly values during peak hours from all non-holiday weekdays. The impact of these data limitations becomes more evident in the breakdown of savings by participant sub-group, where sample sizes drop from between roughly 300 and 900 (depending on the pilot test group in question) to often less than 100 (e.g, high-use participants in the Critical Peak Rebate test group).

Readers should view all findings in this report as preliminary and, at best, indicative of what the final findings may be. These preliminary results may change as a result of both the additional data that will be available by the end of the pilot and the fact that participant behavior in response to the pilot may change over time.

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, but without the full investment that would result from premature replacement of existing assets. In particular, a central objective of the pilot was to enable residential dynamic pricing (time-of-use [TOU] and critical peak pricing [CPP] rates and rebates) and two-way direct load control 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 that 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 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 January 2013, about 1,860 customers remained enrolled in the pilot.

Smart Grid Test Plan

The pilot program offerings to customers consist of 1) a rate design and 2) a set of one or more 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, receive a unique combination of rates and technologies in order to test hypotheses regarding the impact of technology on load reduction 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	AC Load Control	Number of Participants[a]
1	Enhanced Information	Access to information on energy consumption only; standard rate		878
2	Peak Time Rebate	$5 rebate for automated participation in "critical peak" events via NSTAR control of a smart thermostat; standard rate	☑	323
3	Time-of-Use (TOU) Rate plus Critical Peak Pricing (CPP)	TOU rate with CPP; smart thermostat controlled by NSTAR during CPP events	☑	309
4		TOU rate with CPP		917
Total				**2,427**

Source: Navigant using NSTAR customer data

[a] NSTAR installed equipment at 2,717 homes. Meter data of quality and quantity sufficient for analysis was available for 2,427 participants.

Alternative Rate Structures

In place of the standard electricity rate, most participants in the pilot receive 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 utilize automated thermostat controls or an automated air conditioning (AC) load control switch to reduce load during critical peak events

There is also one customer segment that receives a base suite of in-home technology but stays on their otherwise applicable standard rate, which allows NSTAR to assess the achievable load reductions from a technology-only option that does not require customers to change rates.

Smart Grid Technology

The underlying technology architecture consists of existing AMR meters and customer broadband connections linked to each other and to NSTAR through in-home and back-office equipment and software provided by Tendril Networks. This technology infrastructure is intended to establish a reliable backhaul communications pathway from the meter to NSTAR's internal systems that allows meter reading resolution suitable for TOU and CPP rate plans. The deployed equipment also enables automated load control of central AC and provides customer information via in-home displays or the Internet.

The basic technology offerings are as follows:

- **Internet gateway to** transmit consumption data from the meter to NSTAR and allow communication back to in-home energy displays
- **In-home energy display** that shows real-time power demand, billing-period electricity consumption and cost, the current TOU electricity price or critical event status, and other related information
- **Smart thermostat allowing customers** to program temperature set points either manually or via a user interface on the Internet, and allowing NSTAR to send a signal that increases the temperature setting on thermostats by between 1 and 6 degrees
- **Web portal,** a browser-based Internet portal that enables monitoring, management, and control of energy consumption on enabled devices in the home

Pilot Findings

The pilot is intended to assess energy and load reduction impacts and confirm the functionality of smart meter technologies utilizing two-way communications for load control, dynamic pricing, and customer information. Meeting these objectives required an *evaluation approach* that could achieve the following objectives:

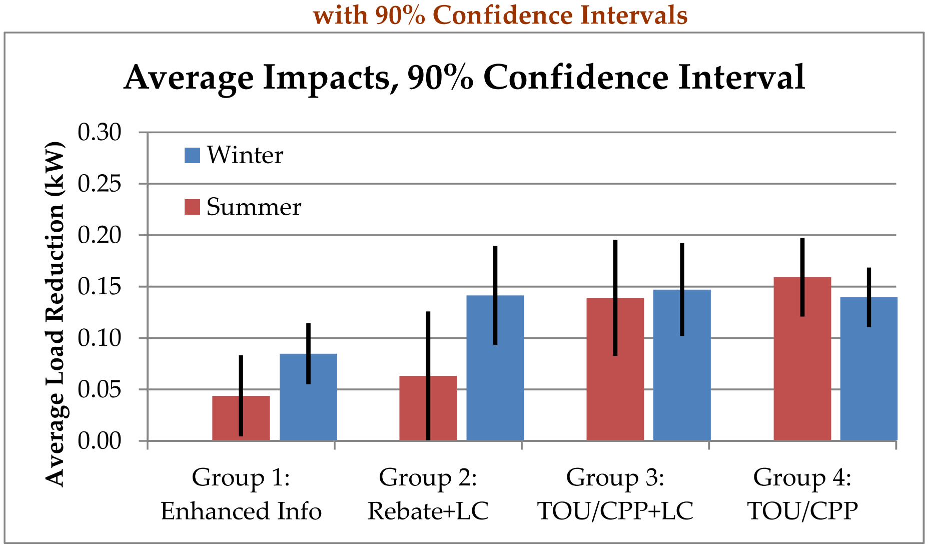
1. Accurately estimate the reductions in peak load and overall energy consumption
2. Assess customer acceptance
3. Establish minimum functional requirements for the Smart Grid technologies

Impact Analysis

The purpose of the impact analysis is to quantify changes in energy consumption resulting from participation in the pilot program. The pilot program design is intended to affect both the amount of energy consumed and the timing of consumption (on-peak or off-peak). Based on participant consumption data from January 2012 through September 2012, major findings of the impact analysis include the following:

- **Impacts of load control and CPP events**
  - Customers with automated load control (pilot test Groups 2 and 3) reduced consumption by approximately 0.5 kilowatt (kW) during events (19% for the Rebate group and 26% for the CPP with LC group). Customers on the CPP rate without automated load control (Group 4) reduced consumption by an average of 0.08 kW (6%) during events.
  - For customers with automated load control, reductions declined each hour over the course of events, with an estimated load drop of 0.6 kW in the first hour of the event and 0.4 kW in the last hour of five-hour events.
- **Peak load and time-of-day impacts**
  - Customers on the TOU rate (pilot test Groups 3 and 4) reduced consumption by approximately 0.15 kW during peak hours (summer afternoons and winter late afternoons/evenings). Customers not on the TOU rate also reduced their consumption during peak hours, but only by approximately one-third as much (summer) to two-thirds as much (winter) (see Figure ES-1).

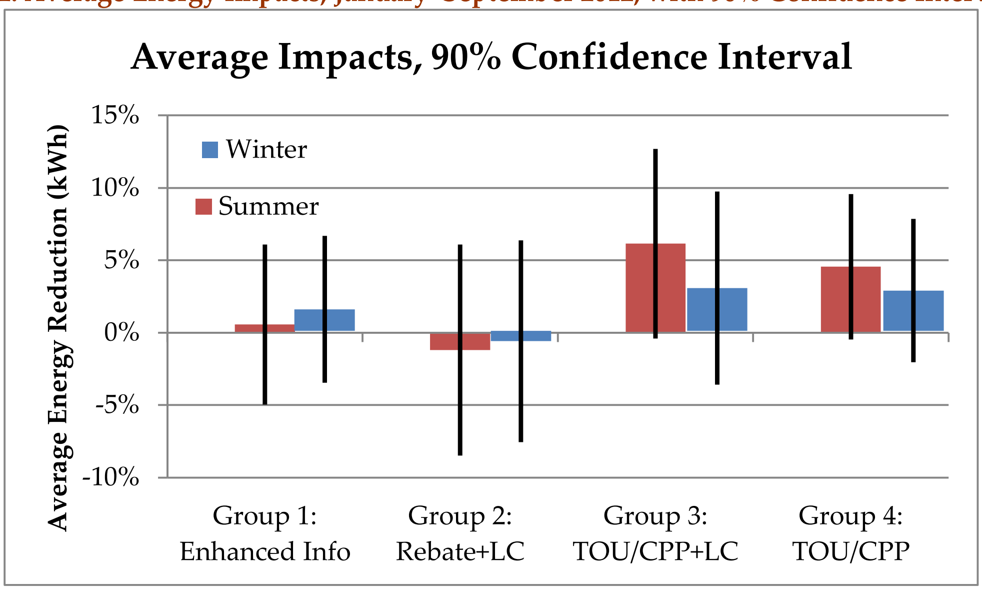
Figure ES-1. Average Peak Period Load Reductions, January–September 2012, with 90% Confidence Intervals



Source: Navigant analysis

- **Annual and seasonal energy impacts**
  - Customers on the TOU rate without load control (pilot test Group 4) reduced their energy consumption by 141 kilowatt-hours (kWh) (5%) during the summer months and by 92 kWh (3%) during the winter months. Customers on the TOU rate with load control (Group 3) reduced their energy consumption by 250 kWh (6%) during the summer months and by 109 kWh (3%) during the winter months.
  - In fact, participants in three of the four pilot groups (all but the Rebate group) reduced their energy usage in both the summer and winter seasons; however, these results were not statistically significantly different from zero at the 90% confidence level (Figure ES-2).[1]

Figure ES-2. Average Energy Impacts, January–September 2012, with 90% Confidence Intervals



Source: Navigant analysis

The results presented above address participants in each of the four pilot test groups. The appendix to this report includes impact findings broken out by demographic subgroups, such as low-income, high consumption, and households with a senior. In many cases, the results were not statistically significant at a 90% confidence level. This is due primarily to two factors: 1) data for this evaluation covered only nine of the 24 months of the pilot, and 2) sample sizes for some demographic subgroups were relatively small, especially when further broken down by pilot test group.

[1] The billing data used for estimation of energy and peak demand savings covers the period January 2012 through September 2012; thus, there is incomplete data for a full winter season, and only 9 months' worth of data overall, compared to the 24 months that will be available for the final evaluation report. As a consequence, there is a relatively high degree of uncertainty in savings estimates as of this interim evaluation, reflected in the report by 90% confidence intervals on the impact results.

The sample size limitation was especially evident for low-income participants. Despite inclusion in the pilot of a mixed-income neighborhood, only 24 participants were on a low-income rate prior to joining the program. The number of low-income participants in the pilot is more than 50 when the definition of low income includes participants whose self-reported income (from the pre-pilot survey) places them at or below 150% of the federal poverty level. The final pilot evaluation report in 2014 will estimate savings for all low-income participants.

Customer Perspectives

NSTAR is obtaining customer feedback on the pilot through surveys of a sample of participants at various stages of pilot program implementation, including prior to the customers receiving equipment or starting on a new rate (pre-pilot survey), post-installation of equipment, after CPP events, and part-way through pilot participation. NSTAR also surveyed customers who dropped out of the pilot.

Based on the surveys, participants appear to be finding their experience with the NSTAR Smart Grid pilot program to be quite positive. Most participants are well educated homeowners with higher incomes. They expressed interest and understanding of the pilot's goals and have high expectations about the savings they will realize through participation in the pilot. Satisfaction with the program is high in all dimensions measured, although some customers believe NSTAR could do a better job of explaining the goals and benefits, and drop-outs also expressed uncertainty about the pilot's goals and benefits.

Recruitment and demographics. NSTAR recruited customers using a variety of channels, including direct mailings, postcards, and several waves of emails to customers in the targeted communities. These communities 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. Interest in pilot participation was overwhelmingly from relatively well-educated, high-income customers. Ninety-five percent of participants have at least undergraduate degrees, and 67% have completed advanced degrees. Eighty percent of participants reported annual incomes exceeding $75,000, while only about 2% are considered low income based on their electric rate or their self-reported income. NSTAR plans to conduct a survey and/or focus groups in 2013 to elicit feedback from low-income customers (both participants and non-participants) on the Smart Grid in general and on technologies and rates specific to the pilot.

Participant satisfaction. The majority of participants have had positive experiences with the pilot according to surveys conducted part way through the pilot. Nearly three quarters (74%) of all participants surveyed rated their experience as "somewhat positive" or "very positive." Overall, TOU participants report higher satisfaction with the program than non-TOU participants, as shown in Figure ES- 3.

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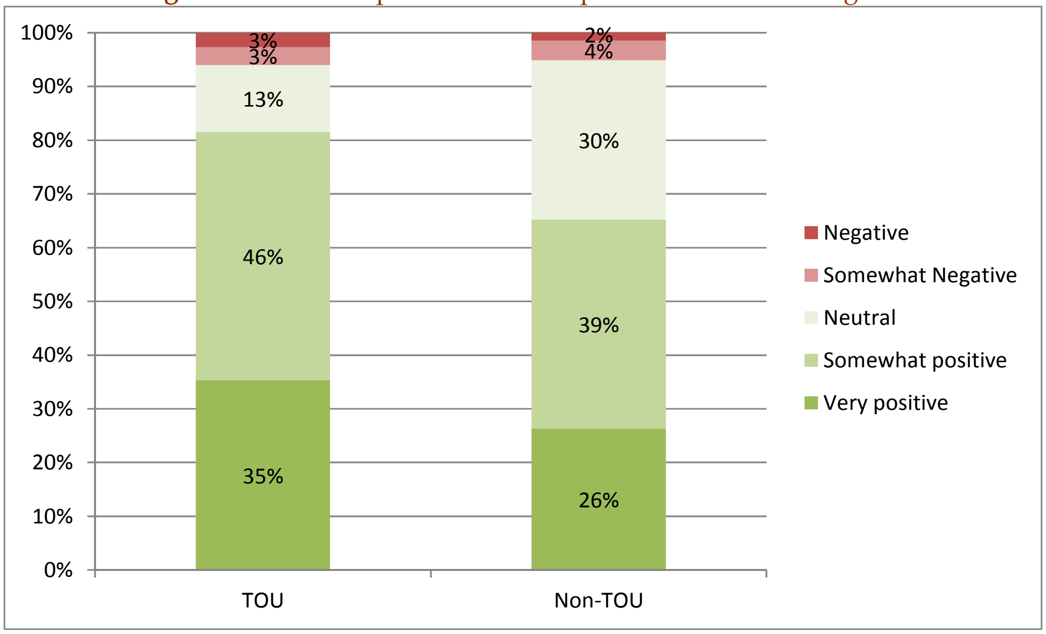
Figure ES- 3. Participants' Overall Experiences with the Program



Source: Mid-point survey

Views on technology. Participants have expressed mixed views on the Smart Grid technologies provided to aid in understanding energy consumption (based on surveys conducted when participants had been enrolled in the pilot for between one and six months). Half of participants with in-home displays reported using their display "frequently" and another 21% used it "occasionally." However, more than a quarter (27%) of all participants found the display to be "not at all helpful" in making decisions regarding energy consumption. Many participants describe a desire for more detailed and more real-time data from the in-home display, ideally providing energy consumption information at the appliance or equipment level rather than the whole-house consumption. Some infrequent users of the in-home display indicate that they prefer the web portal, which they describe as providing the same or better information. However, most participants use the web portal infrequently, with over half using it rarely or never, and roughly 20% using it at least once per week.

Smart Grid Technologies and Systems

The objectives of the technology assessment included an assessment of the initial reliability of the equipment and overall technology solution and a determination of whether the consumption information being collected from customer meters will be sufficient to perform the required customer billing (in support of TOU and CPP rates). Preliminary findings suggest 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*, but 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.

One interesting observation in the interval data is that two different types of meters are currently 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. 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 may not reveal the energy consumption impacts and in some cases have underperformed customer expectations. Newer technology releases from Tendril, combined with a steady increase in the share of high-resolution meters in the NSTAR service territory, will likely result in improved technology performance and customer satisfaction in any future deployment of a similar Smart Grid system.

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 full investment that would result from premature replacement of existing assets.[2] In particular, a central objective of the pilot was to enable residential dynamic pricing (time-of-use and critical peak rates and rebates) and two-way direct load control 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 that 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 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 January 2013, about 1,860 customers remained enrolled in the pilot. The pilot sampling design, including alternative rates and enabling technologies, allows the project to provide 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 this new infrastructure to provide two-way communication and interval metering more economically than via investment in advanced metering infrastructure (AMI).
- **Maintain flexibility for future Smart Grid technology.** The pilot retains flexibility for an expanded rollout. The in-home communications hardware and load control equipment use a common, standards-based, non-proprietary (Internet Protocol (IP) and ZigBee) home-area network (HAN) protocol that are compatible with foreseeable alternatives to the proposed Smart Grid architecture. Thus, if the pilot rate structures and technology functionality prove to be worthy of a more widespread deployment, the Company can then select from among the latest Internet protocol and HAN technology offerings to enable the Smart Grid of the future.

[2] 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.

Specific objectives for the pilot include 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 are being 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 is gathering 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 include 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 uses the information to modify energy usage, if any. Various participant demographic data, including income, are being analyzed in the pilot evaluation in order to inform if and to what extent low income participants use this information to modify energy usage.

Recipient Team Overview

Key members of the smart grid project team are as follows:

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

Tendril Networks. Tendril has been delivering 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 meter data is successfully converted to a non-proprietary internet protocol that can be communicated via customers' broadband connections to Tendril servers. From there, the data format is being modified to ensure compatibility with NSTAR CIS and billing systems such that NSTAR can use the new interval data (as opposed to monthly single-point reads) to calculate TOU-based bills.

Tendril has 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 the Company in order that Company program managers and marketing staff could monitor progress. The Tendril team also arranged for onsite 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 adjust thermostat settings (for those participants receiving smart thermostats).

Navigant has the role of evaluating the program's impacts, technical viability, and processes. Impact evaluation addresses the changes in total energy consumption, peak demand, and customer bills resulting from participation in the program. Changes in total energy consumption are calculated by comparing meter data from the various participant groups to data from the control group. Changes in peak demand are 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

2.1 Project Plan

2.1.1 Smart Grid Test Plan

The pilot program offerings to customers consist of 1) a rate design and 2) a set of one or more 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, receive a unique combination of rates and technologies in order to test hypotheses regarding the impact of technology on load reduction 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.

Table 2-1. Smart Grid Pilot Customer Test Groups

	Test Group	Description of Test Group[a]	AC Load Control[b]	Number of Participants[c]
1	Enhanced Information	Access to information on energy consumption only; standard rate		878
2	Peak Time Rebate	$5 rebate for automated participation in "critical peak" events via NSTAR control of a smart thermostat; standard rate	☑	323
3	Time-of-Use (TOU) Rate plus Critical Peak Pricing (CPP)	TOU rate with CPP; smart thermostat controlled by NSTAR during CPP events	☑	309
4		TOU rate with CPP		917
Total				**2,427**

[a] All groups received an Internet gateway and an in-home energy display. See 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 installed equipment at 2,717 homes. Meter data of quality and quantity sufficient for analysis was available for 2,427 participants.

a. *Alternative Rate Structures*

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

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

There is also one customer segment that receives a base suite of in-home technology but stays on their otherwise applicable standard rate, which allows NSTAR to assess the achievable load reductions from a technology-only option that does not require customers to change rates.

Time-of-Use Rate with Critical Peak Pricing

An illustrative example of the total electricity rate, including delivery service and other variable charges, is presented in Table 2-2. For customers who were originally on the standard rate, the peak price is more than double the off-peak price and the critical peak price is nearly ten times the off-peak price. The off-peak rate provides roughly a 40% discount off the standard rate. Note that the rate differential applies to the supplier charge portion of the bill; the delivery portion of the bill remains 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 are 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 apply to customers on the standard rate.

Critical Peak Rebate

The critical peak rebate is intended to address peak demand and system emergencies by providing a financial incentive for customers to reduce load during critical events called by NSTAR. Supplier charges under this rate are according to each participant's standard applicable rate; however, when a critical event is in effect, participants are eligible for a rebate. All customers participating in the critical peak rebate offering must have central air conditioning and are provided a smart thermostat that enables automated load control by adjusting AC temperature during events.

Participants agree to allow a temperature increase of between one and six degrees (the amount may vary by event, as determined by NSTAR), and they have the option to override the setting. All participants who do not override the load control setting during a given event receive a $5 rebate for that event. Rebates are cumulative and are reflected as a reduction on the customer's monthly bill. Customers who override the temperature setting (i.e., lower the temperature during the event) do not receive the rebate for that event but are eligible for rebates during subsequent events.

b. *Smart Grid Technology*

The underlying technology architecture consists of existing AMR meters and customer broadband connections linked to each other and to NSTAR through in-home and back office equipment and software provided by Tendril. This technology infrastructure is intended to establish a reliable backhaul communications pathway from the meter to NSTAR's internal systems that allows meter reading resolution suitable for TOU and CPP rate plans. The deployed equipment also enables automated load control of central air conditioning and provides customer information via in-home displays or the internet.

The basic technology offerings are as follows:

- **Internet gateway:** All participating homes have been equipped with an Internet gateway connected to a wireless (ZigBee protocol) home area network. This gateway transmits consumption data from the meter to NSTAR (via a bridge device to convert electronic receiver/transmitter, or ERT, signals from the meter) and allows communication back to in-home energy displays.

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

- **Smart thermostat:** Participants receiving a wireless (ZigBee protocol) smart thermostat are able to program temperature set points either manually or via a user interface on the Internet. At the onset of a critical event, NSTAR sends a signal that increases the temperature setting on thermostats by between 1 and 6 degrees (the amount may vary by event, as determined by NSTAR). In this manner, the technology serves to automatically reduce load to avoid heavy consumption during the highest priced hours or when a customer is eligible to earn a rebate. Any changes made to thermostat settings supersede the previous load control signal.

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

These technologies constitute the Smart Grid from the **customer perspective**. They provide feedback on energy consumption (via an in-home display or a web portal) and offer participants the convenience of remotely controlling household temperature in the event that typical schedules change. The automated response to critical events may allow for greater load reductions and bill savings.

From the utility perspective, the Tendril platform offers the capability of utilizing the customer's existing Internet connection as the communications backhaul. This is accomplished by an Internet gateway device

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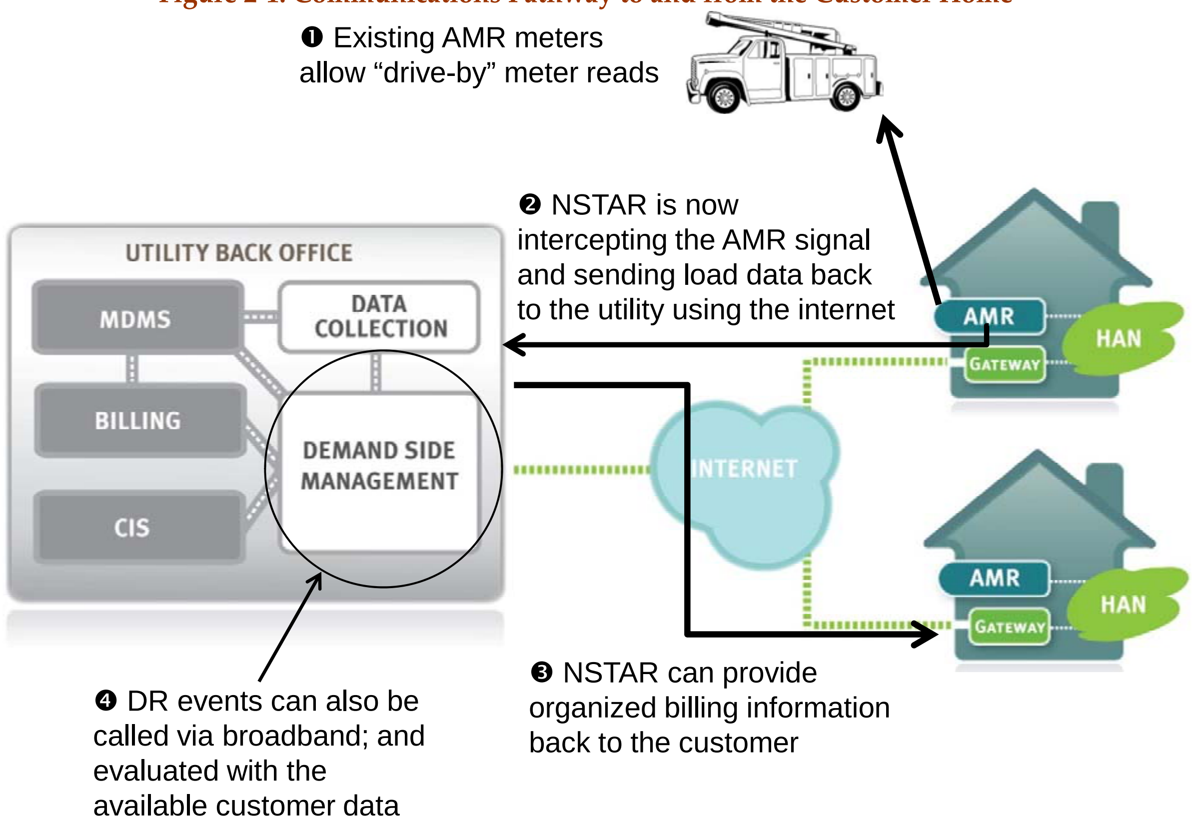
that enables wireless communications to and from the home-area communications network. The AMR meter transmits wirelessly the consumption information on regular intervals and the ERT Bridge captures it. Time-stamped data is then transmitted wirelessly via the Internet Gateway to NSTAR utilizing the customer's broadband connection, as illustrated in Figure 2-1.

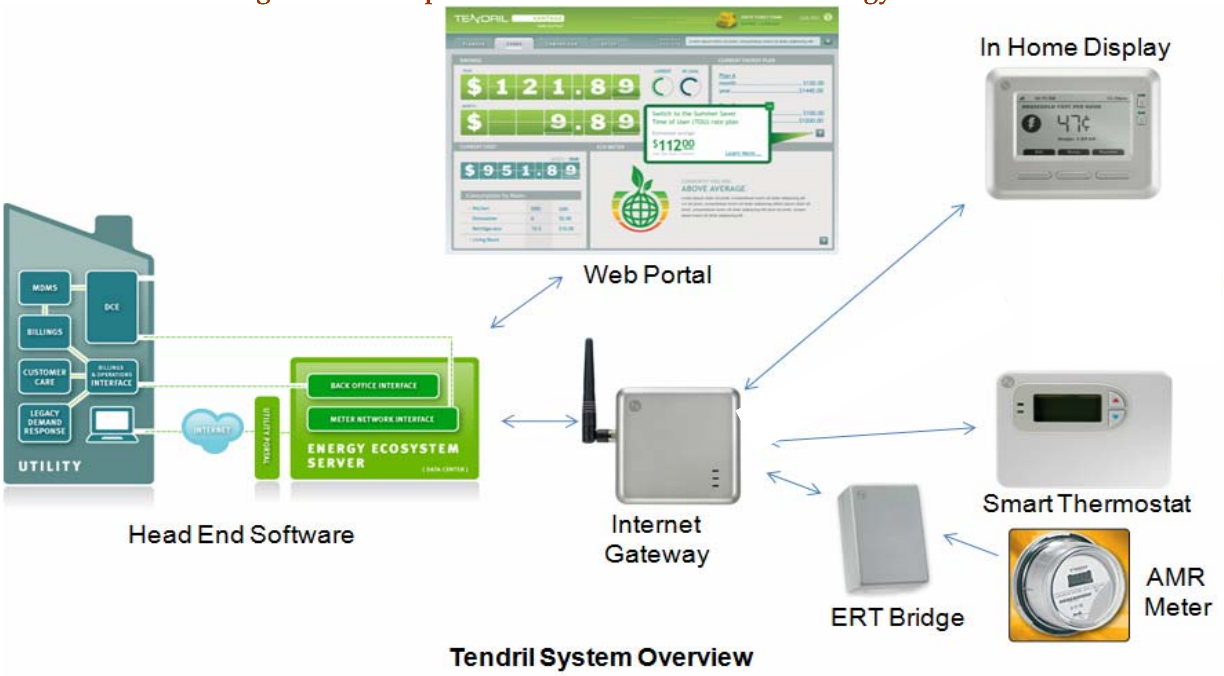
Figure 2-1. Communications Pathway to and from the Customer Home



Source: Tendril, adapted by Navigant

Components of the Smart Grid architecture—including the in-home display, smart thermostat, load control switch, and web portal— are illustrated in Figure 2-2.

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



Source: Tendril

2.1.2 Steps for Deployment

a. Customer Recruitment

Customers from the communities of Newton, Hopkinton, and Jamaica Plain (in Boston), all within the NSTAR service territory, were invited to participate in the pilot. The Company ultimately expanded the target communities to include Waltham and Framingham in order to reach a larger audience and increase the number of pilot participants. Prior to inviting participation, the Company established the recruitment criteria including demographic, geographic, usage identity, and rate information. One specific requirement was that participants have 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.

Recruitment was targeted to help ensure that customers invited to participate are eligible and live 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 were 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 are contained in *The NSTAR Smart Energy Pilot Marketing and Recruitment Plan.*

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

- Lower electric bills through installation of a wireless digital display and an internet web portal that help customers to reduce energy consumption by providing real-time information on energy usage and costs.
- Smart thermostats for some participants that allow customers to pre-set cooling times to meet household needs and to conserve energy when the home is not occupied. Internet communications enable remote programming for when schedules change, so the home will be at a comfortable temperature when customers return.
- Reduced rates for 85% of all hours when on time-of-use rates.
- Automated load control to respond to critical events and reduce usage in order to lessen the impact of critical peak prices or earn critical peak rebates.
- Help to improve reliability of the electric grid and avoid the need to build new power plants by reducing energy usage during times of the highest system energy demand.

b. Equipment Procurement and Installation

Tendril was retained as the implementation vendor to oversee the scheduling and execution of equipment installation at participants' homes. Tendril contacted customers who agreed to participate and reported back to the Company in order that Company program managers and marketing staff were able to monitor progress. The Tendril team arranged for onsite visits to install the equipment 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. Tendril 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). In some cases it could take several hours before the In Home Displays successfully communicated with the customers' meter. In those cases where it was not practical for the installation technician to wait for that communication link, the customer would be educated on the program, including receiving the education materials, but additional follow-up action (via phone or, in some cases, additional visits) might have been required to troubleshoot.

c. Integration of with 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, declaration of critical pricing events, etc. NSTAR integrated the AMR/Tendril ecosystem to the following major back-office applications:

- Customer Information Systems,
- Customer Relationship Management,
- Bill presentment and payment,

- Corporate web site,
- Interactive Voice Response, and
- 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 are billed accurately and timely based on the rates established for the Smart Grid pilot. In addition, charges and rebates such as the ones associated with the critical peak pricing were tested extensively to ensure they are being calculated properly and presented consistently over the multiple channels available to the customer (i.e., IHD, web portal, 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.

d. Bill Calculation, Rendering and Payment Operations

For customers taking service under the pilot time-of-use rates, NSTAR calculates the bill using the Department-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 compare 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 does not match the total consumption of the drive-by meter reading (outside an acceptable tolerance level; see below), NSTAR will produce the bill using the otherwise applicable basic service rate (i.e., if the interval data does not match the drive-by data, NSTAR will not use the interval data for billing and will instead bill 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 customers standard rate. For 2013 NSTAR has moved to a threshold of 10 kWh per month in order to increase the success rate for billing on the TOU rates. Customers who are actively engaged in the pilot and on the TOU rates will often call when they are billed on the flat (rather than the dynamic) rate. By increasing the acceptable tolerance level, NSTAR intends to improve participant satisfaction by using the interval data more frequently.

e. Customer Care Services

Customer Care resources are available to address various customer inquiries related to the operation of customer facing equipment, billing and payment, and other inquiries. These services encompass 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 is provided by both Tendril and NSTAR, depending on the nature of the inquiry. In general, Tendril support is available to respond to equipment- and pilot- related inquiries while NSTAR support is available for billing inquiries.

2.2 Experimental Design and Evaluation Methods

This section addresses guidance provided in the TPR under the heading of Data Collection and Benefits Analysis in that it 1) indicates what data was collected and analyzed (both baseline and pilot data) and 2) describes how the benefits analysis was performed, including the methodology for calculating impacts.

Customer segmentation for the pilot was based on a combination of the applicable rate (standard, TOU with CPP, or critical peak rebate) and the technologies provided. All participants received at least two types of technology: 1) an in-home energy display, and 2) Smart Grid communications infrastructure including an internet gateway, ERT bridge, and access to the web portal. In addition, roughly half of the CPP participants and all participants eligible for the critical peak rebate received a programmable smart thermostat that can automate load curtailment of air conditioners according to customer preferences in response to an event called by NSTAR. Based on the proposed rate structures and technology options, *the pilot participants were categorized into one of four unique test groups, as noted above in Table 2-1.*

This combination of time-variable rates and enabling technologies allows for testing of various hypotheses regarding the impact of individual rate structures and technologies. For example, Test Groups 3 and 4 can be compared to a control group (see Table 2-3 below) 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 Customer Segment 2 with Segment 3 then allows for measurement of how a critical peak *price* influences consumption relative to a critical peak *rebate* among participants with smart thermostats to control their air conditioners.

The pilot is intended to assess energy and load reduction impacts and confirm the functionality of smart meter technologies utilizing two-way communications for load control, dynamic pricing, and customer information. Meeting these objectives required an *evaluation approach* that could achieve the following objectives:

1. Accurately estimate the reductions in peak load and overall energy consumption,
2. Assess customer acceptance, and
3. Establish minimum functional requirements for the Smart Grid technologies.

Navigant developed a customized evaluation approach, as described below, while maintaining consistency with the guidance in the *Common Evaluation Framework*, developed by the Massachusetts Smart Grid Collaborative Technical Subcommittee for use by Massachusetts utilities in evaluating smart grid pilot programs.[3]

2.2.1 Energy and Load Impact/Benefits Analysis

The estimation of the consumption impacts of all four participant groups requires at least hourly meter data collected for each participant as well for appropriately sized control groups that serve as

[3]Massachusetts Smart Grid Collaborative Technical Subcommittee, *Massachusetts Smart Grid Collaborative "Common Evaluation Framework"*, Docket 10-82, March 23, 2011.

benchmarks for purposes of estimating load impacts.[4] The evaluation employed the following control groups (Table 2-3), each selected to best serve the intended purpose:

Table 2-3. 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 non-participants in order to assess time-varying impacts adjusted for weather, economic, and other macro factors.
Monthly bill customers*	Annual and seasonal	Monthly billing data is readily available and allows for a large control group; interval data is not needed for annual and seasonal energy impacts.
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 is using a subsample of each control group population to serve as the comparison group, based on matching of energy consumption patterns with the participant group.		

The evaluation team first consolidated all of 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). Once the team cleaned the consumption data of obvious outliers, erroneous readings, and missing values, the consumption impacts of all four groups were estimated using regression analysis. Refer to 0 for a detailed description of the data and methodology used in the impact analysis.

Baseline estimation. An advantage of regression analysis relative to straight comparison of a participant group and a control is that it implicitly establishes a baseline from which deviations, such as customer response to a CPP event, may be estimated through the inclusion of dummy indicator variables. As noted above, *interval data is available for a group of customers not participating in the pilot*; this data will allow for estimation of a baseline consumption level for each hourly interval (i.e., what consumption would be if the customer were *not* a participant in the pilot) against which the participant's true consumption can be compared. The model architecture does this analysis inherently for each hour and each participant, but the analysis can utilize the model to explicitly calculate a baseline consumption level.

Weather normalization. Additional time-series variables have been included in each regression to control for variations in ambient temperature, weather, and whether a day is a weekend, holiday or weekday. The inclusion of weather and temperature variables implicitly performs weather normalization and

[4] Navigant typically uses hourly data for its analysis of DR, pricing, and customer information programs and has found this level of resolution to be sufficient for estimating impacts of all program types. Although it is not necessary, 15-minute data can be useful for more precise assessment of snap-back effects immediately after an event and can add accuracy if the start/end of load control events do not line up with the beginning and end of the interval metering period.

obviates the need for explicit adjustments to the data to account for weather impacts. Essentially, the regression controls for weather effects and allows the analyst to forecast the effect that weather changes will have on the variable of interest (i.e., electricity consumption).

2.2.2 Process Evaluation (Customer Feedback)

The process evaluation is the primary research tool used to assess achievement of evaluation objectives, which include the following:

» Identification of the level of customer acceptance and satisfaction with each of the pilot groups overall and the devices, technologies, and provided information in particular;

» Assessment of barriers to participation (including for the low-income population) and possible changes in marketing strategies and program structure that can help customers to overcome these barriers; and

» Recommended improvements to each pilot group offering going forward.

Process evaluation encompasses a review of how well the Company is administering the program, how pilot customers perceive the program, how customers react to the information provided, and how the technologies are working from the customer's perspective. Program delivery assessment includes interviews with Company staff, vendors, and participants to identify each of the four pilot groups' strengths, areas for improvement, and features that are preferred or disliked by customers. Selected customers declining to participate are also being interviewed to understand their concerns and potential barriers to participation.

Customer Surveys. Customer feedback is the primary input to the process evaluation and is being obtained primarily through surveys of a sample of participants at various stages of pilot program implementation. For each pilot group, depending on its applicability, the following customer surveys are being administered:

1. **Pre-pilot surveys** administered at the time of enrollment to determine motivations, expectations, concerns, and customer characteristics.
2. **Decline-to-Participate surveys** administered immediately after a customer declines to participate during telephone recruitment to help identify barriers to participation and means to overcome those barriers.
3. **Post-installation surveys** to evaluate the equipment installation and education process, customer rationale for selecting their chosen automated response strategy.
4. **Participant drop-out surveys** to assess the reasons for customers dropping out of the program and opportunities to enhance long-term participation rates.
5. **Critical event surveys** to assess awareness of the events, impacts on customer comfort, and any manual load curtailment response
6. **Mid-point participant satisfaction and feedback surveys**.
7. **End-of-pilot participant satisfaction and feedback surveys.**

Surveys are being administered via the internet using email invitation wherever feasible. In this way, all participants have an opportunity to respond to relevant surveys. Telephone surveys are used where needed, such as to reach participants immediately after critical events and to reach customers who declined to participate. Sample sizes vary by survey type and are based on customer response to survey invitations. More than half of all customers responded to the recruitment and installation surveys, and the evaluation team expects approximately 1000 responses for the end-of-pilot surveys, depending on participant drop-outs and survey participation at year-end.

Survey Topics. A unique set of survey questions were developed for each participant group, but where possible similar questions were posed to enable comparison between program offerings with similar characteristics and objectives. Survey questions were based in part on guidance from the Massachusetts Smart Grid Collaborative Technical Subcommittee for use by Massachusetts utilities in evaluating smart grid pilot programs. Table 2-4 presents a summary of major survey topics, covering customer perceptions, preferences, and willingness to participate in a full scale program.

Table 2-4. Major Customer Survey Topics

• Perceived program value and benefits throughout the pilot	• Perceived usefulness of information provided
• Perceived ease of device use and technology/frequency	• Immediate and longer term behavior changes
• Perceived usefulness of information and feedback	• Satisfaction with involvement, technology, media
• Comfort impact from critical events	• Expected savings, awareness of and satisfaction with actual
• Frequencies of and reasons for overrides during events	• Willingness to continue participation
• Reaction to voluntary events (if applicable)	• Impact on customer satisfaction with NSTAR
• Preferences regarding information format or content	• Suggestions for improvement – technology, information, processes

2.3 *Technology Assessment*

The technology assessment addresses the reliability and customer acceptance of the various technologies associated with the pilot architecture. These technologies include the customer-facing equipment such as in-home displays, smart thermostats, and web portals, as well as communication gateways, the HAN platform and back-end systems. The evaluation is specifically addressing system communication success and failure rates, AMR/ERT meter data collection completeness, processing of meter reads, and incorporation of participant billing data into the billing system.

The assessment also examines the process and initial success of the installation and operation of thermostats and communications devices, and is tracking equipment failure rates and other issues throughout the pilot. The knowledge gained from this information will help ensure successful installation and operation of equipment and systems as the pilot scales.

These objectives will be met through review of meter data, thermostat settings (as available), and other available device information, as well as actual data obtained from continuous operation of the system. Navigant is obtaining the information from various sources, including the technology vendor's system, log files, etc. as available. This includes information from load control events to assess the efficacy of the systems under real conditions.

The analysis will characterize the operation of the overall system, including any issues or trends with equipment and communications that could be indicators of concern for scaling up the technology or approach in question to a full load curtailment program. The assessment will measure, to the extent this information can be obtained from vendor, the percentage of thermostats and other equipment operated correctly or that had to be replaced, and how much of the meter data and other information was successfully communicated either to or from the devices and the home.

Tendril is providing system level data to track the success and failure rates of messages sent to and from the customer equipment, such as thermostats, in-home displays, and web-portals. Key determinants of the technologies' ability to transmit data are the characteristics of the home (for example, stucco construction typically uses a wire mesh underlayment which can significantly attenuate radio signals used for some HAN communications, such as Zigbee radios), the location of equipment, and (in the case of the broadband communications pathway), the internet service provider.

Data collected onsite by the installation contractor and via a pre-pilot survey of participants includes:

- Home characteristics (age, size, construction type, number of stories)
- Equipment locations
- Broadband service provider
- Air conditioner characteristics (make/model, size in tons)

It is anticipated that the pilot Smart Meter architecture based on existing AMR meters and installed HANs will provide many of the features and capabilities of a full AMI deployment such as remote upgrades, net metering, and meter diagnostics. Table 2-5 presents a comparison of the features and capabilities of these two alternative technologies. Evaluation of the pilot will provide test data to assess the performance of the pilot architecture with respect to the first four system features listed.

Table 2-5. Comparison of Features: AMI vs. Pilot Architecture

System Feature Comparison		
Description	**AMI with HAN**	**Pilot Architecture with HAN**
Interval Data	☑	☑
Customer Information	☑	☑
Direct Load Control	☑	☑
Temperature Setbacks	☑	☑
Remote Upgrades	☑	☑
Revenue Protection	☑	☑†
Net Metering	☑	☑
Meter Diagnostics	☑	☑
Remote Disconnect	☑	
Automated Outage Reporting	☑	☑*

†Interval data may be used to determine some level of revenue protection.
*Future enhancement proposed.
Source: Based on assessments by NSTAR Engineering, Tendril product information and expected enhancements prior to deployment, and Navigant analyses.

3. Impact Metrics and Benefits Analysis

The purpose of the impact analysis is to quantify changes in energy consumption resulting from participation in the pilot program. The pilot program design is intended to affect both the amount of energy consumed and the timing of consumption (on-peak or off-peak). Based on participant consumption data from January 2012 through September 2012, major findings of the impact analysis include:

- **Impacts of load control and CPP events**
    - Customers with automated load control reduced consumption by approximately 0.5 kW during events (19% for the Rebate Group and 26% for the CPP with LC Group).
    - Customers on the CPP rate without automated load control reduced consumption by an average of 0.08 kW (6%) during events.
    - For customers with automated load control, reductions declined each hour over the course of events, with an estimated load drop of 0.6 kW in the first hour of the event and 0.4 kW in the last hour of 5-hour events.
- **Peak load and time-of-day impacts**
    - Customers on the TOU rate reduced consumption by approximately 0.15 kW during peak hours (summer afternoons and winter late afternoons/evenings).
    - Customers not on the TOU rate also reduced their consumption during peak hours, but only by approximately 1/3 as much (summer) to 2/3 as much (winter).
- **Annual and seasonal energy impacts**
    - Customers on the TOU rate without load control reduced their energy consumption by 141 kWh (5%) during the summer months and by 92 kWh (3%) during the winter months.
    - Customers on the TOU rate with load control reduced their energy consumption by 250 kWh (6%) during the summer months and by 109 kWh (3%) during the winter months.

The remainder of this chapter will discuss the impact analysis findings. Navigant also estimated impacts by several demographic characteristics, including 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 Event Impacts

NSTAR called seven load control and CPP events during summer 2012: five 5-hour events and two 3-hour events. The dates, times, and hourly temperature for each event are given in Table 3-1.

Table 3-1. Summer 2012 Event Temperatures

Event Date	Temperature (F)				
	12-1pm	1-2pm	2-3pm	3-4pm	4-5pm
21-Jun	90	90	91	92	93
22-Jun	90	92	93	92	93
17-Jul	92	92	92	94	94
18-Jul	85	85	82	77	75
3-Aug	-	-	91	92	92
8-Aug	82	83	82	83	85
31-Aug	-	-	87	88	88

Source: Navigant analysis of NOAA data.

Average Event Impact

Navigant found that impacts vary across and within groups. **Participants with load control (Groups 2 and 3) had the largest load reductions, while participants on the TOU/CPP rate without load control (Group 4) realized modest load reductions, and participants in the Enhanced Information group (Group 1) had negative load reductions[5].** The results indicate that automated load control technology results in larger load reductions compared to the CPP rate, which relies on customers' willingness and ability to respond to the high energy price. Maximum load reductions are approximately 1.5 times larger than the average load reductions; minimum load reductions range from 1/3 to 3/4 the average load reduction. Table 3-22 gives the average load reduction across all summer 2012 event hours, as well as the minimum and maximum load reduction for each group. Figure 3-1 displays the average load reductions with the 90% confidence interval for each group. Note that average load impacts are statistically significantly different from zero at the 90% confidence level for all groups.

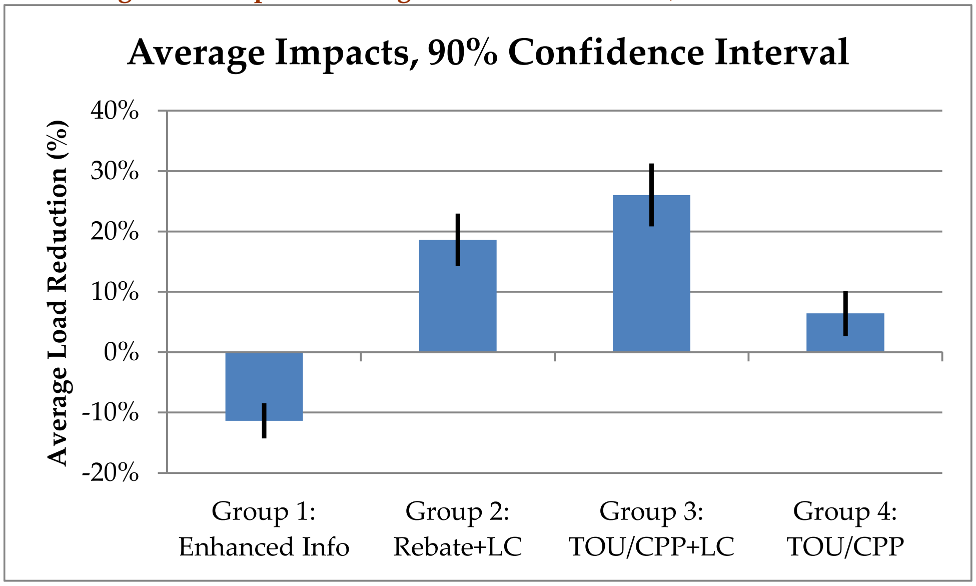
Table 3-2. Impacts from Summer 2012 Events

	Group	Number of Participants	Number of Participants Included in Model	Demand Reductions During Summer 2012 Events					
				Average		Minimum		Maximum	
				%	kW	kW	Date/Time	kW	Date/Time
1	Enhanced Information	878	510	-11%	-0.182	-0.307	6/21, 4-5pm	-0.037	7/18, 4-5pm
2	Peak Time Rebate + LC	323	242	19%	0.482	0.288	8/8, 1-2pm	0.750	6/21, 12-1pm
3	TOU/CPP + LC	309	216	26%	0.518	0.408	8/8, 12-1pm	0.655	6/21, 12-1pm
4	TOU/CPP	917	491	6%	0.084	0.026	8/8, 1-2pm	0.130	7/18, 3-4pm

Source: Navigant analysis. Notes: Only 60% (1,459 of 2,427) of 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. These results are preliminary. Navigant is investigating the cause of the negative load reductions for Group 1 participants.

[5] For future analyses, Navigant will investigate the cause of the negative load reductions for the Enhanced Information participants.

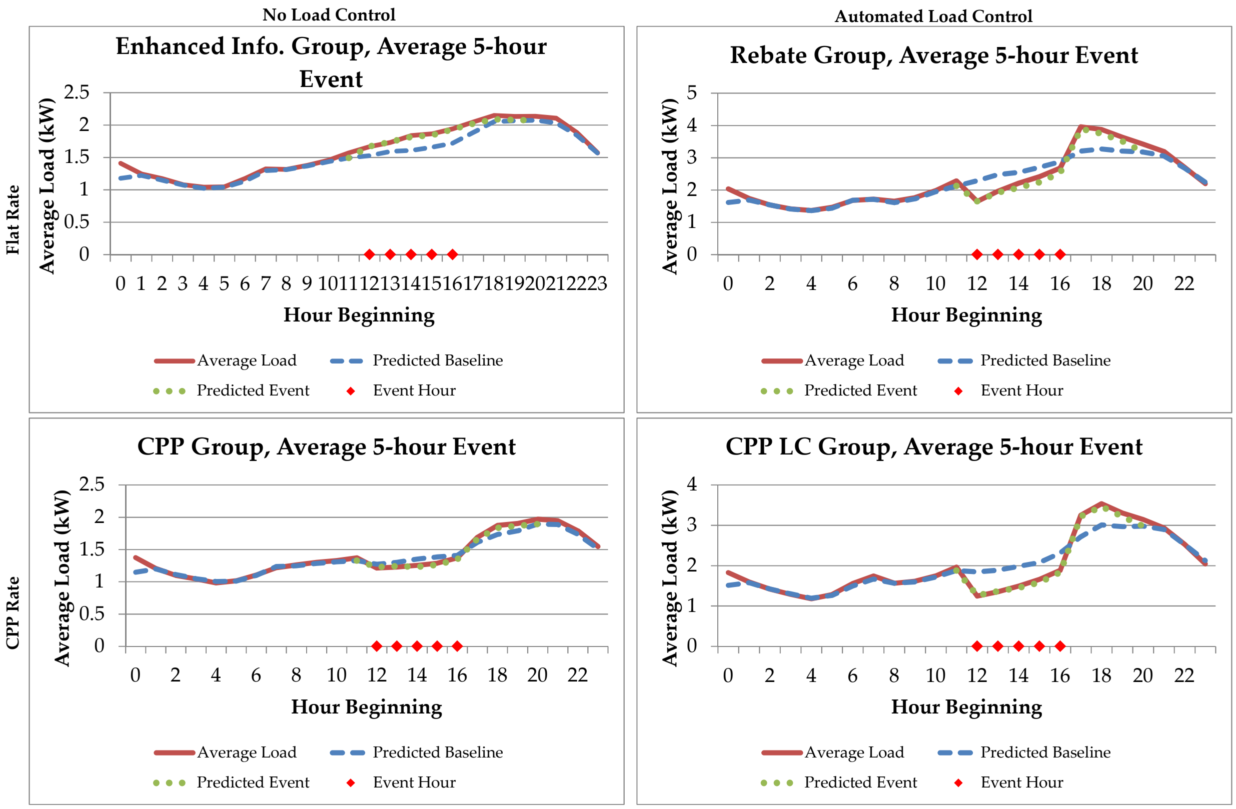
Figure 3-1. Average Load Impacts During Summer 2012 Events, with 90% Confidence Intervals



Source: Navigant analysis

Figure 3-2 displays the average hourly load curves and baselines for the five 5-hour events. Red diamonds indicate event hours. The solid red line indicates the average load for participants on the event days. The dashed blue line indicates the predicted baseline (absent an event) and the green dotted line indicates the predicted load during event hours and the following three hours where snapback might occur, both outputs of the regression model. The difference between the predicted baseline (blue) and predicted event load (green) is determined by the parameters corresponding to the event variables and indicates the predicted impact of the event according to Navigant's regression modeling.

Figure 3-2. Average Impacts, Summer 2012 5-Hour Events



Source: Navigant analysis

The hourly load curves displayed in Figure 3-2 indicate the model does reasonably well at predicting load. The customers with automated load control demonstrate a sudden drop in their load at the start of the event. Reduced load persists throughout the event, although the reduction decreases as the event progresses. Snapback occurred immediately after the event period for the customers with automated load control. 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.

For future analyses, Navigant will investigate the cause of the negative load reductions for the Enhanced Information participants. The data indicate that the average load curve increases at a greater rate (is steeper) during the afternoon hours on event days compared to non-event days. Navigant will investigate load curves for individual customers in the Enhanced Information group in an attempt to determine what is driving the increased load on event days. Note that the regression model accounts for weather differences between event and non-event days.

Navigant also tested for differences in impacts by customers in various demographic subgroups. The full results of this analysis are given in Appendix B; however, for some subgroups the sample sizes were too small to produce meaningful results. Notable findings include:

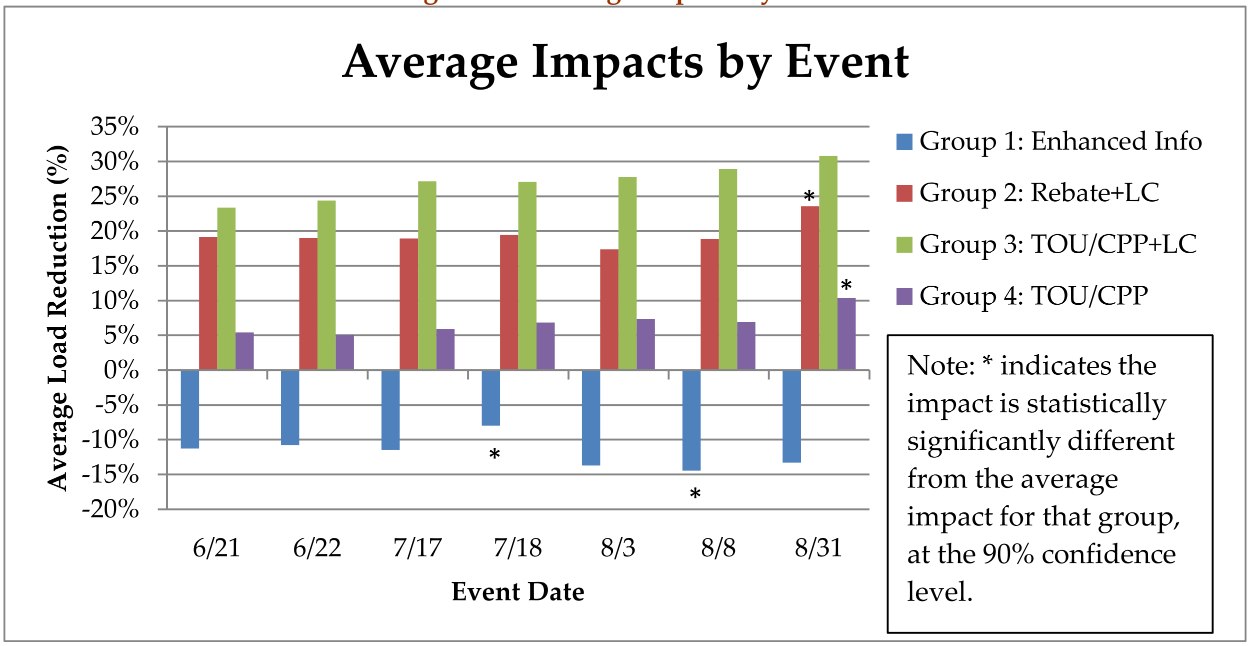
- High-use participants (with the exception of the Enhanced Information group) realize load reductions approximately double those for all participants, and this difference is statistically significant at the 90% confidence level.

- Participants with large homes (with the exception of the Enhanced Information group) realize greater load reductions than those for all participants, and this difference is statistically significant at the 90% confidence level.

Impacts by Event Day

Although the event period was consistent across events (12-5 pm for 5-hour events, 2-5 pm for 3-hour events), estimated load impacts varied slightly across events, as shown in Figure 3-3. **However, the impacts for most of the individual events are not statistically significantly different from the average event impact at the 90% confidence level.**[6] The most notable trend is that for participants with load control (Groups 2 and 3), percent impacts are higher for August events compared to June and July events. However, kW impacts are lower for August events compared to June and July events. As indicated in Table 3-1, temperatures were lower during August events compared to June and July events, and so reduced kW impacts likely resulted from reduced air conditioning load. However, given the lower load level during the August events, the reduction represented a greater proportion of load.

Figure 3-3. Average Impacts by Event



Source: Navigant analysis

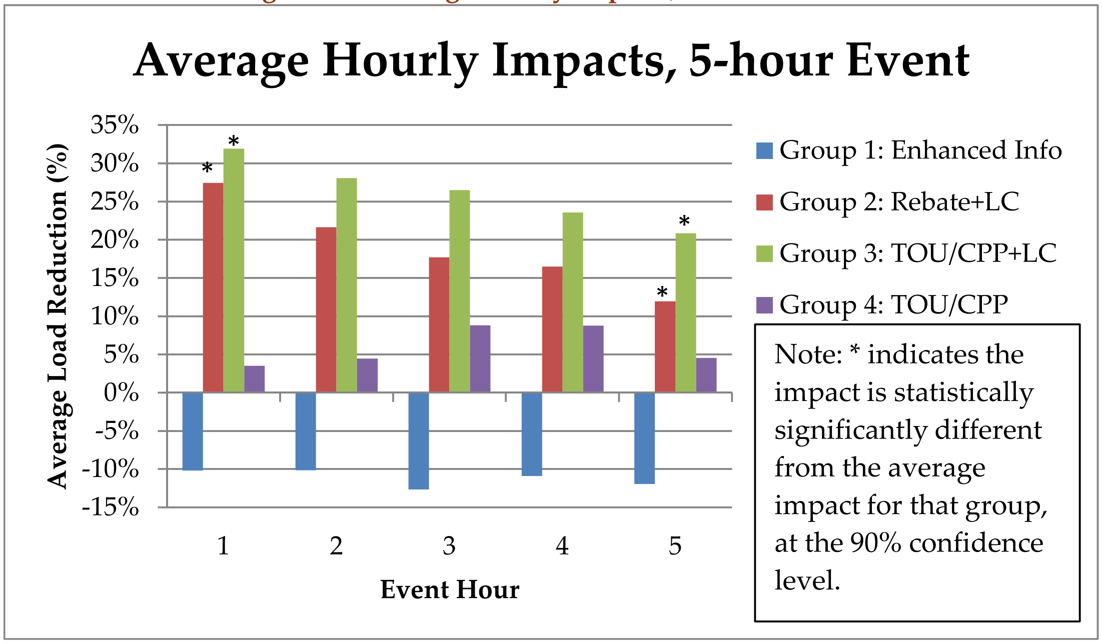
Impacts by Event Hour

Estimated load impacts vary slightly by hour of the event, as shown in Figure 3-4 and Figure 3-5, but **most of the hourly impacts are not statistically significantly different from the average event impact at the 90% confidence level.**[7] For participants with load control (Groups 2 and 3), impacts fade as the event progresses, especially during the 5-hour events. At the time of installation, Tendril technology was not

[6] The following event impacts are statistically significantly different from the group average event impact at the 90% confidence level: August 31st event for the Rebate Group and CPP Group, July 18th and August 8th events for the Enhanced Information group.

capable of ramping the curtailment, for example by increasing the thermostat set point by one degree per hour. Instead, the thermostat set point is increased at the start of the event and remains 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.

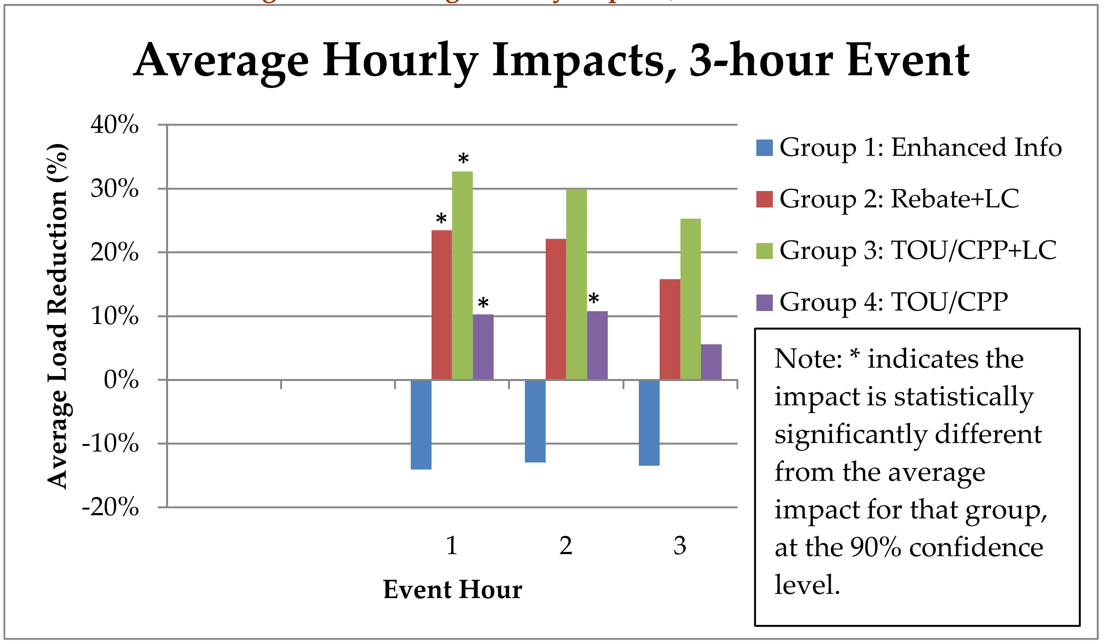
Figure 3-4. Average Hourly Impacts, 5-Hour Events



Source: Navigant analysis

[7] The following hourly impacts are statistically significantly different from the group average event impact at the 90% confidence level: the first and last hours of the 5-hour events and the last hour of the 3-hour events for the Rebate Group.

Figure 3-5. Average Hourly Impacts, 3-Hour Events



Source: Navigant analysis

3.2 *Peak Load and Time-of-Day Impacts*

Pilot participants in groups 3 and 4 are exposed to a TOU rate, in which customers are 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 pm in the summer (June to September) and 4-9 pm 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 flat rate (Groups 1 and 2) reduced their peak demand by 4% in the summer and 10% (Group 1) to 12% (Group 2) in the winter. Participants on the TOU rate (Group 4) reduced their peak demand by 16% in both summer and winter, while participants on the TOU with load control reduced their peak demand by 10% in the summer and 15% in the winter. Table 3-3 provides the average peak load reduction for each pilot group.

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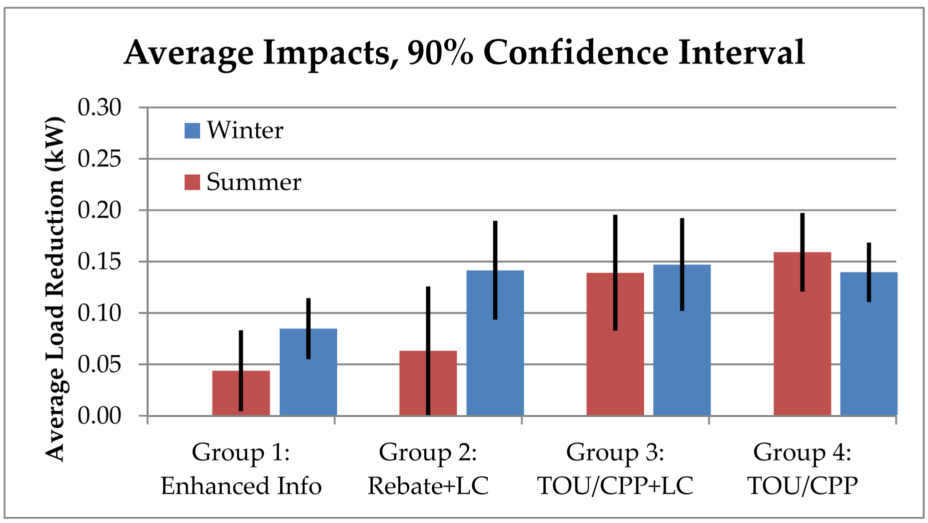
Table 3-3. Average Peak Period Demand Reduction, January–September 2012

Group		Peak Period Demand Reduction, January - September 2012			
		Summer Weekdays, 12-5 pm		Winter Weekdays, 4-9 pm	
		%	kW	%	kW
1	Enhanced Information	4%	0.044	10%	0.083
2	Peak Time Rebate + LC	4%	0.063	12%	0.139
3	TOU/CPP + LC	10%	0.139	15%	0.145
4	TOU/CPP	16%	0.159	16%	0.137

Source: Navigant analysis. Notes: 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. Holidays are excluded from the analysis. Demand reductions are calculated as the difference in load between pilot participants and matched controls. Some of this difference may not be attributable to the pilot.

Figure 3-6 displays the average peak period demand reductions with the 90% confidence interval for each group. All peak period demand reductions are statistically significantly different from zero at the 90% confidence level. However, the data do not allow for such a strong conclusion regarding any apparent differences in impacts between summer and winter. This is illustrated by the significant overlap between the winter and summer confidence intervals for each test group.[8]

Figure 3-6. Average Peak Period Load Reductions, January–September 2012, with 90% Confidence Intervals



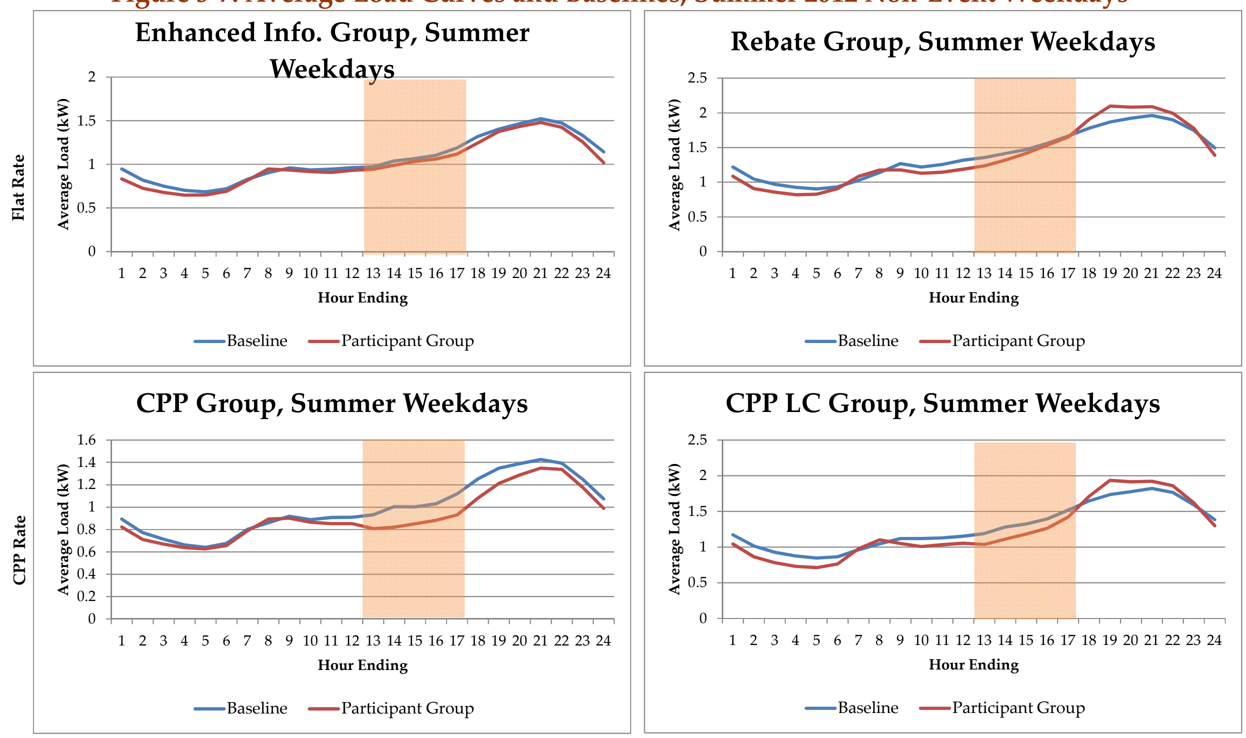
Source: Navigant Analysis

[8] Estimation of peak period load impacts requires comparison with a control group that has interval meter data covering the peak periods; NSTAR's existing load research sample provides such data. However, since interval data were not available for the participants themselves prior to the pilot, their load shapes were not known. As a result, Navigant had to identify an appropriate control group using monthly data, which means that participant load shapes may be a good match with the controls monthly/seasonally, but not necessarily hourly during peak periods.

Figure 3-7 and Figure 3-8 display the average weekday load curves (excluding event days) and baselines for summer (June–September) and winter (January–May). The red line represents the average load for pilot participants and the 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 pm, load reductions also occur during the afternoon hours (11 am-4 pm) for all groups. This could 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 pm.

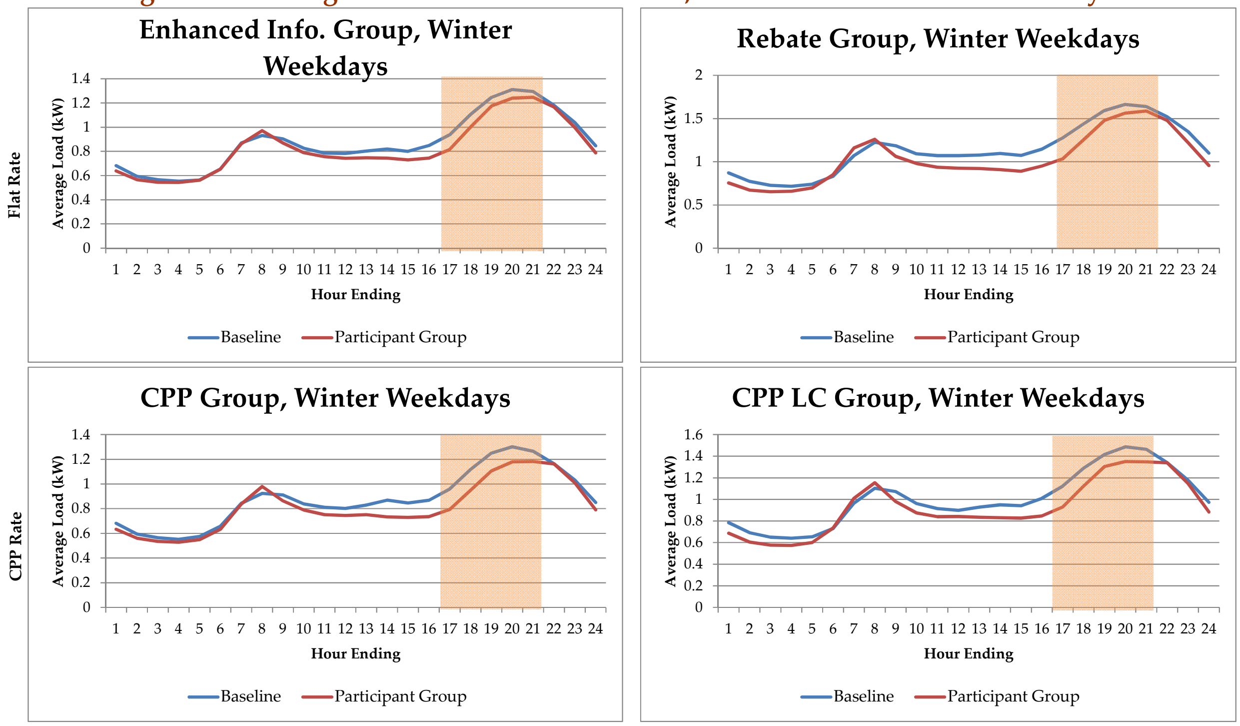
Figure 3-7. Average Load Curves and Baselines, Summer 2012 Non-Event Weekdays



Source: Navigant Analysis

NAVIGANT

Figure 3-8. Average Load Curves and Baselines, Winter 2012 Non-Event Weekdays



Source: Navigant Analysis

Navigant also tested for differences in peak load reductions in various demographic subgroups. The full results of this analysis are given in Appendix B. All reported peak load impacts for subgroups are statistically significantly different from the group average impact at the 90% confidence level.[9] Notable findings include:

- High-income participants have greater peak load reductions in the summer compared to all participants.
- Low-use participants have smaller peak load reductions in both the summer and winter compared to all participants.
- High-use participants in the CPP and Rebate groups reduce their peak load approximately twice as much in both the summer and winter compared to all participants.
- Participants with small homes have smaller peak load reductions in both the summer and winter compared to all participants.

3.3 Energy Impacts

A major purpose of the pilot program is to encourage participants to shift their load from peak periods to off-peak periods, through exposure to time-of-use rates and/or enabling technology. The two previous

[9] Navigant tested statistical significance only for kW and kWh impacts, not for percentage impacts.

sets of findings address these peak load reductions. Aside from reductions at peak, increased information about energy consumption, provided by the in-home display and the web portal, could result in energy conservation. The energy impact analysis described below presents estimated changes in energy usage.

Navigant found that participants in three of the four pilot groups (all but the Rebate group) reduced their energy usage in both the summer and winter seasons; however, these results were not statistically significantly different from zero at the 90% confidence level. Participants on the TOU rate (Groups 3 and 4) reduced their energy usage by 4.6-6.1% in the summer and 2.8-2.9% in the winter. Participants in the Enhanced Information group reduced their energy usage by 0.6% in the summer and 1.5% in the winter, while participants in the Rebate group increased their energy usage slightly (1.2% in the summer and 0.7% in the winter).

Table 3-4 gives the average energy impacts for each pilot group. Figure 3-9 displays the average energy impacts with the 90% confidence interval for each group. Energy impacts are not statistically significantly different from zero at the 90% confidence level. The lack of statistical significance is likely driven by the low number of monthly bills included in the model (maximum of four bills per customer for the summer model and five bills per customer for the winter model). Navigant expects the inclusion of an additional year of billing data will yield statistically significant results.

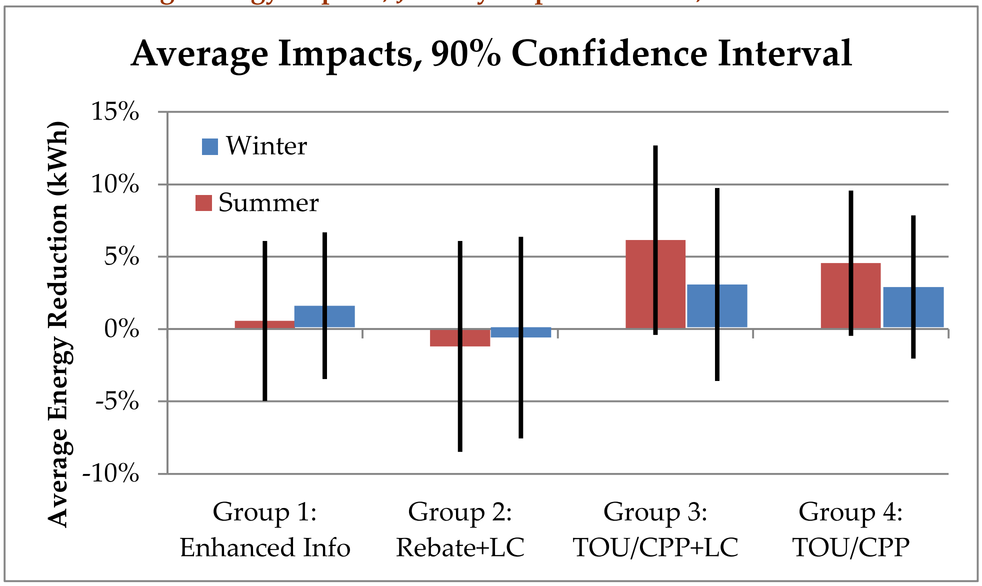
Table 3-4. Average Energy Impacts, January–September 2012

Group		Energy Impacts, January - September 2012			
		Summer (June - September)		Winter (January - May)	
		%	kWh	%	kWh
1	Enhanced Information	1%	18	1%	49
2	Peak Time Rebate + LC	-1%	-51	-1%	-29
3	TOU/CPP + LC	6%	250	3%	109
4	TOU/CPP	5%	141	3%	92

Source: Navigant analysis. Notes: The energy impacts are not statistically significantly different from zero at the 90% confidence level. The lack of statistical significance is driven by the low number of monthly bills included in the model (maximum of four bills for the summer model and five bills for the winter model). Navigant expects an additional year of billing data will yield statistically significant results.

NAVIGANT

Figure 3-9. Average Energy Impacts, January–September 2012, with 90% Confidence Intervals



Source: Navigant Analysis

Navigant also tested for differences in energy impacts in various demographic subgroups. The small number of available bills combined with the small sample sizes yielded results that were not statistically significantly different from zero at the 80% confidence level. Navigant is not reporting the energy savings for the demographic subgroups at this time, but will revisit the analysis for next year's report when an additional year of billing data is available.

4. Customer Perspectives

This section presents an overview of the customer perspective on the Smart Grid pilot, including a discussion of participant demographics with relevance to the findings, participants' initial expectations for energy savings, and participants' satisfaction with the pilot overall and with specific aspects such as the installation process, the in-home display, and the web portal.

This first look at participant reactions indicates that participants are finding their experience with the NSTAR Smart Grid pilot program to be quite positive. Most participants are well educated homeowners with higher incomes. They expressed interest and understanding of the pilot's goals and have high expectations about the savings they will realize through participation in the pilot. Satisfaction with the program is high in all dimensions measured, although some customers believe NSTAR could do a better job of explaining the goals and benefits, and drop-outs also expressed uncertainty about the pilot's goals and benefits.

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. NSTAR obtained customer feedback using surveys that incorporated a standard question set for all Massachusetts Smart Grid pilot programs, developed cooperatively with the Statewide Evaluation Collaborative and its Common Evaluation Framework. NSTAR customized the standard surveys by adding questions of particular interest and relevance to its pilot program. Surveys implemented thus far include those listed in Table 4-1.

Table 4-1. Survey Completions

Survey Effort	Total 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	1,343
Post-event survey, administered after each of five events.	340
Mid-point survey conducted at the end of 2011*	357
Dropout survey of participants who dropped out of the pilot	123

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

Source: Navigant survey data

The discussion of customer perspectives addresses the following topics:

1. Recruitment and demographics
2. Overall satisfaction and areas for improvement
3. Smart Grid technology

4.1 *Recruitment and Demographics*

NSTAR recruited customers using a variety of channels, including direct mailings, postcards, and several waves of emails to customers in the targeted communities. These communities 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.

Interest in pilot participation was overwhelmingly from relatively well-educated, high-income customers. Ninety-five percent of participants have at least undergraduate degrees, and 67% have completed advanced degrees. Eighty percent of participants reported annual incomes exceeding $75,000 (Table 4-2), while only about 2% are considered low income based on their electric rate or their self-reported income. The combination of income and education describes a very particular group, even in a region in which income and education are generally higher than national averages. NSTAR plans to conduct a survey and/or focus groups in 2013 to elicit feedback from low-income customers (both participants and non-participants) on the Smart Grid in general and on technologies and rates specific to the pilot.

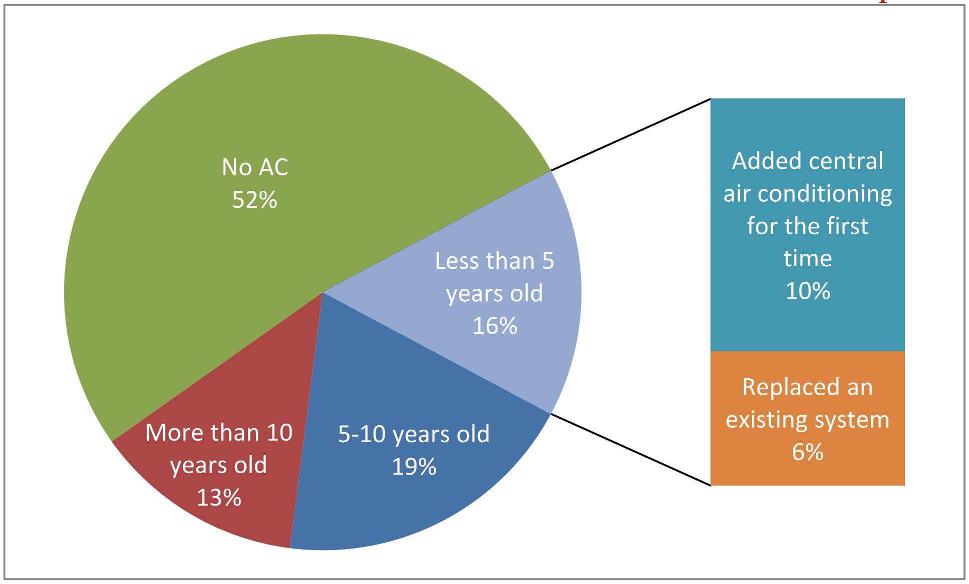
Table 4-2. Participant Income Distribution

Income Range	Percentage
Less than $10,000	0.4%
$10,000-$17,999	1%
$18,000-$29,999	1%
$30,000-$49,000	4%
$50,000-$74,999	13%
$75,000-$99,000	15%
$100,000-$149,999	28%
$150,000 or more	38%
Total	**100%**

Source: Pre-pilot survey. Percentages are rounded.

Increasing Penetration of Central Air Conditioning. Many homes in Massachusetts are old by national standards, and 78% of participant homes were built before 1979. Most participant homes were built without central air conditioning. However, Massachusetts is experiencing an increasing penetration of central air conditioning in existing homes, a trend reflected among pilot participants. Sixteen percent of participants have added central air conditioning systems within the last five years, and first-time installations accounted for 59% of those systems installed in the last five years. Figure 4-1 shows both overall central AC penetration and replacement and first-time installations.

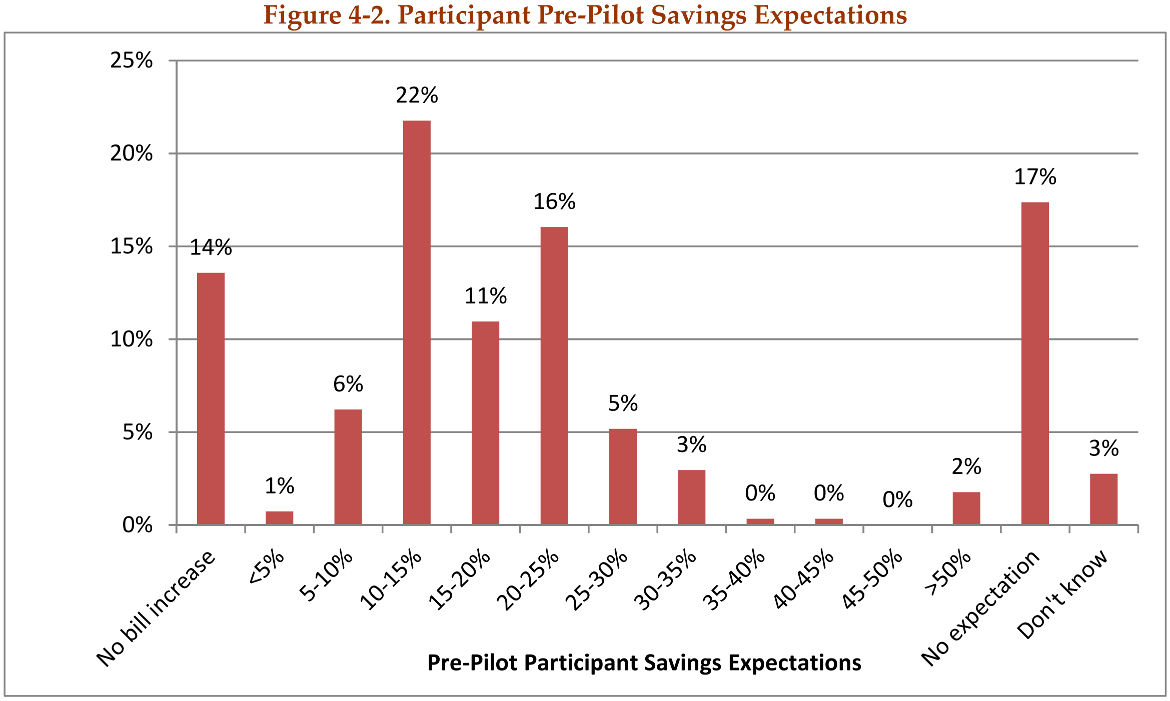
Figure 4-1. Central AC Penetration and First-Time Installations in Recent Participant Purchases



Source: Pre-pilot Survey

Savings Expectations. The combination of income and education and the location of the pilot in a very technology-focused area may also help explain the high degree of expectation for the program with respect to energy savings. As Figure 4-2 shows, at the time of the pre-pilot survey, most participants expected to achieve substantial energy savings from the pilot. Over half of participants (59%) expected to save 10% or more, and 5% expected very substantial savings of 30% or more.

Figure 4-2. Participant Pre-Pilot Savings Expectations

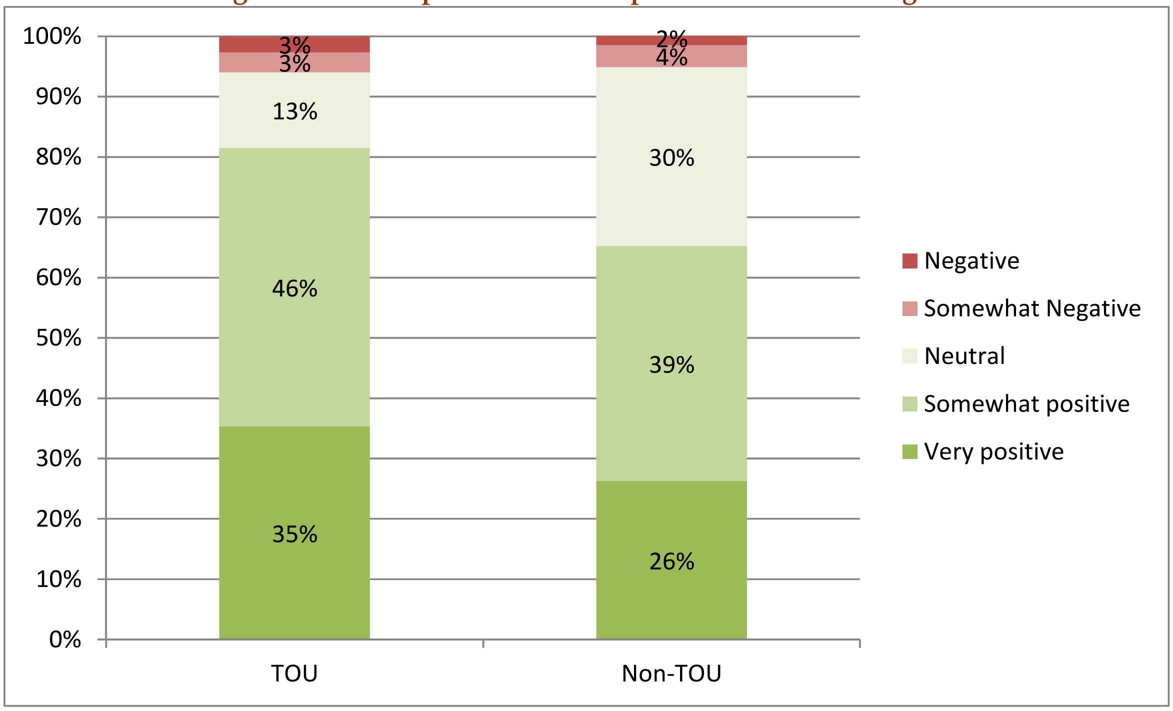


Source: Pre-pilot Survey

4.2 *Overall Satisfaction and Areas for Improvement*

The majority of participants have had positive experiences with the pilot. At the end of 2011,[10] nearly three quarters (74%) of all participants surveyed rated their experience as "somewhat positive" or "very positive." Overall, TOU participants report higher satisfaction with the program than non-TOU participants, as shown in Figure 4-3.

Figure 4-3. Participants' Overall Experiences with the Program

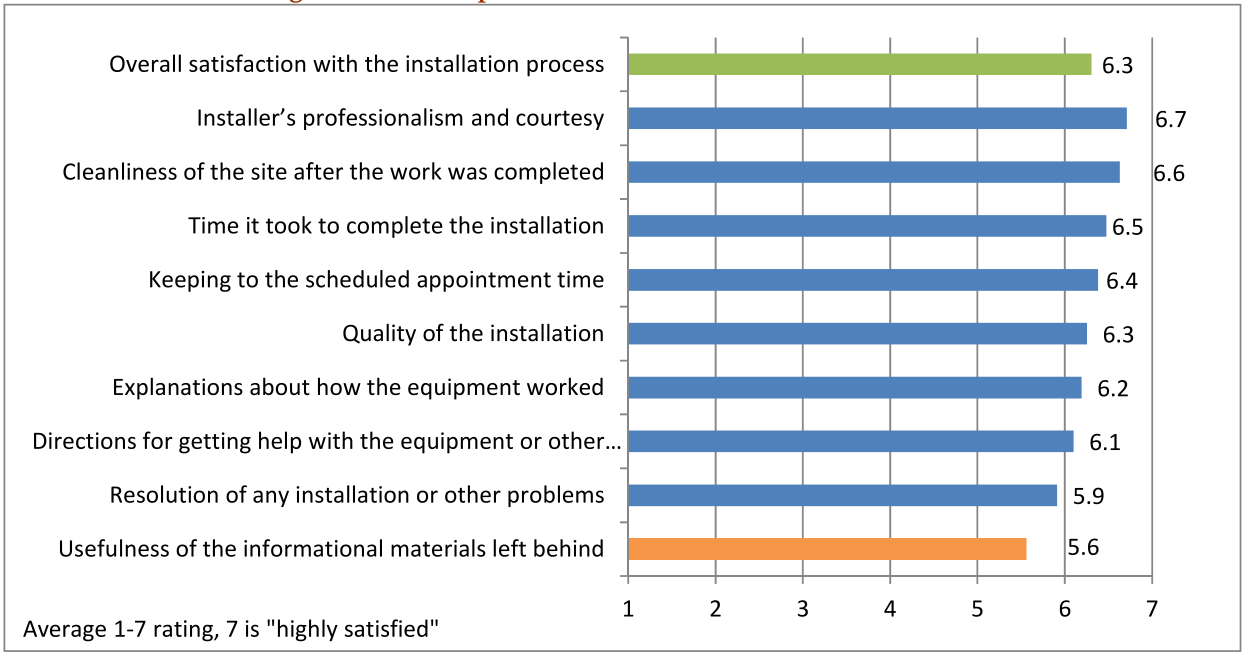


Source: Mid-point survey

Participants were very satisfied with the overall installation process, with an average rating of 6.3 on a 7-point scale (as shown in Figure 4-4). 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," still an overall favorable rating.

[10] NSTAR's soft rollout of the pilot began in late 2010; by December 2011, more than 2,000 customers had signed up, had equipment installed, and were on the applicable Smart Grid rate.

Figure 4-4. Participant Satisfaction with Installation Process



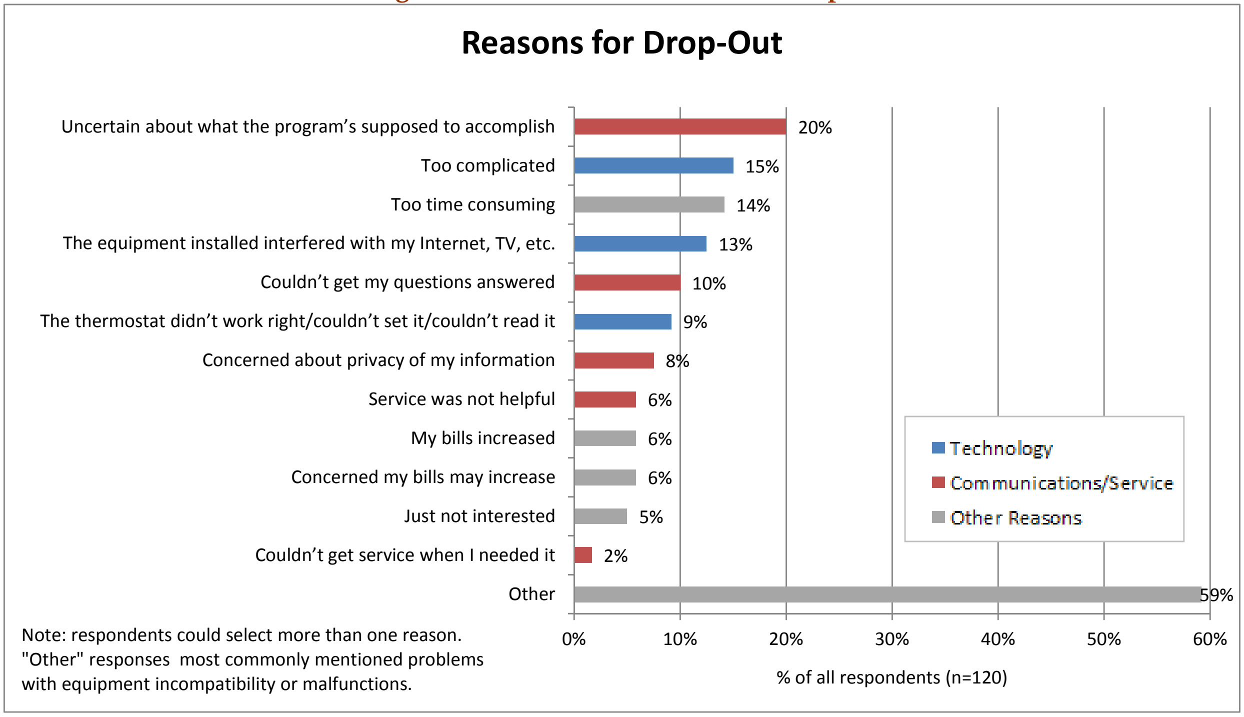
Source: Post-installation survey

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).[11] At year-end, 69% of participants who recalled receiving any informational materials said that they were "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.

Notwithstanding the general popularity of the pilot, more than 800 customers had dropped out of the pilot as of December 2012. The most commonly cited reason for dropping out of the program was that participants were "uncertain what the program was supposed to accomplish." That response suggests additional or improved communications about the program's purpose and its benefits (to the participating customers and NSTAR customers as a whole) may help to reduce the dropout rate. Former participants also cited a number of other communications, service, and technology-related reasons for dropping out of the program, as shown in Figure 4-5.

[11] Customer perceptions about the specific technologies (in-home display and web portal) are discussed in Section 4.3.

Figure 4-5. Customer Reasons for Dropout



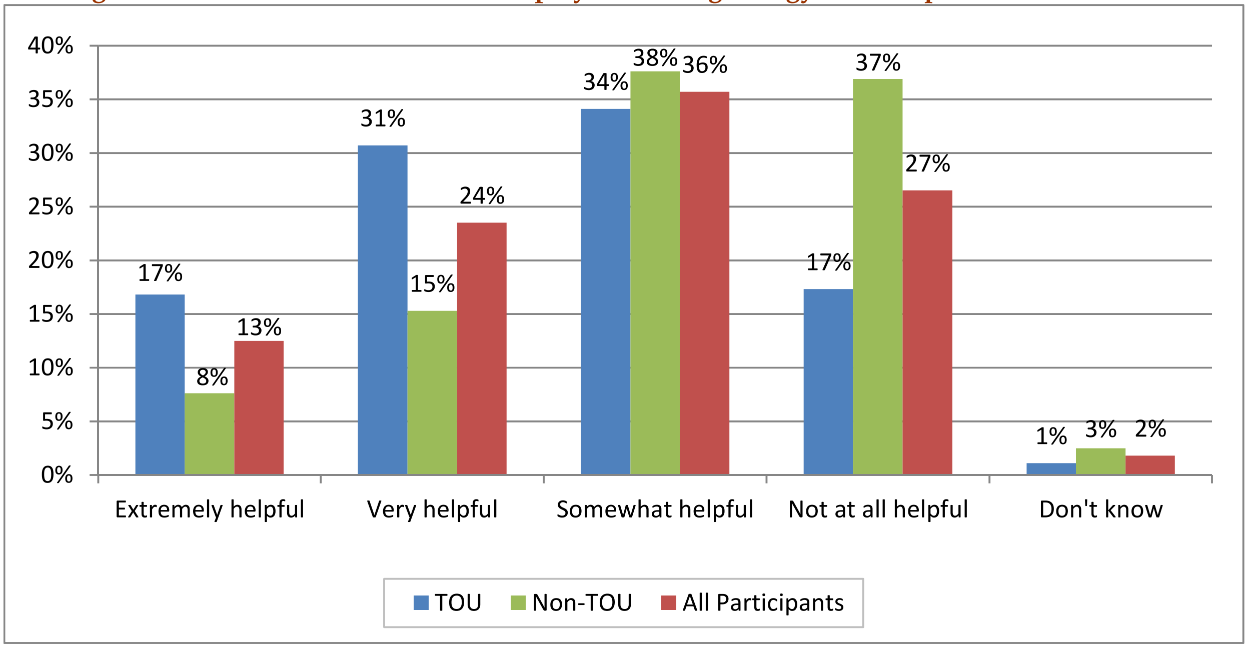
Source: Dropout survey

NSTAR has proactively reached out to customers to keep them informed of the pilot rules 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 using the pilot equipment, and other information related to the pilot. However, the survey findings indicate that improved communication, particularly about the purpose of the pilot and its expected benefits, may be worthwhile.

4.3 Views on Technology

By the end of 2011, half of participants with *in-home displays* reported using their display "frequently" and another 21% used it "occasionally." Participants on TOU rates found the in-home display more useful than non-TOU participants, as shown in Figure 4-6. However, more than a quarter (27%) of all participants found the display to be "not at all helpful" in making decisions regarding energy consumption.

Figure 4-6. Usefulness of In-Home Display in Making Energy Consumption Decisions

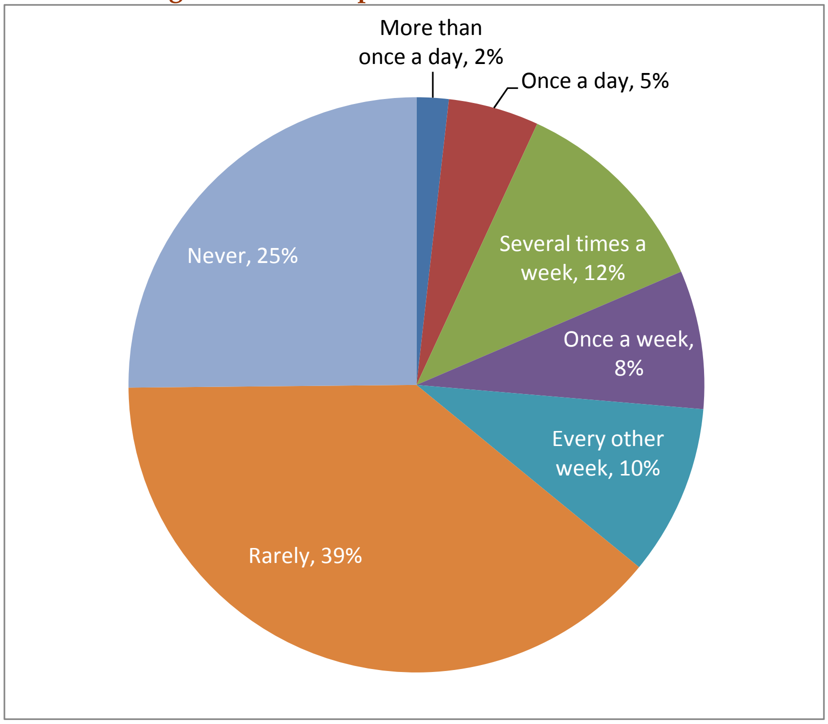


Source: Mid-point survey

Many participants describe a desire for more detailed and more real-time data from the in-home display, ideally providing energy consumption information at the appliance or equipment level rather than the whole-house consumption. Some infrequent users of the in-home display indicate that they prefer the web portal, which they describe as providing the same or better information.

Most participants use the *web portal* infrequently. As shown in Figure 4-7, three-quarters (75%) of participants had accessed the web portal at least once (at year-end). Over a third of respondents (39%) use it "rarely," while 12% use it several times a week.

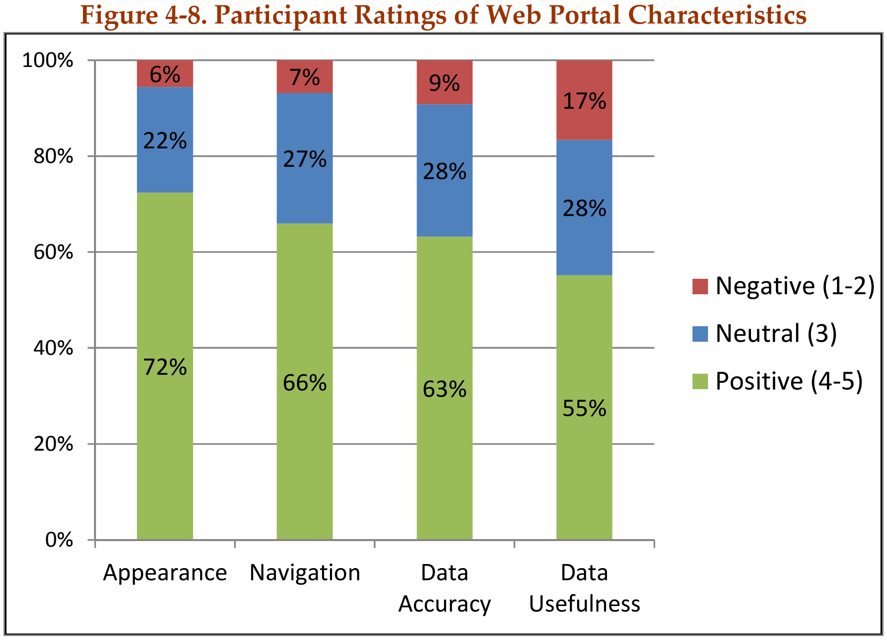
Figure 4-7. Participant Use of the Web Portal



Source: Mid-point survey

Participants want to see less data lag on the web portal, and also want to be able to access the data through smartphone app. Web portal users rate the site's attractiveness most positively and the data usefulness most negatively. Figure 4-8shows participant reactions to several aspects of the web portal.

Figure 4-8. Participant Ratings of Web Portal Characteristics



Source: Mid-point survey. Percentages are of participants who used the web portal at least once (n = 252).

5. Operation of Smart Grid Technologies and Systems

The objectives of the Technology assessment included the following:

- Determine if the consumption information being collected from customer meters will be sufficient to:
    - perform the required customer billing (in support of TOU and CPP rates, etc.), and
    - support the impact analysis.
- Assess the initial reliability of the equipment and overall technology solution to identify areas of concern or further examination.
- Seek to understand customer acceptance and use issues associated with the in-home equipment and other technology.

To perform this assessment, Navigant requested information from NSTAR and from the primary technology vendor, Tendril Networks. The information requested was intended to meet NSTAR's objectives for the pilot evaluation, and also to understand steps that might be taken to help ensure successful program rollout across the broader service territory, should that path be taken.

The first subsection below discuss the process of understanding what information could be made available for this purpose, and the second subsection describes the analysis methodology and various results.

5.1 Information Collection Overview

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 would or 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.

Thus, Navigant undertook an effort to work with NSTAR and the primary technology vendor, Tendril, to understand the various types and formats of information that would be available for these purposes, the results of this effort were documented and agreed by the technology vendor, so that data covering the evaluation period could be provided at the appropriate time.

The notion of using data from smart grid technologies to improve program evaluation, including adding insights that were not previously possible, is relatively new. As such, Navigant has outline below the process used to discover and understand what data would be available from the technology, and which would be most useful to the utility and evaluators.

1. The primary technology vendor, in this case Tendril Networks, was engaged in initial discussion to gain an understanding of what useful data elements might be generated by their technology. The discussion covered customer sited technology, networking, and head-end/server technology. A subset of the information initially explored was found to be potentially available.

2. Navigant then requested samples of various data types and elements that showed promise in adding insight for evaluation purposes. The objective of this request was to understand the format, level, and depth of each of these data elements to help formulate an analysis plan for the data during the evaluation period.

3. During the evaluation period, various elements of data were requested for analysis purposes, and a subset of these data elements were available, and chosen for analysis. For this TPR report, only a limited set of the data initially identified was determined to be of primary interest for analysis, and has been analyzed below.

Table 5-1 below shows the types of information that were requested in Step 2 above. Fields in black indicate the information that is available and fields in gray indicate that some or all if this information was not available for use in the assessment.

Table 5-1. Information Request for Technology Performance

Category	Requested Information
Consumption and Billing Information	Meter Data Transformation
	Interval Consumption Data for Pilot Participants
	Address-level Geocoding Data for Participants
	Interval Consumption Data for Control Group
	Address-level Geocoding Data for Control Group
Customer Equipment Reliability Data	Installer Database Report
	Enrollment and Installation State Change Data
	Customer Calls During Install
	Call Center Issue Report
	RMA Report
Service Issues and Problem Data	Offline HAN Report
	SLA Report
	Firmware Update Report
Service Issues and Problem Data / Technology Use and Acceptance Data	Server Diagnostic Mode Report
Technology Use and Acceptance Data	Opt-Out Report
	Login Record to Vantage

Source: Navigant

While some information was difficult or not possible to obtain at this point, the information provided yields insights beyond those traditionally possible without the data and information generated by the technology.

5.2 *Technology Assessment Overview*

Navigant broke the program process into two major activity categories to better analyze and understand the results of the preliminary technology assessment:

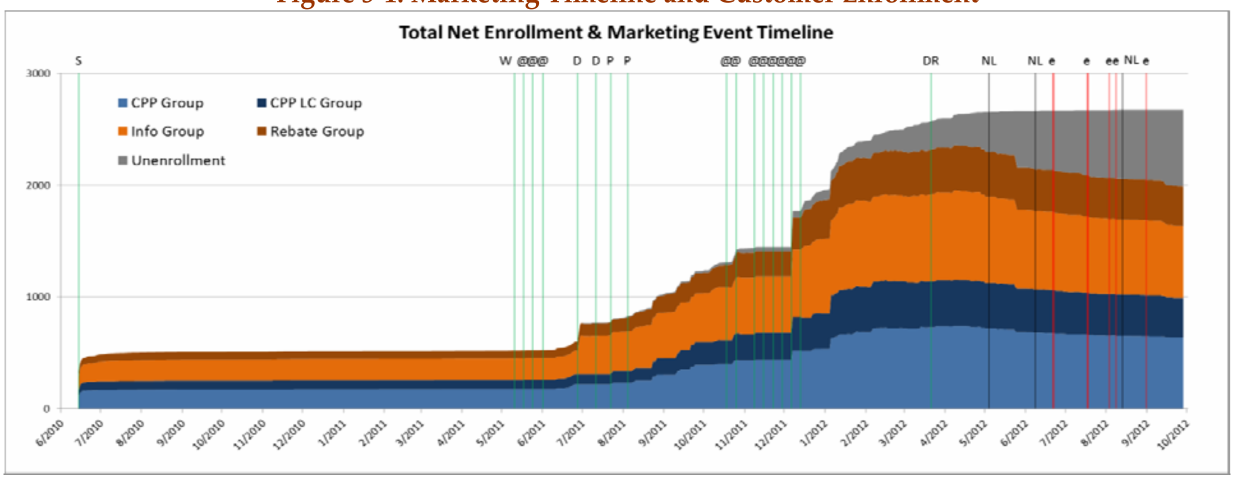
- Marketing/Recruitment: the process of marketing to participants
- Operations: use of the system once a participant has been installed and is up and running.

Analyzing the program in these categories allows the results to be conveyed to specific groups that can take advantage of the information (e.g., the utility marketing group and the billing department), and it provides a logical framework for the analysis.

5.2.1 Marketing Data

The results of NSTAR's program marketing efforts can be seen in Figure 5-1 below, as analyzed using the system enrollment data overlaid with various marketing and outreach events to show possible timing and enrollment impact effects.

Figure 5-1. Marketing Timeline and Customer Enrollment



Source: NSTAR

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, as shown in the Table 5-2 below.

Table 5-2. Schedule of Marketing and Outreach Events

Date	Event	Count	Label
6/14/2010	Soft Launch	5,553	S
5/10/2011	WaitingList Email	291	W
5/17/2011	Recruitment Email1	952	@
5/24/2011	Recruitment Email2	2,155	@
6/1/2011	Recruitment Email3	1,911	@
6/27/2011	5k Customer Mail	5,004	D
7/11/2011	15k Customer Mail	14,510	D
7/22/2011	10k Postcards1	10,000	P
8/4/2011	10k Postcards2	9,517	P
10/18/2011	Email1	483	@
10/25/2011	Email2	5,474	@
11/8/2011	Email3	10,252	@
11/15/2011	Email4	9,500	@
11/22/2011	Email5	9,237	@
11/29/2011	Email6	8,902	@
12/6/2011	Email7	8,616	@
12/13/2011	Email8	4,241	@
3/21/2012	DR Mail	264	DR
5/4/2012	NSTAR Newsletter		NL
6/8/2012	NSTAR Newsletter		NL
6/21/2012	Critical Event		e
6/22/2012	Critical Event		e
7/17/2012	Critical Event		e
7/18/2012	Critical Event		e
8/3/2012	Critical Event		e
8/8/2012	Critical Event		e
8/13/2012	NSTAR Newsletter		NL
8/31/2012	Critical Event		e

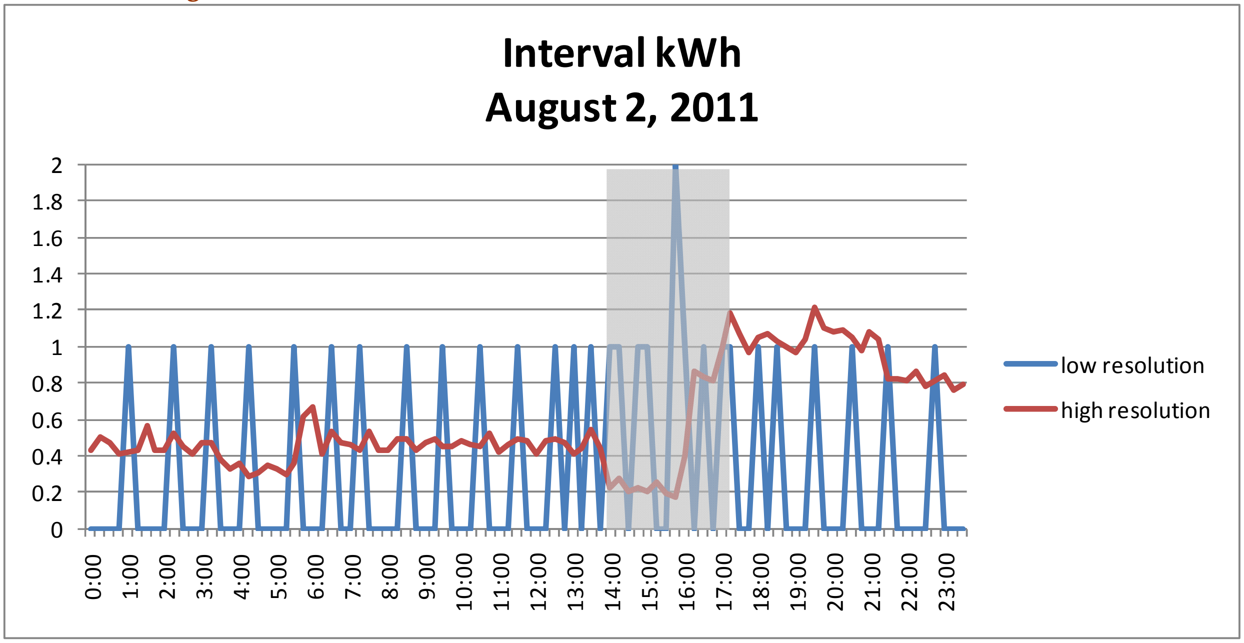
Labels refer to Figure 5-1 above.
Source: NSTAR

5.2.2 Operations data

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 5-2).

Figure 5-2. Relative Resolution of Decawatt-Hour and Kilowatt-Hour Meters



Source: NSTAR and Tendril

These characteristics need to be understood to ensure that bias is not introduced into the impact analysis, and to examine whether one type of meter shows different characteristics than the other. 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 may not reveal the energy consumption impacts and in some cases have underperformed customer expectations. Newer technology releases from Tendril, combined with a steady increase in the share of high-resolution meters in the NSTAR service territory, will likely result in improved technology performance and customer satisfaction in any future deployment of a similar Smart Grid system.

The raw interval information described above was also submitted on a daily basis to an external provider of meter data processing services and validation, estimation, and editing (VEE) to correct any gaps and do estimation needed for billing purposes. Analysis of Event Completed data yields some interesting results. This analysis requires examination of the ZigBee EVENT_COMPLETED signal, which is issued by the residential load control device—in this case a smart thermostat (PCT)—once a demand response event has been successfully completed, without opt-out or other problem.

Table 5-3 below shows a list of ZigBee commands[12] that could be received or sent by the in-home equipment, with the two important events highlighted.

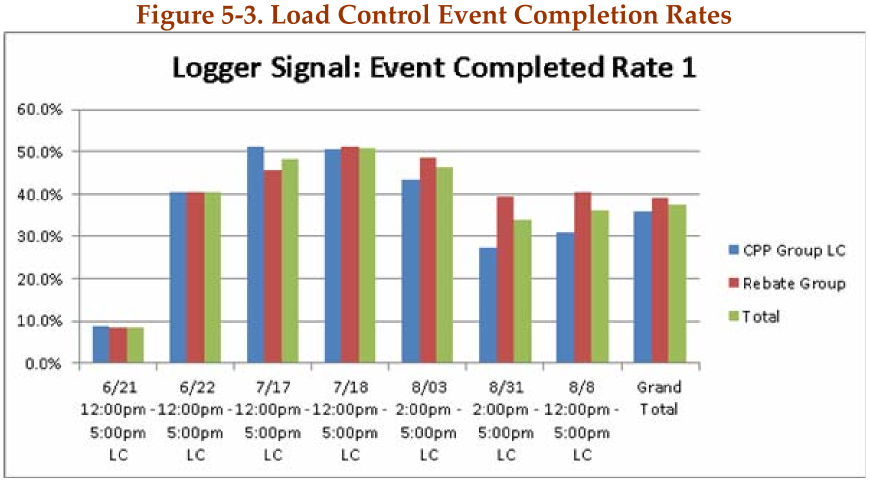
[12]ZigBee Smart Energy Profile Specification, SEP 1.1, Rev. 16, p.147. Document 075356r16ZB

Table 5-3. Zigbee Commands Received by In-Home Equipment

COMMAND_RECEIVED
COMPLETED_NO_USER_PARTICIPATION
COMPLETED_PARTIAL_USER_OPT_IN
COMPLETED_PARTIAL_USER_OPT_OUT
DRLC_CANCEL_REQUEST_FAILED_DEVICE
DRLC_CANCEL_REQUEST_FAILED_GATEWAY
DRLC_CANCEL_REQUEST_FAILED_TIMEOUT
DRLC_CANCEL_SENT
DRLC_REQUEST_FAILED_DEVICE
DRLC_REQUEST_FAILED_GATEWAY
DRLC_REQUEST_FAILED_TIMEOUT
DRLC_REQUEST_SENT
EVENT_COMPLETED
EVENT_STARTED
REJECTED_INVALID_EFFECTIVE_TIME
REJECTED_UNDEFINED_EVENT
USER_OPT_IN
USER_OPT_OUT

As shown in **Figure 5-3** below, the CPP/LC group and PTR Rebate groups had varying percentages of devices completing events, with the average over all events less than 40%. This indicates that the load control devices (smart thermostats or PCTs) did not complete execution of an event more than half the time. The difference between the two groups is not statistically significant.

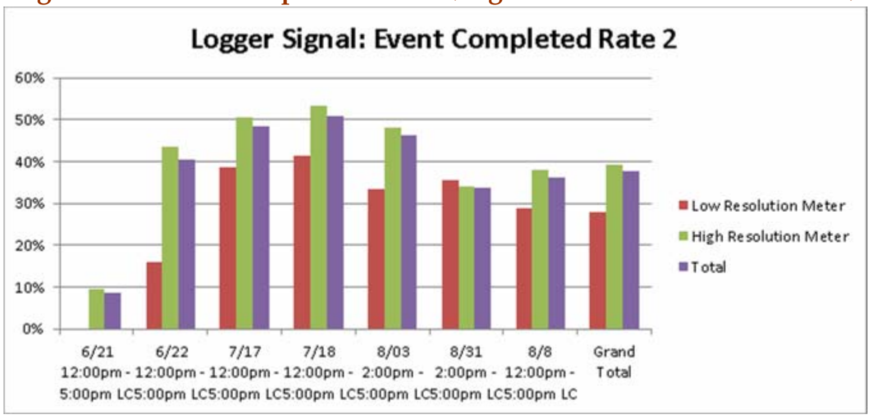
Figure 5-3. Load Control Event Completion Rates



Source: Tendril

Interestingly, the PCTs in homes with high resolution meters show a greater event complete percentage than low resolution meters, and the difference is statistically significant. This difference is unexpected, as the mechanism for meter resolution to affect the Event Completed is unclear.

Figure 5-4. Event Completion Rates (High vs. Low Resolution Meters)



Source: Tendril

Preliminary findings suggest 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*, but 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. Several of the observations merit further analysis and explanation before the system would be ready to scale beyond the pilot.

Appendix A: Impact Analysis Data Requirements and Methodology

This appendix contains the data required for the impact analysis along with a description of the methodology.

For each of the impacts discussed below, Navigant estimated separate models for customers with a certain demographic characteristic. Demographic characteristics of interest were selected by the Massachusetts Smart Grid Collaborative Technical Subcommittee. Demographic characteristics were determined from several different data sources. The pre-pilot participant survey data indicated participants with high income (>$100,000), presence of a senior citizen (65 years and older), small homes (<1,000 square feet), and large homes (>2,500 square feet). Customer billing data indicated customers on a low-income rate and was used to determine customers with low and high usage (< 50% or >150% of the residential class average usage, respectively).

A.1 Event Impact Analysis

The event impact analysis quantified load reductions that occurred in response to events.

Data Requirements

The event impact analysis required hourly impact data for all pilot participants. Navigant received 15-minute interval readings of cumulative kWh, which were then differenced and aggregated to obtain the average kW during a one-hour period. Navigant combined the hourly usage data with hourly weather data acquired from the National Oceanic and Atmospheric Administration (NOAA)[13]. NSTAR provided a list of event dates and times.

Methodology

Navigant estimated a fixed effects regression model using hourly load data for participants. At a high level, Navigant estimated the impacts of load control and CPP events by comparing hourly load on event days to hourly load on non-event days (excluding holidays and weekends). Note that this model isolates the event impacts; these impacts may be considered incremental to any peak load impacts. The regression predicts hourly load as a function of the hour of the day, temperature humidity index (THI), cooling degree hours (CDH)[14], previous day's maximum THI[15], load during the hour beginning at 10am[16], and a series of event-related variables. The event-related variables include binary variables for event hour (hours 12 through 16), THI during the event hour, and a series of binary snapback variables (hours 17

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[13] Navigant used participants' zip codes to map them to the nearest weather station. The dataset for the impact analysis includes hourly data from twelve weather stations.

[14] Cooling degree hours were calculated with a base temperature of 65 degrees Fahrenheit. CDH = max (0, temp – 65).

[15] The previous day's maximum THI is included in the model to capture heat buildup. Heat buildup occurs when the building mass retains heat. A hot day will cause a building to heat up, and even if the next day is mild, the heat buildup can persist in the building mass.

[16] The load during the hour from 10-11 am is included in the model to capture daily idiosyncrasies in the load level. This variable is analogous to using a day-of adjustment for the load curve in comparison day methodologies.

through 19). The regression models were estimated separately for each of the four pilot groups. Formally, Navigant estimated the following model:

$$kW_{it} = \alpha_i + \beta * LagMaxTHI_{it} + \gamma * Load10am_{it} + \sum_{j=1}^{23} \delta_j * Hour_{jt} + \sum_{j=1}^{23} \eta_j * Hour_{jt} * THI_{it} + \sum_{j=1}^{23} \theta_j * Hour_{jt} * THI_{it}^2 + \sum_{j=1}^{23} \lambda_j * Hour_{jt} * CDH_{it} + \sum_{j=1}^{23} \rho_j * Hour_{jt} * CDH_{it}^2 + \sum_{j=12}^{16} \omega_j * Event_{jt} + \sum_{j=12}^{16} \psi_j * Event_{jt} * THI_{it} + \sum_{j=17}^{19} \tau_j * Snapback_{jt} + \varepsilon_{it}$$

Where $\beta, \gamma, \delta, \eta, \theta, \lambda, \rho, \omega, \psi, \tau$ are parameters to be estimated by the model and:

i	= Index for participants
t	= Index for hourly time intervals
kW	= Average hourly kW
LagMaxTHI	= Previous day's maximum THI
Load10am	= Average kW from 10-11am
$Hour_j$	= Indicator variable for hour j (set of 23 variables)
THI	= Temperature Humidity Index
CDH	= Cooling Degree Hours
Event	= Indicator variable for event hour j (set of 5 variables)
Snapback	= Indicator variable for snapback hour j (set of 3 variables), the 3 hours following an event.
α_i	= The customer-specific constant term ("fixed effect").
ε_{it}	= The cluster-robust error term[17]

The event impacts are determined by the parameter estimates for the Event indicator variables and the Event*THI variables (ω, ψ).

[17] Cluster-robust errors account for heteroscedasticity and autocorrelation at the customer level. Ordinary Least Squares (OLS) regression models assume the data are homoscedastic and not autocorrelated. If either of these assumptions is broken, the resulting standard errors of the parameter estimates are likely underestimated. A random variable is heteroscedastic when the variance is not constant. A random variable is autocorrelated when the error term in this period is correlated with the error term in previous periods.

Data were excluded from the regression model if any of the following criteria were met:

- The interval was outside the date range of June 16, 2012 to September 7, 2012 (these dates correspond to roughly one week prior to the first event and one week after the last event)
- The interval occurred during a weekend or holiday
- The customer was missing more than 25% of event-day observations
- The interval duration was less than 45 minutes or greater than 75 minutes
- The usage was determined to be erroneous or an outlier[18]

A.2 Peak Load and Time-of-Day Impact Analysis

The peak period and time-of-day impact analysis quantified the amount of load shifting that occurred in response to the pilot.

Data Requirements

The peak load and time-of-day impact analysis required hourly impact data for all pilot participants and a control group (refer to Table 2-4). For pilot participants, Navigant received 15-minute interval readings of cumulative kWh, which were then differenced and aggregated to obtain the average kW during a one-hour period. The control group was selected from the NSTAR load research group; customers in the load research group are on the standard flat rate. Navigant received hourly data for 533 customers in the load research group. Navigant combined the interval data with weather data and demographic characteristics, as described in Section A.1. Note that demographic data was only available for pilot participants. Navigant also used monthly bills for participants prior to their enrollment in the pilot program, as discussed in the next section.

Methodology

The first step of the peak load and time-of-day impact analysis was to select matched controls from the load research group for each of the pilot participants. Ideally this process would compare load shapes for participants and load research customers during the pre-program period. However, interval data for pilot participants does not exist prior to the start of the program. Consequently, matching pilot participants to load research customers based on their load shapes was not possible. Instead, Navigant matched pilot participants to load research customers by comparing monthly bills via the following process:

1. Aggregate hourly interval data for each load research customer to the corresponding billing period for each pilot participant. For example, if a pilot participant has a monthly bill spanning

[18] Two customers had observations with erroneous usage; the erroneous observations were dropped. One customer had significantly higher usage on their first two days in the program compared to usage on all other days; observations during these two days were dropped, but subsequent observations were included. Additionally, Navigant removed observations corresponding to meter spikes (extremely large increases or decreases in cumulative usage readings).

July 18th to August 17th, all hourly intervals during this period for each load research customer are summed to create the corresponding monthly bill for all potential controls.

2. For each participant – load research customer pair, calculate the sum of squared differences between the participant's bills and the load research customer's bills.

3. Select the load research customer with the minimum sum of squared differences for each participant. This is the matched control for that participant. Note that a given load research customer may be selected as the matched control for multiple pilot participants.

This matching process ensures that, on average, participants and matched controls have the same monthly energy consumption *prior* to the pilot period, implying that any difference in monthly energy consumption *during* the pilot period is a result of the pilot. However, the matching process does not ensure that participants and matched controls have the same *load shapes* prior to the pilot period. **Therefore, any difference in load shapes during the pilot period could be the result of the pilot, or could be due to differences in load shapes that pre-date the pilot.** Unfortunately, absent pre-pilot interval data for participants, it is not possible to distinguish the source of the difference in load shapes between pilot participants and load research customers. **Navigant recommends that future smart grid pilots and programs collect pre-enrollment interval data**, for example by installing the AMI and delaying the pilot or program enrollment by a short period (at least one month).

Navigant and NSTAR are not aware of any systematic differences between the pilot participants and the load research customers. Customers in the load research group are not aware of their participation in the group and do not receive a monetary incentive for participating. Load research customers were selected by randomly sampling geographic regions within the NSTAR service territory. The load research group was designed to be a representative sample of the residential customer base. However, the possibility remains that load research customers systematically differ from pilot participants, especially due to the opt-in nature of the pilot program.

Once the matched controls were selected, Navigant estimated an hourly regression model using hourly load data for participants and matched controls. At a high level, Navigant estimated the peak load and time-of-day impacts by comparing load for pilot participants to load for matched controls. The regression predicts hourly load as a function of the heating or cooling degree hours (HDH or CDH)[19], temperature humidity index (THI), load from 6-9 am[20], previous day's maximum THI[21], previous day's minimum temperature, participation indicator variable, and a series of participation interaction variables. The participation interaction variables include the participation indicator variable interacted with degree days, THI, and load from 6-9 am to determine whether the impact of the pilot varies with weather. The regression models were estimated separately for each hour, pilot group, day type (weekend or weekday),

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[19] Heating and cooling degree hours were calculated with a base temperature of 65 degrees Fahrenheit. CDH = max(0, temp-65). HDH = max(0, 65-temp).

[20] The load during the hours from 6-9 am is included in the model to capture daily idiosyncrasies in the load level.

[21] The previous day's maximum THI is included in the model to capture heat buildup. Heat buildup occurs when the building mass retains heat. A hot day will cause a building to heat up, and even if the next day is mild, the heat buildup can persist in the building mass.

and season (winter or summer). Formally, Navigant estimated the following hourly model for the summer season:

$$kW_{it} = \alpha + \beta * CDH_{it} + \gamma * CDH_{it}^2 + \delta * THI_{it} + \eta * THI_{it}^2 + \theta * MorningLoad_{it} + \lambda * LagMaxTHI_{it} + \rho * Participant_i + \omega * Participant_i * CDH_{it} + \psi * Participant_i * THI_{it} + \tau * Participant_i * MorningLoad_{it} + \epsilon_{it}$$

Navigant estimated the following hourly model for the winter season:

$$kW_{it} = \alpha + \beta * HDH_{it} + \gamma * HDH_{it}^2 + \theta * MorningLoad_{it} + \lambda * LagMinTemp_{it} + \rho * Participant_i + \omega * Participant_i * HDH_{it} + \tau * Participant_i * MorningLoad_{it} + \epsilon_{it}$$

Where $\alpha, \beta, \gamma, \delta, \eta, \theta, \lambda, \rho, \omega, \psi, \tau$ are parameters to be estimated by the model and:

i	= Index for participants
t	= Index for days
kW	= Average hourly kW
CDH	= Cooling Degree Hours
HDH	= Heating Degree Hours
THI	= Temperature Humidity Index
MorningLoad	= Average kW from 6-9am
LagMaxTHI	= Previous day's maximum THI
LagMinTemp	= Previous day's minimum temperature (F)
Participant	= Indicator variable for pilot participants
ϵ_{it}	= The cluster-robust error term[22]

Peak load and time-of-day impacts are determined by the parameter estimates for the participation indicator variable and interaction terms (ρ, ω, ψ, τ).

Data were excluded from the regression model if any of the following criteria were met:

- The interval occurred during an event day or holiday
- The interval was outside the date range of January 1, 2012 to September 30, 2012

[22] Cluster-robust errors account for heteroscedasticity and autocorrelation at the customer level. Ordinary Least Squares (OLS) regression models assume the data are homoscedastic and not autocorrelated. If either of these assumptions is broken, the resulting standard errors of the parameter estimates are likely underestimated. A random variable is heteroscedastic when the variance is not constant. A random variable is autocorrelated when the error term in this period is correlated with the error term in previous periods.

- The interval duration was less than 45 minutes or greater than 75 minutes
- The usage was determined to be erroneous or an outlier[23]

A.3 Energy Impact Analysis

The energy impact analysis quantified the change in seasonal energy usage.

Data Requirements

The energy impact analysis required monthly energy billing data for all pilot participants and a control group (refer to **Error! Reference source not found.**). The control group was selected from a pool of 10,000 non-participants, randomly selected from NSTAR's residential customer population. Navigant received monthly billing data spanning December 2008 through September 2012. Navigant used daily weather data to calculate the heating and cooling degree days for each bill cycle. Monthly billing data was combined with the weather and demographic characteristics, as described in Appendix A. Note that demographic data was only available for pilot participants.

Methodology

The first step of the energy impact analysis was to select matched controls from the pool of 10,000 randomly selected non-participants. Navigant matched pilot participants to non-participants by comparing monthly bills during the period prior to pilot enrollment. The process consisted of two steps:

1. For each participant – non-participant customer pair, calculate the sum of squared differences between the participant's bills and the non-participant's bills prior to enrollment in the program. The number of bills available for comparison varies based on the participant's pilot enrollment date.
2. Select the non-participant with the minimum sum of squared differences for each participant. This is the matched control for that participant. Note that a given non-participant may be selected as the matched control for multiple pilot participants.

This matching process ensures that, on average, participants and matched controls have the same monthly energy consumption *prior* to the pilot period, implying that any difference in monthly energy consumption *during* the pilot period is a result of the pilot.

Once the matched controls were selected, Navigant estimated a seasonal regression model using monthly energy billing data for participants and matched controls. At a high level, Navigant estimated the energy impacts by comparing the usage for pilot participants to usage for matched controls. The regression

[23] The 99th percentile of readings was 5.15 kW. Navigant defined an observation as an outlier if the hourly demand exceeded 20 kWh. Navigant identified 576 such observations and determined there were three primary causes for the outliers: 1) meter spikes (extremely large increases or decreases in cumulative usage readings); 2) unusually high readings for a given customer (corresponding to a period of several days to several weeks); and 3) customers with extremely high usage. The second and third causes could correspond to valid meter readings. However, they were assumed to come from a different distribution than the majority of the observations, and were therefore excluded from the analysis.

predicts average daily energy usage[24] as a function of the heating or cooling degree days (HDD or CDD)[25] and a participation indicator variable. The regression model was estimated separately for each pilot group and season (winter or summer). Formally, Navigant estimated the following model for the summer season:

$$kWh_{it} = \alpha + \beta * CDD + \gamma * Participant + \epsilon_{it}$$

Navigant estimated the following model for the winter season:

$$kWh_{it} = \alpha + \beta * HDD + \gamma * Participant + \epsilon_{it}$$

Where α, β, γ are parameters to be estimated by the model and:

i	= Index for participants
t	= Index for days
kWh	= Average daily kWh
CDD	= Average daily Cooling Degree Days
HDD	= Average daily Heating Degree Days
Participant	= Indicator variable for pilot participants
ϵ_{it}	= The cluster-robust error term[26]

Energy impacts are determined by the parameter estimate for the participation indicator variable (γ).

Data were excluded from the regression model if any of the following criteria were met:

- The bill period end date was outside the date range of January 1, 2012 to September 30, 2012
- The bill period end date occurred before the participant enrolled in the pilot

[24] Monthly energy usage is normalized by the number of days in the billing cycle to reduce variation in energy usage attributable to variation in billing cycle length. Such normalization is standard industry practice.

[25] Heating and cooling degree days were calculated with a base temperature of 65 degrees Fahrenheit. CDD = max(0, temp-65). HDD = max(0, 65-temp).

[26] Cluster-robust errors account for heteroscedasticity and autocorrelation at the customer level. Ordinary Least Squares (OLS) regression models assume the data are homoscedastic and not autocorrelated. If either of these assumptions is broken, the resulting standard errors of the parameter estimates are likely underestimated. A random variable is heteroscedastic when the variance is not constant. A random variable is autocorrelated when the error term in this period is correlated with the error term in previous periods.

Appendix B. mpact Analysis Detailed Results

This appendix contains the detailed results from the impact analysis. The tables comply with the Common Evaluation Framework prepared by the Massachusetts Smart Grid Collaborative Technical Subcommittee and filed with the Massachusetts Department of Public Utilities on March 23, 2011[27]. Note that the group numbers here differ from the NSTAR convention used throughout the report.

Summer is defined as the period from June 1 through September 30, 2012. Winter is defined as the period from January 1 through May 31, 2012. Total pilot reductions are the sum of summer and winter reductions. The peak period is defined as 12-5pm during the summer and 4-9pm during the winter. Summer and winter peak energy reductions are the peak demand reductions multiplied by the number of hours during the season.

Results – All Participants, by Pilot Test Group

Table B-1 below contains the impacts during the period of January 1 to September 30, 2012 for all pilot participants, by pilot test group. *Impacts in bold are statistically significantly different from zero at the 90% confidence level.*

Table B-1. Impact Results, All Participants*

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Table 2A
Demand Response Impact Table - All Participants

1	Company		Test Group	# of parts.	Overal Reduction										Demand Reduction during Peak Periods				Demand Reduction during CPP			
					Summer		Winter		Summer Peak		Winter Peak		Total Pilot		Summer Peak		Winter Peak		Summer		Winter	
					%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	%	kW
	NSTAR	1	Enhanced Information	878	0.6%	17.8	1.5%	49.3	**4.1%**	**18.4**	**9.9%**	**43.6**	7.3%	67.1	**4.1%**	**0.04**	**9.9%**	**0.08**	**-11.4%**	**-0.18**	NA	NA
		2	Peak Time Rebate + LC	323	-1.2%	-50.9	-0.7%	-28.6	**4.2%**	**26.6**	**12.3%**	**73.1**	8.7%	-79.6	**4.2%**	**0.06**	**12.3%**	**0.14**	**18.6%**	**0.48**	NA	NA
		3	TOU + CPP w/ LC	309	6.1%	249.6	2.9%	109.5	**10.4%**	**58.4**	**14.6%**	**76.0**	12.7%	359.1	**10.4%**	**0.14**	**14.6%**	**0.14**	**26.0%**	**0.52**	NA	NA
		4	TOU + CPP	917	4.6%	140.6	2.8%	91.5	**15.6%**	**66.8**	**15.7%**	**72.1**	15.7%	232.2	**15.6%**	**0.16**	**15.7%**	**0.14**	**6.4%**	**0.08**	NA	NA

Source: Navigant analysis, based on participant billing data from January 1 through September 30, 2012
* Impacts in bold are statistically significantly different from zero at the 90% confidence level.

[27] The Common Evaluation Framework is part of Docket 10-82, available at http://www.env.state.ma.us/dpu/docs/electric/10-82/32311msfl.pdf

Results – by Demographic Subgroup and by Pilot Test Group

Table B-2 through Table B-10 below contain the impacts during the period of January 1 to September 30, 2012 for pilot participants, by pilot test group and demographic characteristic. Demographic characteristics were determined from several different data sources. The pre-pilot participant survey data indicated participants with high income (>$100,000), presence of a senior citizen (65 years and older), small homes (<1,000 square feet), and large homes (>2,500 square feet). Customer billing data indicated customers on a low-income rate and was used to determine customers with low and high usage (< 50% or >150% of the residential class average usage, respectively).

Impacts in bold are statistically significantly different from the group average (provided in Table B-1) at the 90% confidence level.[28] Gray boxes indicate that results were not statistically significantly different from zero at the 80% confidence level or that sample sizes were too small to produce meaningful results. Note that even if results are statistically significant, the sample size may be extremely small. Generally, with smaller sample sizes the results are less generalizable to the entire population. Navigant recommends that results based on fewer than 30 customers are considered not generalizable to additional participants.

Impact results for the following demographic subgroups are presented below:

- Low income
- High income
- Low use
- High use
- Low income, low use
- Low income, high use
- Presence of a senior
- Small homes
- Large homes

[28] Only kW and kWh impacts were tested. Percentage impacts were not tested.

Table B-2. Impact Results, Low Income Participants

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Table 2B
Demand Response Impact Table - Low Income Participants

Company		Test Group	# of parts.	Overal Reduction										Demand Reduction during Peak Periods				Demand Reduction during CPP			
				Summer		Winter		Summer Peak		Winter Peak		Total Pilot		Summer Peak		Winter Peak		Summer		Winter	
				%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	%	kW
NSTAR	1	Enhanced Information	20	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	NA	NA
	2	Peak Time Rebate + LC	4	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	NA	NA
	3	TOU + CPP w/ LC	0	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	NA	NA
	4	TOU + CPP	0	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	NA	NA

Source: Navigant analysis, based on participant billing data from January 1 through September 30, 2012

* All reported impacts are statistically significantly different from zero at the 80% confidence level. Gray boxes indicate results were not statistically significant or that sample sizes were too small to produce meaningful results. Navigant tested the difference in kW or kWh impacts for each demographic subgroup compared to the pilot group average; impacts in bold are statistically significantly different from the pilot group average (Table B-1) at the 90% confidence level.

<u>Note</u>: Only 24 participants were on a low-income rate prior to joining the program. The number of low-income participants in the pilot is more than 50 when the definition of low income includes participants whose self-reported income (from the pre-pilot survey) places them at or below 150% of the federal poverty level. The final pilot evaluation report in 2014 will estimate savings for all low-income participants. NSTAR also plans to conduct a survey and/or focus groups in 2013 to elicit feedback from low-income customers (both participants and non-participants) on the Smart Grid in general and on technologies and rates specific to the pilot.

Table B-3. Impact Results, High Income Participants

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Table 2C
Demand Response Impact Table - High Income Participants

Company		Test Group	# of parts.	Overal Reduction										Demand Reduction during Peak Periods				Demand Reduction during CPP			
				Summer		Winter		Summer Peak		Winter Peak		Total Pilot		Summer Peak		Winter Peak		Summer		Winter	
				%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	%	kW
NSTAR	1	Enhanced Information	285	%	kWh	%	kWh	9.4%	**45.9**	10.0%	**66.2**	%	kWh	9.4%	**0.11**	10.0%	**0.13**	-10.4%	**-0.17**	NA	NA
	2	Peak Time Rebate + LC	143	%	kWh	%	kWh	5.4%	**34.4**	7.5%	**61.1**	%	kWh	5.4%	**0.08**	7.5%	**0.12**	18.3%	0.48	NA	NA
	3	TOU + CPP w/ LC	159	%	kWh	%	kWh	14.6%	**87.8**	11.2%	**83.4**	%	kWh	14.6%	**0.21**	11.2%	**0.16**	28.7%	**0.60**	NA	NA
	4	TOU + CPP	384	%	kWh	%	kWh	17.2%	**84.4**	9.7%	**66.0**	%	kWh	17.2%	**0.20**	9.7%	**0.13**	5.1%	**0.08**	NA	NA

Source: Navigant analysis, based on participant billing data from January 1 through September 30, 2012

* All reported impacts are statistically significantly different from zero at the 80% confidence level. Gray boxes indicate results were not statistically significant or that sample sizes were too small to produce meaningful results. Navigant tested the difference in kW or kWh impacts for each demographic subgroup compared to the pilot group average; impacts in bold are statistically significantly different from the pilot group average (Table B-1) at the 90% confidence level.

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Table B-4. Impact Results, Low-Use Participants

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Table 2D
Demand Response Impact Table - Low-Use Participants

Company		Test Group	# of parts.	Overal Reduction										Demand Reduction during Peak Periods				Demand Reduction during CPP			
				Summer		**Winter**		**Summer Peak**		**Winter Peak**		**Total Pilot**		**Summer Peak**		**Winter Peak**		**Summer**		**Winter**	
				%	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**	**kW**	**%**	**kW**	**%**	**kW**	**%**	**kW**
NSTAR	1	Enhanced Information	155	%	kWh	%	kWh	15.5%	**25.6**	12.3%	**33.2**	%	kWh	15.5%	**0.06**	12.3%	**0.06**	-14%	**-0.07**	NA	NA
	2	Peak Time Rebate + LC	19	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	37%	**0.32**	NA	NA
	3	TOU + CPP w/ LC	21	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	43%	**0.22**	NA	NA
	4	TOU + CPP	130	%	kWh	%	kWh	9.0%	**13.4**	10.9%	**29.8**	%	kWh	9.0%	**0.03**	10.9%	**0.06**	%	kW	NA	NA

Source: Navigant analysis, based on participant billing data from January 1 through September 30, 2012

* All reported impacts are statistically significantly different from zero at the 80% confidence level. Gray boxes indicate results were not statistically significant or that sample sizes were too small to produce meaningful results. Navigant tested the difference in kW or kWh impacts for each demographic subgroup compared to the pilot group average; impacts in bold are statistically significantly different from the pilot group average (Table B-1) at the 90% confidence level.

Table B-5. Impact Results, High-Use Participants

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Table 2E
Demand Response Impact Table - High-Use Participants

Company		Test Group	# of parts.	Overal Reduction										Demand Reduction during Peak Periods				Demand Reduction during CPP			
				Summer		**Winter**		**Summer Peak**		**Winter Peak**		**Total Pilot**		**Summer Peak**		**Winter Peak**		**Summer**		**Winter**	
				%	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**	**kW**	**%**	**kW**	**%**	**kW**	**%**	**kW**
NSTAR	1	Enhanced Information	149	%	kWh	%	kWh	-3.5%	**-34.5**	6.8%	**84.0**	%	kWh	-3.5%	**-0.08**	6.8%	**0.16**	-11%	**-0.42**	NA	NA
	2	Peak Time Rebate + LC	84	%	kWh	%	kWh	5.4%	**61.2**	9.9%	**131.0**	%	kWh	5.4%	**0.15**	9.9%	**0.25**	19%	**0.90**	NA	NA
	3	TOU + CPP w/ LC	81	%	kWh	%	kWh	0.4%	**3.7**	9.1%	**104.3**	%	kWh	0.4%	**0.01**	9.1%	**0.20**	32%	**1.20**	NA	NA
	4	TOU + CPP	112	%	kWh	%	kWh	12.7%	**116.7**	13.3%	**166.4**	%	kWh	12.7%	**0.28**	13.3%	**0.32**	12%	**0.37**	NA	NA

Source: Navigant analysis, based on participant billing data from January 1 through September 30, 2012

* All reported impacts are statistically significantly different from zero at the 80% confidence level. Gray boxes indicate results were not statistically significant or that sample sizes were too small to produce meaningful results. Navigant tested the difference in kW or kWh impacts for each demographic subgroup compared to the pilot group average; impacts in bold are statistically significantly different from the pilot group average (Table B-1) at the 90% confidence level.

Table B-6. Impact Results, Low Income and Low-Use Participants

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Table 2F
Demand Response Impact Table - Low-Use & Low Income Participants

Company	Test Group	# of parts.	Overal Reduction										Demand Reduction during Peak Periods				Demand Reduction during CPP			
			Summer		Winter		Summer Peak		Winter Peak		Total Pilot		Summer Peak		Winter Peak		Summer		Winter	
			%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	%	kW
NSTAR	1 Enhanced Information	3	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	NA	NA
	2 Peak Time Rebate + LC	1	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	NA	NA
	3 TOU + CPP w/ LC	0	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	NA	NA
	4 TOU + CPP	0	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	NA	NA

Source: Navigant analysis, based on participant billing data from January 1 through September 30, 2012

* All reported impacts are statistically significantly different from zero at the 80% confidence level. Gray boxes indicate results were not statistically significant or that sample sizes were too small to produce meaningful results. Navigant tested the difference in kW or kWh impacts for each demographic subgroup compared to the pilot group average; impacts in bold are statistically significantly different from the pilot group average (Table B-1) at the 90% confidence level.

Table B-7. Impact Results, Low Income and High-Use Participants

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Table 2G
Demand Response Impact Table - High-Use & Low Income Participants

Company	Test Group	# of parts.	Overal Reduction										Demand Reduction during Peak Periods				Demand Reduction during CPP			
			Summer		Winter		Summer Peak		Winter Peak		Total Pilot		Summer Peak		Winter Peak		Summer		Winter	
			%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	%	kW
NSTAR	1 Enhanced Information	1	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	NA	NA
	2 Peak Time Rebate + LC	0	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	NA	NA
	3 TOU + CPP w/ LC	0	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	NA	NA
	4 TOU + CPP	0	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	NA	NA

Source: Navigant analysis, based on participant billing data from January 1 through September 30, 2012

* All reported impacts are statistically significantly different from zero at the 80% confidence level. Gray boxes indicate results were not statistically significant or that sample sizes were too small to produce meaningful results. Navigant tested the difference in kW or kWh impacts for each demographic subgroup compared to the pilot group average; impacts in bold are statistically significantly different from the pilot group average (Table B-1) at the 90% confidence level.

Table B-8. Impact Results, Participants with the Presence of a Senior

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Table 2H
Demand Response Impact Table - Participants with the presence of a senior

				Overal Reduction										Demand Reduction during Peak Periods				Demand Reduction during CPP			
				Summer		**Winter**		**Summer Peak**		**Winter Peak**		**Total Pilot**		**Summer Peak**		**Winter Peak**		**Summer**		**Winter**	
Company		**Test Group**	**# of parts.**	**%**	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**	**kW**	**%**	**kW**	**%**	**kW**	**%**	**kW**
NSTAR	1	Enhanced Information	57	%	kWh	%	kWh	-21.1%	**-85.9**	4.7%	**29.0**	%	kWh	-21.1%	**-0.20**	4.7%	**0.06**	-12%	-0.20	NA	NA
	2	Peak Time Rebate + LC	14	%	kWh	%	kWh	-11.5%	**-42.0**	4.8%	**26.6**	%	kWh	-11.5%	**-0.10**	4.8%	**0.05**	30%	0.54	NA	NA
	3	TOU + CPP w/ LC	20	%	kWh	%	kWh	14.5%	**67.5**	8.0%	**49.3**	%	kWh	14.5%	**0.16**	8.0%	**0.09**	33%	**0.61**	NA	NA
	4	TOU + CPP	81	%	kWh	%	kWh	14.0%	**62.9**	11.7%	**74.9**	%	kWh	14.0%	**0.15**	11.7%	**0.14**	%	kW	NA	NA

Source: Navigant analysis, based on participant billing data from January 1 through September 30, 2012

* All reported impacts are statistically significantly different from zero at the 80% confidence level. Gray boxes indicate results were not statistically significant or that sample sizes were too small to produce meaningful results. Navigant tested the difference in kW or kWh impacts for each demographic subgroup compared to the pilot group average; impacts in bold are statistically significantly different from the pilot group average (Table B-1) at the 90% confidence level.

Table B-9. Impact Results, Participants with Small Homes

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Table 2I
Demand Response Impact Table - Small homes

				Overal Reduction										Demand Reduction during Peak Periods				Demand Reduction during CPP			
			# of	Summer		Winter		Summer Peak		Winter Peak		Total Pilot		Summer Peak		Winter Peak		Summer		Winter	
9	Company	Test Group	parts.	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	%	kW
	NSTAR	1 Enhanced Information	54	%	kWh	%	kWh	4.4%	**8.8**	10.4%	**31.5**	%	kWh	4.4%	**0.02**	10.4%	**0.06**	-17%	**-0.11**	NA	NA
		2 Peak Time Rebate + LC	10	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	43%	0.51	NA	NA
		3 TOU + CPP w/ LC	15	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	44%	0.50	NA	NA
		4 TOU + CPP	48	%	kWh	%	kWh	5.2%	**10.6**	9.0%	**27.5**	%	kWh	5.2%	**0.03**	9.0%	**0.05**	%	kW	NA	NA

Source: Navigant analysis, based on participant billing data from January 1 through September 30, 2012

* All reported impacts are statistically significantly different from zero at the 80% confidence level. Gray boxes indicate results were not statistically significant or that sample sizes were too small to produce meaningful results. Navigant tested the difference in kW or kWh impacts for each demographic subgroup compared to the pilot group average; impacts in bold are statistically significantly different from the pilot group average (Table B-1) at the 90% confidence level.

Table B-10. Impact Results, Participants with Large Homes

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Table 2J
Demand Response Impact Table - Large homes

				Overal Reduction										Demand Reduction during Peak Periods				Demand Reduction during CPP			
			# of	Summer		Winter		Summer Peak		Winter Peak		Total Pilot		Summer Peak		Winter Peak		Summer		Winter	
10	Company	Test Group	parts.	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kW	%	kW	%	kW	%	kW
	NSTAR	1 Enhanced Information	102	%	kWh	%	kWh	-8.7%	**-52.9**	7.0%	**58.1**	%	kWh	-8.7%	**-0.13**	7.0%	**0.11**	-10%	**-0.25**	NA	NA
		2 Peak Time Rebate + LC	77	%	kWh	%	kWh	0.7%	**5.1**	5.5%	**50.0**	%	kWh	0.7%	**0.01**	5.5%	**0.10**	18%	**0.58**	NA	NA
		3 TOU + CPP w/ LC	62	%	kWh	%	kWh	17.8%	**132.7**	10.3%	**94.4**	%	kWh	17.8%	**0.32**	10.3%	**0.18**	34%	**0.89**	NA	NA
		4 TOU + CPP	139	%	kWh	%	kWh	13.3%	**80.3**	12.4%	**105.9**	%	kWh	13.3%	**0.19**	12.4%	**0.20**	14%	**0.30**	NA	NA

Source: Navigant analysis, based on participant billing data from January 1 through September 30, 2012

* All reported impacts are statistically significantly different from zero at the 80% confidence level. Gray boxes indicate results were not statistically significant or that sample sizes were too small to produce meaningful results. Navigant tested the difference in kW or kWh impacts for each demographic subgroup compared to the pilot group average; impacts in bold are statistically significantly different from the pilot group average (Table B-1) at the 90% confidence level.