Impacts of Smart Grid Technologies on Residential Energy Efficiency

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ABSTRACT

This paper examines some technology approaches for connecting residential customers to the Smart Grid, and it looks at the mechanisms these technologies use to reduce energy consumption. Areas discussed include customer behavior change, optimization of end-use equipment through interaction with Home Area Networks (HANs), Smart Grid-enabled home appliance diagnostics, and improved ability to target and deploy energy efficiency programs.

If these approaches can impact energy conservation by even a small amount, the expected benefits from reduced energy costs and deferred capital expenditures on new generation will be significant.

Smart Grid for Residential Energy Efficiency – What Is It?

A number of Smart Grid programs have focused on the potential for Smart Grid technologies to improve demand response and load-shaping impacts and benefits. The potential energy efficiency (EE) and conservation impacts have received less focus. However, a number of studies discussed below in this paper suggest that the benefits could be substantial. The sections below examine some of these potential benefits as they relate to residential applications and contrast the mechanisms by which increased impacts could be achieved with those of traditional energy efficiency.

Definition of Smart Grid Relative to the Residential Consumer

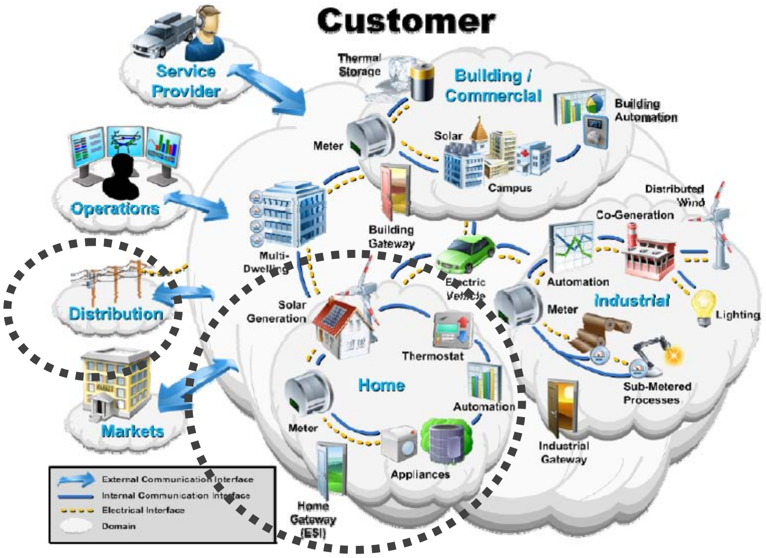
To more clearly understand the role of the residential consumer within the Smart Grid, we can leverage a conceptual model of the Smart Grid Customer Domain developed by the National Institute of Standards and Technology. This conceptual model, shown in Figure 1, provides an expanded view of the primary customer segments (i.e., residential, commercial and industrial) and the other aspects of the Smart Grid (e.g., distribution) that impact these segments.

The home portion of the conceptual model (emphasis added in Figure 1) identifies seven different technology elements that play a role in a Smart Grid-enabled home, including:

- **Home area network (HAN)**: Acts as the primary mechanism for communication between the devices in the home. (Represented by the blue lines connecting each of the Smart Grid technologies.)
- **Smart meter**: Allows two-way communication between the home and the utility. Often referred to as Automated Metering Infrastructure (AMI).
- **Automation/in-home display (IHD)**: Shows the consumer information related to energy management.
- **Thermostat**: Leverages two-way communication, via the HAN, to the utility. Typically referred to as a Programmable Communicating Thermostat (PCT).

- **Smart appliances**: Home appliances (e.g., refrigerators, washer-dryers), which can react to remote management (e.g., price, grid integrity, or other energy management signaling).
- **Home gateway**: Used as a communication and application interface to the utility. This device could be located inside the smart meter or in a separate device that connects, for example, through the internet.
- **Distributed energy resources**: Include small-scale generation such and solar, as well as electric vehicles and other forms of energy storage.

Figure 1. Overview of the Customer Smart Grid Domain



Source: Report to NIST on the Smart Grid Interoperability Standards Roadmap (Contract No. SB1341-09-CN-0031). Prepared by the Electric Power Research Institute, June 17, 2009. [Emphasis added to highlight the Home and Distribution domains.]

Note that in Figure 1, some emphasis has also been added to the distribution domain. The potential energy savings from Smart Grid-enabled transmission and distribution (T&D) efficiency enhancements are significant, with some projections greater than 2% of total retail electricity sales in 2030, as discussed below. So, although T&D efficiency does not fit the traditional notion of energy efficiency, which focuses on demand-side efficiencies, it is an important area in which Smart Grid can bring benefits, and is included in the discussion below.

Traditional Energy Efficiency Versus Smart Grid-Enabled Energy Efficiency

Smart Grid technologies will provide utilities, consumers, and possibly third-party service providers with information along two dimensions that have not been available before.

The first dimension is *time*. Through the installation of AMI at customer homes, consumption data that was only available monthly can now be read hourly or at five-minute intervals—with close to real–time granularity. AMI by itself does not have the capability of identifying specific areas for consumer driven energy reduction and demonstrating the real-time impacts of their behaviors, but applications using the data provided by AMI can improve energy efficiency.

The second dimension is the *disaggregation of data* about a household's electricity consumption. New in-home technologies can provide the ability *sub-meter* energy consumption at the device level, and at almost real-time. This capability permits the customer and the utility to view the energy consumption of specific appliances or systems, and potentially act on that information. Disaggregated load information has potential to transform current EE program design and implementation to achieve greater savings through more detailed feedback to customers on how to reduce their energy costs; identification of customers with significant energy efficiency opportunities through data mining; support for more reliable and efficient measurement and verification (M&V) of energy efficiency programs; and simple diagnostics of energy systems to allow early detection of problems (PNNL 2010).

These two dimensions hold great promise to improve upon traditional utility EE programs that must rely on aggregated data about a household's total consumption, typically collected by the utility on a monthly basis. In addition to new levels of *information* about loads, Smart Grid technologies can also allow automatic or remote *control* of loads, providing additional flexibility.

Drawing from the benefits associated with more frequent data, disaggregated load monitoring, and remote control, this paper discusses the following six mechanisms as the most likely sources of residential energy efficiency benefits through Smart Grid deployment:

- Consumer behavior change
- Increased DSM program deployment efficiency
- Enhanced M&V for DSM programs
- Automated system and equipment diagnostics
- Advanced equipment control for energy efficiency
- Voltage optimization for increased distribution efficiency[1]

To illustrate the six mechanisms outlined above, we consider a common household appliance—a residential refrigerator—and explore what additional energy efficiency benefits could be realized with Smart Grid technologies. Table 1 compares the energy efficiency opportunities possible for a residential refrigerator in a home with no advanced metering or automated control technologies, against a home with AMI, and against a home with Smart Grid-enabled technologies. As Table 1 illustrates, coupling Smart Grid communications and control with a residential refrigerator could augment program and equipment efficiencies for both utilities and customers, even for homes that already have advanced metering.

The potential for residential energy savings through Smart Grid technologies is not limited to refrigerators. Manufacturers, such as GE, are already developing other "smart" appliances, including water heaters, ovens, clothes washers, dryers, and dishwashers. Heating and cooling equipment also present significant opportunities for more efficient installation, operation, and maintenance, as discussed below in "Advanced Equipment Control for Energy Efficiency."

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[1] Unlike the first five mechanisms, voltage optimization for increased distribution efficiency falls into the T&D efficiency category discussed above.

Table 1. Comparison of Energy Efficiency Opportunities for a Residential Refrigerator with Smart Grid, AMI, and Traditional DSM Methods

Smart Grid Mechanisms	Examples of DSM EE Opportunities for a Residential Refrigerator	DSM Methods for a Residential Refrigerator		
		Traditional	With AMI	With Smart Grid [1]
Consumer Behavior Change	Encouraging Consumers to Adjust Refrigerator Temperature Level	Information mailers		Real-time feedback about impact on energy consumption
Increased DSM Program Deployment Efficiency	Identifying Customers with an Opportunity to Replace an Inefficient Refrigerator	None or billing analysis	Meter interval data analysis	Review of sub-metered consumption for targeted outreach
Enhanced M&V for DSM Programs	Determining Energy Savings Achieved for Program Rebates and M&V	Review of deemed or *ex ante* savings (often discounted to account for uncertainty)		Review of sub-metered consumption to more precisely gauge impact
Automated System and Equipment Diagnostics	Identifying Maintenance Opportunities (e.g., coil cleaning)	None		Automated fault detection and diagnostics
Advanced Equipment Control for Energy Efficiency [2]	Achieving Energy Savings through Peak Load Shifting [2]	None		Load control for "smart" refrigerator capable of reducing energy consumption on demand and delaying defrosts to off-peak periods
T&D: Voltage Optimization for Increased Grid Efficiency	T&D: Optimizing Grid Voltage for Efficient Distribution of Electricity [3]	None		Optimized voltage results in reduced distribution line losses

[1] Smart Grid-enabled methods assume the use of AMI, HAN, and Gateway. Peak load shifting for this application would also require a "smart" refrigerator.

[2] Energy savings are not likely to be significant for a refrigerator due to peak load shifting, since offset cooling may be compensated for off-peak. See "Advanced Equipment Control for Energy Efficiency" section below for more discussion on the uncertainty of savings from this mechanism.

[3] Not specific to refrigerators. Would result in energy savings for any type of load.

Mechanisms for Smart Grid-Enabled Residential Energy Efficiency

Consumer Behavior Change

A number of studies cited below indicate that significant reductions in electricity usage can be achieved through a multitude of feedback mechanisms, ranging from a monthly report comparing current to previous months' consumption, to 15-minute interval consumption data tied to "smart" devices and a utility pricing structure. Table 2 illustrates the potential savings estimated from various studies and the range of mechanisms employed to achieve these savings.

Table 2. Estimation of Percent Energy Savings from Consumer Behavior Changes Due to Smart Grid-Related Mechanisms

Smart Grid Mechanism	Estimated End-Use Energy Savings	Source	Traditional		With AMI	With Smart Grid
			Consumption Feedback	**Real-Time Consumption Feedback**	**Pricing**	**HAN, Gateway, “Smart” Devices**
Consumer Behavior Change	Low = 1.6% High = 2.3%	SBC 2009b	X			
	1.5%	SBC 2009a			RTP	
	3.7%	Erickson & Klos 2008	X		TOU CPP	
	3.3%	Erickson & Klos 2008	X		TOU CPP	Communicating Thermostat
	Low = 5.0% High = 15.0%	Darby 2006		X		
	5.0% [1]	EPRI 2008		X		
	6.5%	Hydro One 2006		X		
	6.7%	Hydro One 2008		X		
	7.6%	Hydro One 2008		X	TOU	
	8.0%	Country Energy 2006		X	TOU CPP	
	6.0% Low = 1.0% High = 10.0%	PNNL 2010	Various			
	6.0% Low = 5.0% High = 20.0%	Fischer 2008	Various			

[1] Assumed for the residential sector as a whole, rather than what can be saved at the household level.
In addition to the savings in the above table that may be achieved for the residential end-use sector, several studies also estimate the total percent of forecasted electricity retail sales across all sectors that could be saved through consumer behavior change, including 3.0% in 2030 (PNNL 2010), 0.8-2.6% in 2030 (EPRI 2008), and 1.3-3.8% in 2020 (GeSI 2008).
Time-of-Use (TOU): characterized by a finite number of fixed prices for discrete pricing periods throughout each day;
Critical Peak Pricing (CPP): a variation of TOU rates, but with an additional, higher-priced period in effect during select “events” as called by the utility for reliability or economic purposes;
Real-Time Pricing (RTP): prices typically vary each hour and are commonly established one day ahead of the time that the prices are in effect. Also generally true for CPP.

As shown in Table 2, changes in consumer behavior to save energy are not contingent on full Smart Grid deployment. In the case of one pilot, conducted by Positive Energy,[2] consumers simply received reports comparing their energy consumption to the consumption of other similar households, with no AMI, pricing, or Smart Grid technologies involved. On average, these reports encouraged energy savings of 1.6% at households that received quarterly reports and 2.3% at households that received monthly reports (SBC 2009b).

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[2] Positive Energy is now called OPOWER.

Dynamic pricing[3] of electricity rates has also been demonstrated to significantly affect consumer behavior. Variable pricing is typically deployed in conjunction with AMI, which allows the utility to accurately bill customers according to the time of their electricity consumption and can act as a gateway for communicating real-time prices to in-home displays and automated devices. Benefits from variable pricing are likely to come from intelligent thermostats and appliances that can adjust usage based on prices; however, several pilot programs, such as those conducted by the Ameren Illinois Utilities and PSE&G, have found that consumer energy reductions as a result of variable pricing structures can occur independently of installed control technologies (SBC 2009a, Erickson & Klos 2008). In the case of the Ameren program, the introduction of AMI and a real-time pricing structure sufficiently encouraged the average consumer to achieve overall annual energy savings of 1.5% (SBC 2009a).

The introduction of real-time feedback through in-home displays or web-based portals enables customers to both benchmark their energy consumption and visualize the benefits associated with usage reductions. Real-time feedback could be provided in conjunction with AMI or independent of AMI, as a lower-cost solution. As an example of the latter, a pilot conducted by Hydro One in 2006 measured an average 6.5% energy reduction for consumers that were given a Blue Line PowerCost Monitor™, a device that displays real-time aggregated energy consumption information without the use of AMI (Hydro One 2006). However, the combination of real-time feedback and AMI enables two-way communications between the customer and the utility about real-time energy consumption, which then enables the utility to send out real-time usage and pricing alerts to the customer. The 2008 Hydro One pilots and Country Energy study results shown in Table 2 suggest that these savings may be even higher than those achieved through an in-home display alone (Hydro One 2006, Country Energy 2006). In either case, EPRI concluded that “the potential to transform consumer behavior through direct feedback alone — not including effects of energy efficient end-use devices, demand response programs or dynamic pricing — is potentially high. However, consensus is lacking on which feedback mechanisms are most effective” (EPRI 2008).

A fully Smart Grid-enabled household would take this a step further and link the consumer’s AMI, in-home display, and end-use devices through a HAN that can respond to real-time consumer preferences, such as turning off the A/C in response to a time of high electricity prices. These technologies would also allow consumers to *pre-program* preferences to control individual devices in response to utility pricing signals or pre-determined settings like “away on vacation.” The disaggregation of load monitoring and control through a HAN is the key piece that differentiates these Smart Grid capabilities from behavior influenced by feedback and pricing mechanisms.

That said, there is dispute on the relative magnitude of savings achieved through technologies designed to affect consumer behavior change, as compared to the other mechanisms discussed above that require less capital investment. A prime example of this is a recent PSE&G evaluation that compared the energy savings of residential customers on a TOU/CPP rate that received a programmable, communicating thermostat with customers on a TOU/CPP rate that did *not* receive a “smart” thermostat. While the customers with the “smart” thermostat showed greater usage reductions during demand response events, they had lower overall annual energy savings—3.3% compared to 3.7% for the customers without a “smart” thermostat. Furthermore, only the customers without the thermostat showed reductions during the winter months. Since

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[3] “Variable pricing” is a broad term for non-standard pricing methods, including time-of-use (TOU) rates, critical peak pricing (CPP), and real-time pricing (RTP).

the customers without a “smart” thermostat had to take regular behavioral action to take advantage of the TOU/CPP rate, these findings suggest that constant attention to overall energy use may have encouraged more lasting and habitual behavior patterns (Erickson & Klos 2008).

It is worth noting that the full Smart Grid vision not only entails the use of the technologies discussed above, but also intelligent usage optimization and adaptive controls to consider consumer preferences. There has been very little, if any, research done to determine consumer behavior with that level of automation and optimization. The full deployment of Smart Grid technologies will likely facilitate more precise control of energy usage by consumers and may also encourage more efficient long-term choices when pre-programming energy preferences than currently available technologies.

The other significant question is how persistent these consumer behavior changes will prove to be over time. PNNL recently reviewed a large number of studies on energy savings through consumer behavior change and found that fewer than 10% investigated long-term effects past one year (PNNL 2010). EPRI found that “consumer behavior generally persists if it is formed over three months or longer, provided that the feedback is continued” (EPRI 2008). It remains to be seen whether the consumer continues to seek out feedback to enforce the behavior change or whether it is internalized and translated into permanent changes in behavior (PNNL 2010).

Increased DSM Program Deployment Efficiency

With more detailed information about customers’ consumption, utilities will have an improved understanding of customer loads and potential reduction opportunities. As a result, utilities may use this information to directly target specific customers for marketing and outreach to promote program literature and measure rebates. This could results in cost savings to the utility in program administration, as well as a higher percentage of implemented measures.

Energy savings related to this mechanism are likely to be highly variable, depending on the targeted measure, the utility, and the customer profile in the utility’s territory.

Enhanced M&V for DSM Programs

Better tracking of savings from energy efficiency programs will be enabled by more detailed data available for billing analysis and the analysis of typical energy use patterns. This would enable program managers to eliminate any measures that are not actually achieving savings and to promote measures that were not previously cost-effective. In addition, the measurement, storage, retrieval and management of data to more easily verify energy savings will give planners more confidence to incorporate energy efficiency into integrated resource planning activities.

Overall, these capabilities are likely to help accelerate deployment of DSM, streamline program offerings, and get past the “low-hanging fruit” of EE.

The traditional DSM program allocates an average 3% of total program costs to M&V. PNNL suggests that rather than invest that 3% in short-term M&V work with resource-intensive field measurements and one-time analyses, M&V budget could be invested in a consistent methodology for long-term analysis (PNNL 2010).

Reduced uncertainty of program impact could encourage greater program investment in energy efficiency as a reliable resource. EPRI points out that changes to utility business models, such as a shift to decoupling, would also put greater importance on precise verification of savings (EPRI 2008).

Table 3. Estimations of Percent Energy Savings from Enhanced M&V for DSM Programs

Smart Grid Mechanism	Estimated End-Use Energy Savings	Estimated Savings of 2030 Forecasted Electricity Retail Sales	Source	Details of Study or Program
Enhanced M&V for DSM Programs	**7%** [1] Low = 5.0% High = 20.0%	**1%**	PNNL (2010)	M&V for EE Programs
		Low = 0.2% High = 0.8%	EPRI (2008)	Accelerated Deployment of EE and DR through Superior M&V Capabilities

[1] For residential heat pumps and air conditioners

This table shows savings that may be achieved for the residential end-use sector in "Estimated End-Use Energy Savings," as well as the percent of forecasted electricity retail sales for 2030 across all sectors that could be saved through enhanced M&V.

Automated System and Equipment Diagnostics

No simple methods exist for the detection of faulty or underperforming equipment in the residential sector, although degraded equipment performance often leads to increased energy consumption (PNNL 2010). Faulty equipment typically requires time- and resource-intensive site visits to identify and repair problems, while poorly performing equipment often goes undiagnosed.

The two-way communications and disaggregated load data provided by Smart Grid technologies would permit utilities and customers to benchmark equipment performance against a nominal performance rating and isolate abnormal operations due to maintenance or equipment failure issues. Examples of possible maintenance applications include HVAC air filter replacements, A/C refrigerant charge adjustments, and condenser coil cleaning in refrigerators and A/C units.

PNNL recently reviewed a number of regional studies and estimates that the deployment of automated diagnostics could save an average of 15% of heat pump and A/C electricity consumption at the end-use level (PNNL 2010).

Advanced Equipment Control for Energy Efficiency

Advanced or "smart" monitoring and control of household equipment will be facilitated through disaggregated load control and new equipment designs under Smart Grid. Most of these "smart" systems are envisioned in the context of demand response, but permanent energy savings may also be achieved through intelligent device communications and programming. There are two potential sources of these savings:

Permanent reductions in equipment usage that can be pre-programmed and automated through a home's HAN and "smart" end-use devices. Heating, cooling and other end-use settings can be optimized so only the needed amount of heating, cooling, and other end uses is done according to changing schedules of use. One example of this includes setting back thermostats at night, which can reduce heating energy consumption by about 10% by turning the thermostat back 10% to 15% for 8 hours (PNNL 2010).

Temporary reductions in equipment usage as part of a demand response event that result in lasting energy savings. Lighting and electronics are examples of equipment that could provide energy savings during demand response events because their reduced operation does not necessitate load shifting to compensate for the event (e.g., pre-cooling or pre-heating to maintain a satisfactory temperature). The potential for energy savings through peak load reductions with thermostat-controlled equipment is less clear, since HVAC, water heating, and refrigeration loads typically require load shifting. "Smart" energy systems that can fully optimize shifted heating and cooling, based on consumer preferences and most efficient operations, have the potential to save some energy (e.g., deferred air conditioning usage to the evening when operation is more efficient), but the more significant source of savings through demand response events is likely to be the heightened awareness and feedback provided to customers about their consumption during the events (PNNL 2010).

T&D: Voltage Optimization for Increased Grid Efficiency

Although not traditionally considered in the context of energy efficiency, a Smart Grid-enabled distribution system holds considerable potential for energy savings that will contribute to lowering the net energy consumption. One of these opportunities, termed *advanced voltage control* or *adaptive voltage control*, would use the Smart Grid's monitoring and communication capabilities to optimize the voltage at the residential customer level. Optimized voltage would effectively reduce distribution line losses between the distribution feeder and the end-use customer. Since line losses represent about 5% of total electricity generation, and up to 8% of electricity generated when lines are under peak load conditions, savings through advanced voltage control could be substantial (PNNL 2010). For instance, a field study conducted in the Pacific Northwest found that a 1% change in distribution line voltage resulted in a 0.25% to 1.3% change in energy consumption, with the potential to reduce line voltages estimated at 1% to 3.5% (Beck 2007).

Table 4. Estimations of Percent Energy Savings from Voltage Optimization for Increased Grid Efficiency

Smart Grid Mechanism	Estimated Savings of 2030 Forecasted Electricity Retail Sales	Source	Details of Study or Program
T&D: Voltage Optimization for Increased Grid Efficiency	**2%**	PNNL 2010	Conservation Voltage Reduction and Advanced Voltage Control
	Low = 0.1% High = 0.6% [1]	EPRI 2008	Reducing Line Losses (Voltage Reduction for Residential Sector)
	Low = 2.3% High = 4.3% [2]	GeSI 2008	Reduce T&D Losses
	Low = 1% High = 3% [3]	NEEA Pilot 2007	Distribution System Efficiency and Voltage Optimization

[1] Represents savings for the residential sector only

[2] Relative to 2020 DOE/EIA 2020 Reference Case, rather than 2030 Reference Case

[3] Representative of savings achieved through NEEA's pilot demonstration project, not necessarily a projection of savings out through 2030.

Potential for Energy Efficiency Benefits through Smart Grid Technologies

Table 5 presents a qualitative assessment of likely energy efficiency impacts from the five end-use smart grid mechanisms that have been discussed above.

Table 5. Likelihood of Energy Efficiency Impacts from Smart Grid-Enabled Mechanisms by Household End Use [1]

	End-Use	**HVAC [2]**		**Lighting**	**Water heating**	**Appliances**					**Other**				
	Equipment	**Space cooling**	**Space heating**			**Refrig/ freezer**	**Clothes dryer**	**Oven/ cooking**	**Dish-washer**	**Clothes washer**	**TV related**	**Computer related**	**Pool pump**	**Misc**	**Building envelope**
	% of House Load [3]	19%	6%	15%	9%	10%	6%	2%	2%	1%	7%	3%	21%		N/A
Smart Grid-Enabled Mechanisms	**Consumer Behavior Change**	High	High	High	High	Mid	Mid	Mid	Mid	Mid	Mid	Mid	Mid	Mid	Low
	Increased DSM Program Deployment Efficiency	High	High	Mid	High	High	Mid	Mid	Mid	Mid	Mid	Low	High	Low	High
	Enhanced M&V for DSM Programs	High	High	Mid	High	High	Mid	Mid	Mid	Mid	Mid	Low	High	Low	High
	Automated System and Equipment Diagnostics	High	High	Mid	Mid	Mid	Low	Low	Low	Low	Low	Low	Low	Low	Mid
	Advanced Equipment Control for EE	Mid	Mid	High	Mid	Mid	Low	Low	Low	Low	High	High	Low	Low	Low

[1] Darker boxes indicate benefits that have a high likelihood of being realized if the appropriate Smart Grid mechanisms and technologies are deployed. Lighter boxes indicate that even with full Smart Grid deployment, these benefits may occur, but are less certain.

[2] Space cooling includes central A/C, room A/C, and heat pumps. Space heating includes furnaces, boilers, and heat pumps.

[3] Source: Based on actual data for 2007 from U.S. Energy Information Administration, Annual Energy Outlook 2010 Early Release, “Table 4: Residential Sector Key Indicators and Consumption,” Released: December 14, 2009.

[4] “Voltage Optimization for Increased Distribution Efficiency” not included in this table, since energy saving impacts enacted at the utility level, not the household level.

Conclusions

It is important to remember that we are in the early days of Smart Grid deployment, with a limited number of residential end-use technology deployments at scale. There are still many lessons to be learned, including understanding the persistence of efficiency gains seen in initial studies, the acceptability of new energy efficiency program ideas to consumers, and the price and availability of new, smart-appliances. Nevertheless, a number of Smart Grid enabled mechanisms hold great promise for improving residential energy efficiency efforts. Specifically, this paper has identified the following mechanisms:

- Smart Grid technologies will provide utilities, consumers, and possibly third-party service providers with *disaggregated information about household loads in close to real-time granularity*. This previously unavailable data can be leveraged to identify and monitor energy efficiency opportunities.
- Significant reductions in electricity usage can be achieved through a multitude of *customer feedback mechanisms*, although uncertainty surrounds the likely magnitude of the energy savings. A review of existing studies found a wide range of savings estimates from 1.5-20%, depending on the type of technology and pricing program deployed. These studies also indicate uncertainty around the persistence of savings and the most effective combinations of technologies and pricing programs. Furthermore, few, if any, studies exist that quantify the effects of full deployment of Smart Grid technologies.
- With more detailed information about customers' consumption, utilities can *streamline and target DSM program deployment to customers* through an improved understanding of customer loads and potential reduction opportunities.
- Similarly, more detailed data available for billing analysis and the analysis of typical energy use patterns will enable better tracking of savings from energy efficiency programs and *enhanced M&V of DSM programs*.
- The two-way communications and disaggregated load data provided by Smart Grid technologies would permit utilities and customers to benchmark equipment performance against a nominal performance rating and isolate abnormal operations due to maintenance or equipment failure issues. This would essentially allow for *automated system and equipment diagnostics*, which have never been available previously.
- *Automated monitoring and control* may result in energy savings through reductions in equipment usage. Permanent reductions can be pre-programmed and automated through a home's HAN and "smart" end-use devices, while some demand response events can also result in lasting energy savings.
- Although not traditionally considered in the context of energy efficiency, a Smart Grid-enabled distribution system holds considerable potential for energy savings, particularly through *voltage optimization* to reduce distribution line losses using the Smart Grid's monitoring and communication capabilities.

Initial results from experiments and pilots look quite promising. The lessons learned in the next three to four years from over 100 ARRA smart grid focused federal grant programs should be both valuable and enlightening.

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