Smart Homes and Smarter Consumers: How the Internet and Home Area Networks Can Enable Energy Efficient Behavior

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Abstract

Residential Smart Grids efforts typically require a massive investment in metering and communications infrastructure that can result in stranded assets through the premature replacement of fully functioning and non-depreciated equipment. However, Boston, Massachusetts-based Eversource (NSTAR), an electric utility company serving more than 1 million customers, has demonstrated the viability of leveraging existing automated meter reading (AMR) deployments common throughout the U.S. and Europe to mimic advanced metering infrastructure (AMI) capabilities at significantly lower cost. By using home-area networks (HAN) and customer broadband connections to create a two-way communications pathway, the utility has enabled residential dynamic pricing, two-way direct load control, and the provision of near real-time customer information. This paper describes the technology and program/pricing designs and presents final energy savings and peak load reduction findings from the 2,700-customer, three-year smart grid pilot that concluded in 2014.

More generally, the paper reports on the successes and uncertainties in 1) enabling time-differentiated rates without replacing existing metering infrastructure, and 2) integrating with legacy billing and back-office applications. The pilot was part of the U.S. Department of Energy's Smart Grid Demonstration grant program (part of the post-recession economic stimulus package) and is now providing information to policy makers in the state of Massachusetts regarding the merits of a large scale investment in smart meters. The findings are applicable throughout the U.S. and Europe where smart meter investments are pending.

Introduction

Residential Smart Grids efforts typically require a massive investment in metering and communications infrastructure (smart meters[1]) that can result in stranded assets through the premature replacement of fully functioning and non-depreciated equipment. However, Boston, Massachusetts-based NSTAR Electric & Gas Corporation ("the Company" or "NSTAR")[2], an electric utility company serving more than 1 million customers, has demonstrated the viability of leveraging existing automated meter reading (AMR) deployments common throughout the U.S. and Europe to mimic advanced metering infrastructure (AMI) capabilities at significantly lower cost. By using home-area networks (HAN) and customer broadband connections to create a two-way communications pathway, the utility has enabled residential dynamic pricing, two-way direct load control, and the provision of near real-time customer information.

NSTAR developed and implemented a Smart Grid pilot program beginning in 2010 to demonstrate the viability of leveraging existing AMR deployments to provide much of the Smart Grids functionality of AMI, but without the large capital investment that AMI rollouts typically entail.[3] In particular, a central objective of the pilot was to enable residential dynamic pricing (time-of-use [TOU] and critical peak

[1] "Smart meters" is a common term used to describe the customer-sited equipment that is part of an "intelligent metering system", defined as "an electronic system that can measure energy, consumption, providing more information than a conventional meter, and can transmit and receive data using a form of electronic communication." See Energy Efficiency Directive (2012/27/EU), OJ L315, 14 November, 2012, Article 2, Point 28.

[2] In February 2015 NSTAR, its parent company Northeast Utilities, and all subsidiaries rebranded themselves as Eversource Energy.

[3] 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. Source: 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.

rates and rebates) and two-way direct load control (DLC) by continually capturing AMR meter data transmissions and communicating through customer-sited broadband connections in conjunction with a standards-based HAN. This enabled recording of interval consumption data and transfer of data to NSTAR via a two-way communications pathway, which was also used for sending load control signals and measuring demand response load impacts.

By the official start of the pilot in January 2012, NSTAR had enrolled approximately 3,600 customers and ultimately installed the enabling Smart Grids equipment at roughly 2,700 homes. As of the end of the pilot in December 2014, approximately 1,500 customers remained enrolled, or roughly 57% of initial participants.[4]

Pilot Programme Experimental Design

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

Table 1. Smart Grid Pilot Customer Test Groups

#	Test Group	Description of Test Group[a]	AC Load Control[b]	Number of Participants
1	Enhanced Information	Access to information on energy consumption only; standard rate		1,021
2	Peak Time Rebate	$5 (€6) rebate for automated participation in “critical peak” events via NSTAR control of a smart thermostat; standard rate	☑	422
3	TOU Rate plus Critical Peak Pricing (CPP) [c]	TOU rate with CPP; smart thermostat controlled by NSTAR during CPP events	☑	380
4		TOU rate with CPP		894
Total				**2,717**

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

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

[c] The TOU peak supply price was more than double the standard supplier charges, while the off-peak rate was approximately 60% of the otherwise applicable supply rate.

Source: NSTAR

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

1. **A new TOU rate with CPP for events called by NSTAR.** NSTAR established peak period TOU and CPP rates significantly above the standard residential basic service rate in order to provide an effective price incentive for customers to shift usage off-peak. The TOU peak supply price was in effect between 12.00h and 17.00h in the summer months and between. 16.00h and 21.00 in winter. Peak period pricing was roughly double the off-peak price, and the CPP rate was significantly higher still, at nearly seven times the off-peak price.[5]

[4] NSTAR conducted a “pre-launch of the pilot with about 200 participants in 2011. The official commencement of the pilot, January 2012, was determined by agreement with the U.S. Department of Energy (DOE), which co-funded the effort as part of the Smart Grid Demonstration grant program (part of President Obama’s post-recession economic stimulus package).

[5] Illustrative electricity prices in the pilot were $0.13/kWh off-peak, $0.25/kWh on-peak, and $0.90/kWh during CPP events. Actual prices varied over time depending on the wholesale cost of electricity.

2. **A peak time rebate overlaid on the standard applicable rate,** with a pre-established rebate amount awarded to customers who utilized automated thermostat controls or an automated AC load control switch to reduce load during critical peak events.[6]

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

Smart Grids Technology

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

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

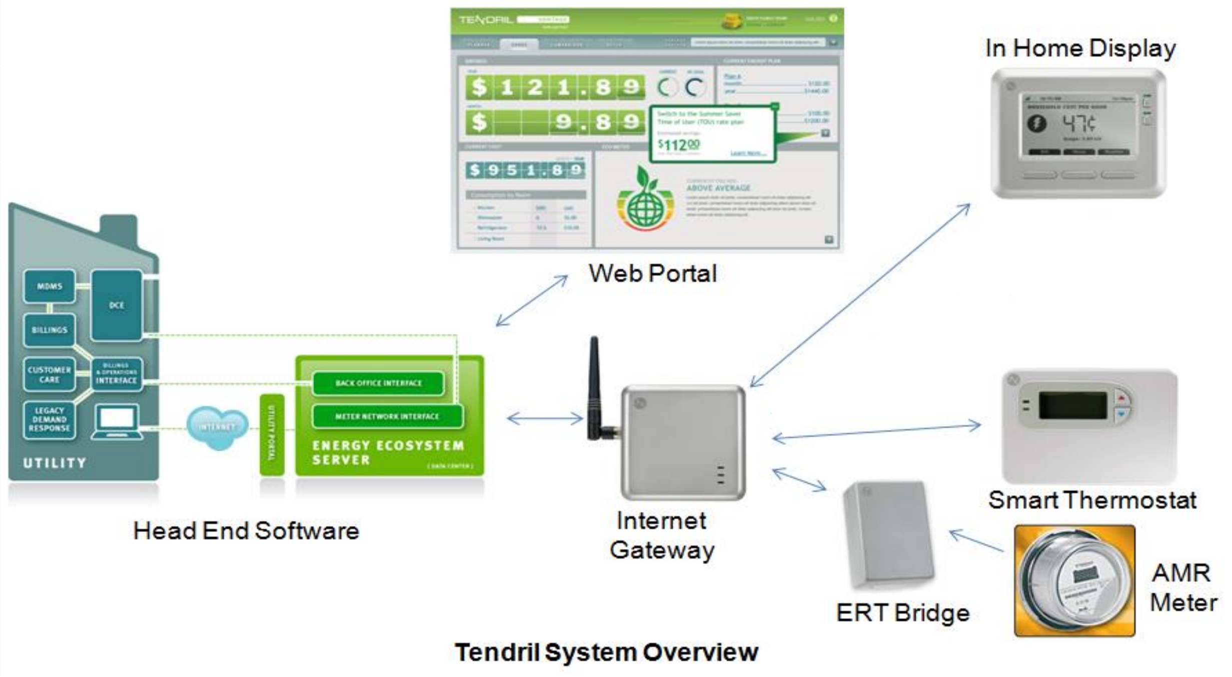
This technology infrastructure was intended to establish a reliable backhaul communications pathway from the meter to NSTAR's internal systems and allow meter reading resolution suitable for TOU and CPP rate plans. The deployed equipment also enabled automated load control of central air conditioning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

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

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

[6] The peak time rebate was a no-risk alternative intended to achieve peak demand reductions by providing customers with a financial incentive to reduce load during critical events called by NSTAR. Customers retained their usual rates but would receive rebates for reduced consumption during events. All customers participating in the critical peak rebate offering were required to have central air conditioning and were provided a smart thermostat that enabled automated load control by adjusting AC temperature during events. During events, thermostat settings were remotely raised by NSTAR to between 1 and 6 degrees F (NSTAR determined the setback for each event). Participants could opt out of any individual event, foregoing the $5 rebate each time they did so.

Figure 1. Components of the Smart Grid Technology Platform



Source: Tendril

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

- **Web portal:** The *Tendril Vantage* is a browser-based Internet portal that enabled monitoring, management, and control of energy consumption on smart ZigBee-enabled devices in the home. Among its features, the web portal allowed customers to view and manage household energy consumption, compare consumption to other households with similar demographics, and receive messages from NSTAR.
- **In-home energy display (IHD):** The display is a digital wireless (ZigBee protocol) device that showed real-time power demand, billing-period electricity consumption and cost, the current TOU electricity price or critical event status (if applicable), and other related information. The display was used by customers to help identify measures to lower consumption, and it served as an additional communications vehicle for NSTAR to inform customers of critical events.
- **Smart thermostat:** Participants who received a wireless (ZigBee protocol) smart thermostat were able to program temperature set-points either manually or via a user interface on the Internet. At the onset of a critical event, NSTAR sent a signal to increase the temperature setting on thermostats by either 3 or 5 degrees. (The amount varied by event.) Any changes made to thermostat settings supersede the previous load control signal.

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

- **AMR meter**: The customer's automated meter reading meter—already deployed at the customer site prior to the pilot—measures customer consumption and transmits the readings via Encoder Receiver Transmitter (ERT)[7] radio signal at frequent intervals so that they can be picked up by drive-by utility trucks for monthly readings.
- **ERT bridge**: This element was able to read the ERT signal from the AMR meter to get household consumption data, and translate that signal into ZigBee radio signal to communicate with the other in-home devices, which all communicate via the ZigBee protocol.
- **Internet gateway**: All participating homes were equipped with an Internet gateway connected to a wireless (ZigBee protocol) HAN. This gateway transmitted consumption data from the meter to NSTAR via the ERT bridge and allowed communication back to in-home energy displays.

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

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

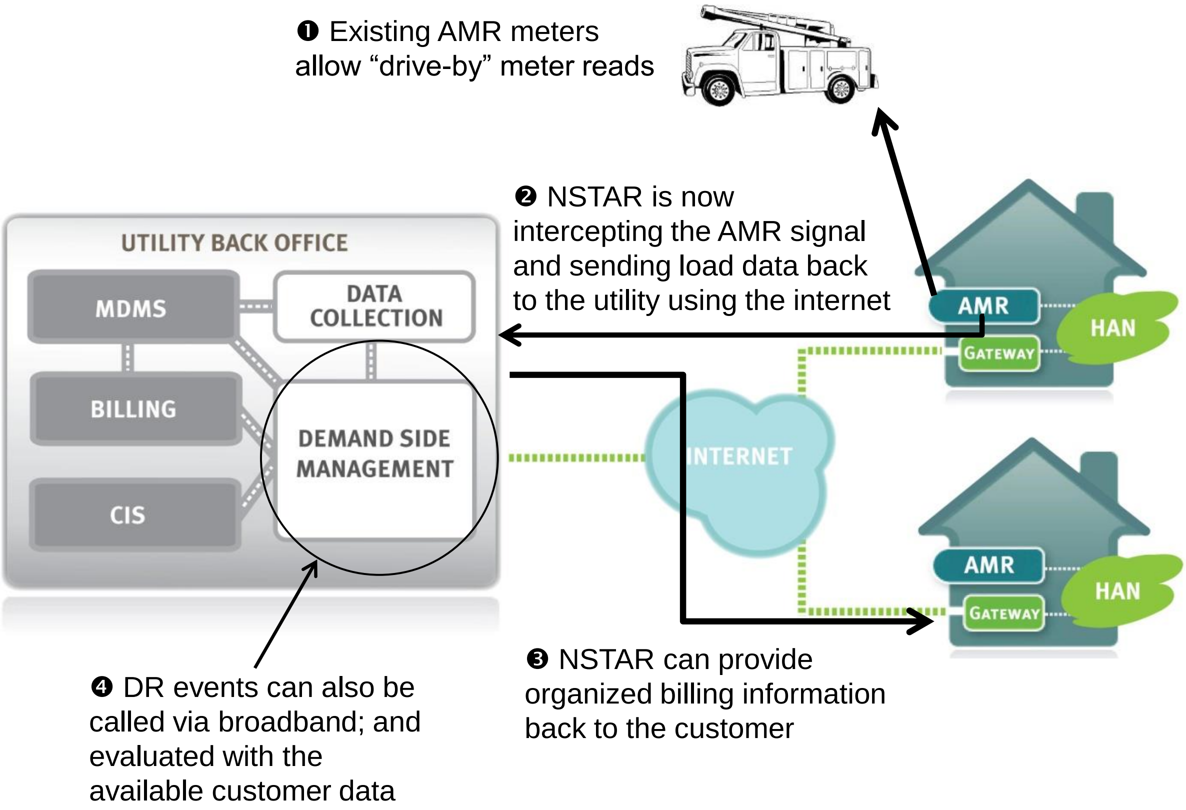
The utility head-end and back-office elements consisted of the following elements, also shown in Figure 2.

» **Tendril Energy Ecosystem Server**: Provided the central control and management functionality for the Tendril system, including Internet connectivity to the participant household equipment and to the NSTAR back-office systems via secure connection. It also performed such functions as enrolling and tracking status of pilot participants, collecting consumption data, and managing demand events.

» **Utility Back-Office Systems**: These are production systems as well as pilot-specific systems at NSTAR that were integrated to perform necessary functions for the pilot, including using pilot data for billing and managing participant calls at the call center.

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

Figure 2. Communications Pathway to and from the Customer Home



Source: Tendril, adapted by Navigant

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

Findings: Energy and Peak Demand Savings

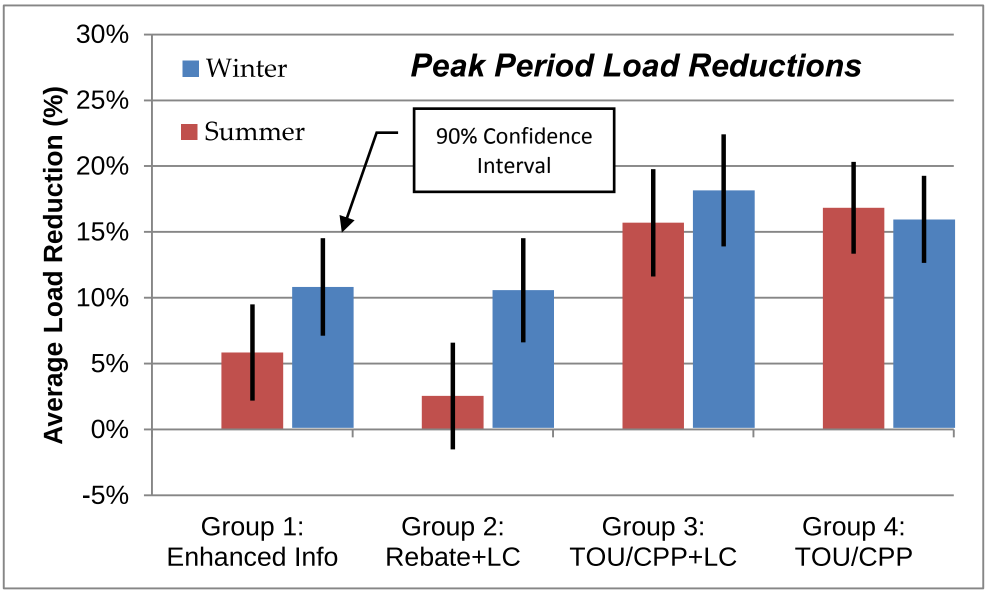
The combination of time-variable rates and enabling technologies allows for testing of various hypotheses regarding the energy savings impact of individual rate structures and technologies. For example, Test Groups 3 and 4 (TOU/CPP rates) can be compared to the control group to assess the impact of a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

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

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

Peak period impacts. Pilot participants in Groups 3 and 4 were placed on a TOU rate, in which customers were charged a higher rate during the peak period and a lower rate during the off-peak period (all non-peak hours). The rate was intended to encourage participants to shift a portion of their peak period load to the off-peak period. Customers on the TOU/CPP rates (Groups 3 and 4) reduced summer peak loads by approximately 0.2 kilowatts (kW), or more than 15% of their average peak period consumption. Customers on the standard rate also reduced their consumption during peak hours, but only by approximately half as much as customers on the TOU rate. Figure 3 provides the average peak period reductions for summer and winter for each pilot group, as well as showing the upper and lower bounds of a 90% confidence interval of the impact estimate.

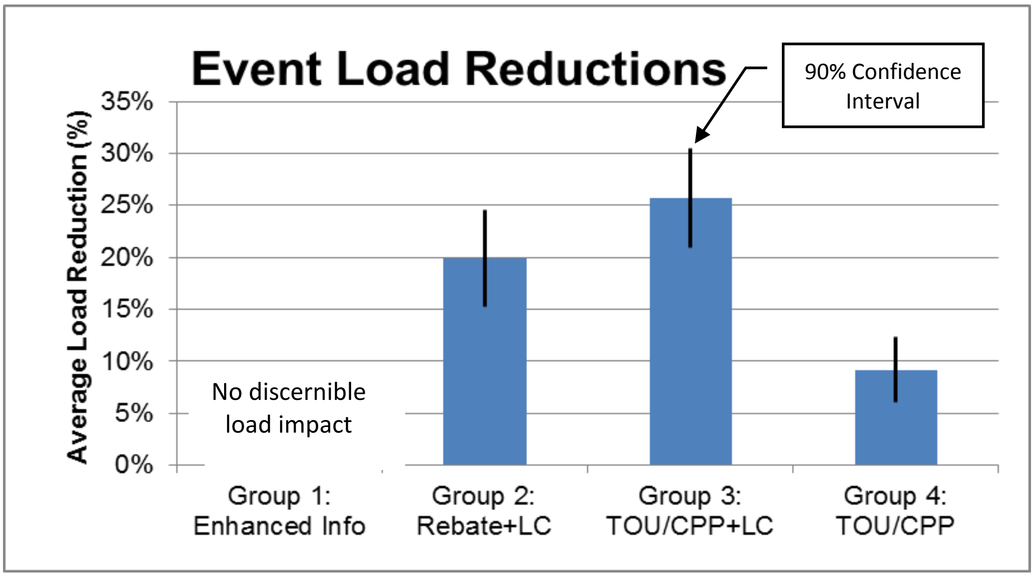
Figure 3. Average Peak Period Load Reductions, by Group and Season



Source: Navigant analysis

Impacts of critical events. NSTAR called a total of 15 summer load control and CPP events during the pilot period. The events varied between either three or five hours in length, with the temperature increase during the event (the increase in the thermostat set point) varying between 3 and 5 degrees Fahrenheit (1.6 and 2.7 degrees Celsius). Event impacts varied widely across groups. Participants with automated load control of central AC (Groups 2 and 3) had the largest reductions—approximately 20-25% of load, or about 0.5 kW. Participants on the TOU/CPP rate without load control (Group 4) realized modest load reductions of nearly 10% (0.13 kW), whereas, participants in the Enhanced Information group (Group 1) produced no discernible load reductions (Figure 3).

Figure 3. Average Load Reductions During Events

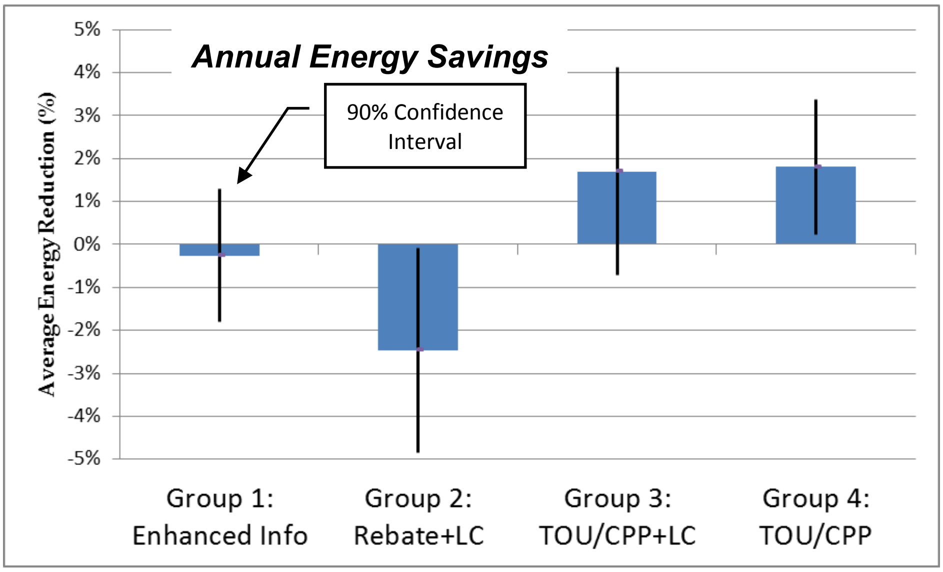


Source: Navigant analysis

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

Customers on the TOU rates reduced their (weather-normalized) annual energy consumption by approximately 2%, while the standard rate participants in Groups 1 and 2 saw little change in consumption or an increase in usage Figure 4. All of the energy-impact results have sufficient statistical uncertainty around the estimates to limit generalizations about whether and how much the pilot led to changes in non-peak-period, non-event-related energy consumption.

Figure 4. Annual Energy Savings



Source: Navigant analysis

The relatively wide confidence intervals (crossing or coming close to the zero line that implies no change in consumption) is driven by two factors:

- The low number of monthly bills available for analysis. At most, there were only eight summer billing periods and 16 winter periods; and
- The fact that the point estimates of energy savings are relatively small—between 0 and 2.5% savings. This suggests that even a model that can estimate energy savings to within 2% of total consumption will still show an uncertainty band roughly as large as the savings estimate itself.[8]

Not shown in the above graphic is the fact that savings appear to have decreased as the pilot progressed, with summer 2012 savings exceeding summer 2013 savings (roughly 2% savings vs. no savings). Winter months showed a similar pattern, with a modest savings in January through May 2012 becoming a modest increase by fall 2012.

Key Learnings from the pilot

This evaluation of NSTAR's Smart Energy Pilot has identified several broad themes, based on the specific findings of the impact evaluation (discussed above) and a review of pilot program processes, technologies, participation, technology performance, and customer viewpoints. Key learnings from the pilot with respect to customer interest, technology performance, participant engagement, and energy and demand impacts are as follows:

1. **Customer interest.** *Smart Grid offerings may appeal to only a limited segment of the population—principally educated, affluent, and technologically savvy customers—absent long-term education efforts and innovative marketing approaches to pique the interest of the broader customer base.* Customer interest in the pilot was relatively strong initially, with response rates to NSTAR's direct mail and email marketing efforts of 4% and 7%, respectively, compared to the 2% to 4% response rates typically seen in Smart Grid program recruitment. While the overall response rate was high, customers expressing interest and enrolling in the pilot were primarily highly educated, affluent households, often with an expressed or demonstrated interest in technology. Despite concerted efforts by NSTAR to market all customers in the pilot territory, low-income customers did not enroll in high numbers, as evidenced by only about one percent of participants being on the low income rate and roughly four percent reporting income below 60% of the median level for their household size.
2. **Technology performance.** *The pilot demonstrated that the technology architecture is capable of AMI-like features through the collection of interval meter data, but that it is not yet viable for the widespread provision of customer information and dynamic rate tariffs.* While the pilot generally demonstrated the capability to deliver on these objectives for many customers, most of the time, the lack of reliability remains a major functional limitation. The following are among the significant reliability issues that must first be addressed before a similar system is deployed on a large scale as an alternative to revenue-grade metering:
    a. Usability of the technologies, from the thermostat that was difficult to install, to the accessibility of customer data, which was not available on mobile applications;
    b. Data intermittency from HAN system disconnections and temporary failure of back-end systems, both of which led to gaps in meter data that rendered TOU rates incomplete and resulted in defaults to the flat rate;
    c. Complexity and inconsistency of meter data validation/estimation process, which caused data gaps and misalignment of intervals, resulting in differences in monthly consumption estimates between the interval data from the pilot architecture and the monthly drive-by reads from NSTAR's standard meter reading procedures.

    Advances in technology since the initial pilot Soft Launch in 2010—such as wireless gateways using IP, extended on-site storage of information, and mobile phone apps—suggest that at least some of the issues raised by the pilot may be substantially resolved and that a similar

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

approach to reading the AMR meters but leveraging these newer technologies might be more effective, and possibly lower cost.

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

   However, it is also possible that some of participants' declining interest and engagement may be experiment fatigue with a pilot environment. Participants knew there was a fixed period of experiment and then things were back to 'normal'. If 'normal' becomes a system of universal time varying electricity rates where electricity costs predictably vary by time of use, engagement will have different stakes and customers may engage differently as well.

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

Implications for the Use of Existing Meter Stock for Smart Grids Services

Taken collectively, the above learnings have several broad implications for the future of possible customer-facing Smart Grids offering based on AMR meters and customer broadband:

1. **The pilot achieved its technology validation objective, including verification that "smart meter" functionality can be achieved without deployment of an advanced metering infrastructure.** The general pilot architecture approach, after improvements in technology and data management, can be an effective, low-cost way for NSTAR or other utilities with AMR meters to enable energy information and TOU rates for customers who want it, without investing in new metering infrastructure for all customers.
2. **The market offering must communicate to customers that they have an important role to play in ensuring the system functions as designed.** Customers have a reciprocal role in that NSTAR will need customers to help maintain the operability of the in-home devices and broadband communications in order for NSTAR to provide usage information and to bill customers on dynamic rates.
3. **A successful offering of dynamic rates and visibility of customer usage information will require an aggressive and intelligent marketing effort to reach customers and engage them to act over a sustained period of time**. Keeping customers engaged after the initial few months or first year of a Smart Grid offering will likely require the incorporation of apps for mobile devices where energy information is more readily accessible and occasional

push messaging and event notifications can engage customers without their having to initiate the engagement.

4. **Only a narrow segment of the population is likely to participate or contribute to savings.** The pilot demonstrated that interest among customers is predominantly among more affluent and educated customers, who also tend to be larger customers with more discretionary load. These demographic groups represent only a small share of the population. By contrast, relatively few low-income participants showed an interest or ability to conserve energy.

Conclusions

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

In particular, the pilot demonstrated the potential to deliver customer benefits by utilizing existing metering infrastructure and broadband communications, provided that (1) technology offerings continue to develop in order to improve usability and reduce data intermittency (2) education and marketing efforts are robust to be able reach customers and engage them to act over a sustained period of time, and (3) the solution is targeted to those customers most likely to embrace and benefit from alternative rate designs and take action by changing their energy usage behaviors. The findings are applicable throughout the U.S. and Europe where smart meter investments are pending. Given that most member states of the European Union have established legal frameworks for smart meter investment in the years following the Third Energy Package,[9] much of Europe is either making significant investments or evaluating the most prudent path forward.[10]

For NSTAR or any other utility in the U.S., Europe, or elsewhere with significant investments in existing metering infrastructure, the decision whether to invest in a future rollout of similar Smart Grids architecture and program offerings must be assessed based on the costs relative to the achievable quantifiable benefits. An important consideration will be who bears the costs and to whom the benefits accrue—to the utility, its participating customers, all ratepayers, or all electricity consumers in the region, who might benefit from lower market prices. For those countries or companies that have not yet committed to the full functionality—and cost—of smart meters, the NSTAR pilot programme provides an interesting alternative that may achieve allow selective investment for customers who most desire a smart metering system.

[9] See *Smart Regions: European Smart Metering Landscape Report 2012,* Intelligent Energy – Europe, update May 2013.

[10] See *Benchmarking Smart Metering Deployment in the EU-27 with a Focus on Electricity*, European Commission, 17 June, 2014.