Demand Responsive Residential Appliances Interface with the Smart Grid

Statement of the Issues to be Addressed

Historically smart grid energy management has been perceived as economically viable only for large utility or industrial scale energy distribution. However, demand response-enabled home appliances and equipment will eventually allow residential electricity customers to interact with the grid. While presently there is no single, unified approach or standard for how appliances will communicate with the grid, availability of low-cost computer processors and modern communication protocols may enable unprecedented levels of demand response grid interaction in a residential end-use context. The term demand response should imply traditional mitigation of peak demand, and also consider near real-time responses to support other needs such as frequency regulation, load following, and renewables integration.

Today's appliances are designed on the premise that electricity is ubiquitously available. Consequently the user interfaces have been perfected to satisfy the customer's needs from the appliance focusing mostly on time to complete the process and/or the efficiency of the overall function. Demand responsive appliances introduce a new paradigm to the residential customer, one that most have little knowledge about; namely, in order to lower the cost of their electric bill, the residential customer will be expected to exercise some flexibility regarding when and how the appliance operates. Although, while consumers will likely see a direct benefit in their reduced electric bill, they will not fully understand the additional benefit of reduced carbon emissions. So while reduced carbon emissions may have economic benefit, the value of this to the consumer through demand response is more difficult to quantify. While smart appliances provide an option for residential customers to manage their energy use and costs, the ability to interact with the grid should reside solely in the technology as a utilitarian function, the result being a more reliable and responsive grid.

This paper will look at some of the key issues central to utility and consumer interaction with demand response-enabled home appliances and equipment that are capable of responding to and interacting with the electric grid. The discussion will focus on an overall systems integration approach, in the context of trying to identify gaps while anticipating advances in smart grid technology on a 5-15 year time horizon. Along these lines, this paper seeks to discuss:

- Residential benefits of the smart grid
- Residential consumer interface and behavior
- Smart grid – residential demand response economics
- Residential demand responsive device manufacturer economics
- Assessing residential loads and demand response viability
- Toward a unified demand response grid friendly appliance standard (connecting residential demand responsive appliances with the smart grid)
- Barriers
- Some conclusions

The paper will also touch on some of the key aspects of manufacturer interest and commitment, and consider what it might take to generate interest of residential consumer to engage with demand responsive appliances and equipment in the home.

Residential Load Benefits to the Smart Grid: Who are the Players and what is their Interest?

Independent System Operators and Regional Transmission Organizations – Wholesale to Retail

Any potential demand-response implementation solution must carefully address the primary concerns of the overall electricity markets. Successful demand response implementation at the residential consumer level must be attractive to consumers through incentives, and, more importantly, ease of use, perhaps even automated use, requiring very little, or no consumer interaction whatsoever. While many consumers can be simply influenced by the savings on their monthly electric bills, and perhaps rebates or tax breaks, the incentives for utilities, independent system operators (ISO) and regional transmission organizations (RTO) are more profit driven, particularly when it comes to efficient operations and ownership of managing the future burdens associated with a residential demand response solution. The ISO/RTO requires an assured market, which is easily provided by the utility's need for peak energy. Peak energy needs are more effectively provided through an independent aggregator because they save the utility the need to build more infrastructure (energy producing capacity) for a limited need. One concern is that utilities will limit demand response programs in favor of new generation, because new generation is rate-based and costs can be more easily recovered in today's regulatory environment.

Deciding where the ownership lines are drawn for successful implementation of a residential demand response solution may be less difficult to determine in vertically integrated markets (no ISO/RTO). Furthermore, aside from recognizing simple profit margin market drivers, the operational benefit to ISO/RTO's and utilities/aggregators must also be given careful consideration. In particular, the potential for managing the grid based on a more interactive residential appliance demand response system could not only help reduce peak load, but could also support better integration of significantly higher penetration of intermittent renewable resources to the grid. As an example, a robust residential demand response market can help ameliorate the need for spilling (very affordable) baseload hydro power to allow for load following and integration of renewable wind farms as have now become common in the Bonneville Power Administration balancing authority.

Utility/Aggregator

A live pricing market (LPM) is a real time wholesale price that is updated on 5, 10, 15 and 60 minute intervals based on supply within the balancing authority (ISO/RTO). The disadvantage of a LPM is that it will not take into account the presence of grid-enabled appliances/frequency controlled signal/events, which may prove to be of value if a blackout is prevented. Utilities/Aggregators may opt to use a 24-hour day-ahead market as a prediction of the supply (capacity) based on the previous days' loads, combined with a forecast and scheduled generation resources. Alternately, demand response markets allow the retail utility and/or aggregator to respond quickly to grid events and ideally notify smart appliances to reduce consumption thereby reducing loads and preserving the system's ability to serve loads, mitigate price peaks, and prevent outages. Ultimately, the consumer decides how much automated interaction is desired with the smart grid by balancing tradeoffs of immediate need or convenience and cost savings on their utility bill[1].

[1] Cost savings assumes the residential tariff structure includes some variant of time of use (TOU) rate and/or the utility/aggregator passes along cost savings to the customer via other avenues including possibly lower or no future utility rate adjustments (increases) that otherwise would have taken place with no demand response program.

Other market structures (that presently exist or may be coming) should also be considered as drivers for successful implementation of a grid-friendly residential appliance system solution. One example worth considering is the Federal Energy Regulatory Commission (FERC) proposal for an energy imbalance market (EIM[2]) in the Western Electricity Coordinating Council (WECC), where one conclusion was that "there are significant benefits to more coordinated operations, particularly under high renewables penetration".

Analysis of historic loads could be used to predict the anticipated future loads, so that windows of opportunity could be established for a residential customer to attain the maximum economic benefit of a smart appliance (see footnote 1 above). However, the smart appliance would still need to interact with the grid closer to *real-time* to fully leverage the potential benefits of maximum cost savings while simultaneously contributing to balancing generation and grid load. However, historic loads are prone to over stress and become non-adaptive. The use of historic loads as a pricing basis tends to under-bid, yielding a loss of revenue. The use of potential loads combines the predicted demand, weather conditions, and transmission/generation failures to predict need. The potential load scenario appears to have the tendency to be a conservative approach, and would likely lead to over-bidding based on perceived need.

A critical initial step would be to examine the operating characteristics of typical residential appliances and determine their individual response and operating characteristics. Certain appliances provide fixed cycle operations (e.g. washer, dryer, pool pump), others provide services (e.g. TV, computer, lights, etc.) and others provide thermal capability (e.g. HVAC, water heater, dryer etc.). Each has different times and characteristics of operation that in turn determine what they can and cannot do to respond to grid conditions or price signals.

One approach to resolving the issue of variable customer and appliance operation characteristics is to use an aggregator is an intermediary service provider. An aggregator can "accumulate" hundreds of customers across a utility service territory (or across an ISO or RTO) and can, with agreement from the customers, enable customer response to price signals. Other services that could be offered by aggregators could include renewables integration and transient management (e.g., site PV), energy storage, electric vehicles integration, load control, microgrids (islanding and/or disaster recovery), and backup generation, or integration of electric vehicles. And while appliance characteristics and operating limitations for aggregators are the same as for utilities, the aggregator can do for the utility demand response program what historically an Energy Services Company (ESCO) has undertaken for utility efficiency and demand-side management programs.

There are huge economic benefits from demand response when the cost to implement signaling (per device) is lowered through an aggregator. However, this can only be accomplished through the use of unified, industry-wide, accepted standards of interface with the customer/customer appliances. Yet, even with customer agreements under an aggregator to engage in demand response via appliances and equipment, a barrier remains with no clear path forward to transfer RTO/ISO or utility benefits to the residential customer.

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[2]Report can be found at http://www.wecc.biz/committees/BOD/EDTSC/EDTTRS/EDTTRS032411/Lists/Presentations/1/E3_EDT_Phase1_2011-03-24_EDTTRS-FINAL.pdf

Residential End Use Customer/Consumer

People typically do not like change, they are creatures of habits. Thus, if notified that high/peak prices are being reached, the consumers often will not reduce their consumption unless they believe that they may experience some kind of interruption (brownout or blackout) if they do not reduce consumption. Residential customers are not presented with a monetary benefit to reduce demand due to peak prices unless they have a time of use (TOU) tariff, which his typically not the case for residential customers. In other words, customers will reduce their energy consumption to reduce their electric bill, but have little or no motivation to reduce use during peak periods.

One of the biggest factors to consider is how effective overall any pricing option will be when this appears to primarily be during summer peaking where after several days of hot weather, the tolerance by consumers for turning down air-conditioning drops off rapidly as temperatures continue to be high, and they don't care nearly as much about what the cost of electricity is compared to maintaining their desired comfort level. The residential electric customer will ultimately decide the success or failure of demand response residential appliances and systems. The smart appliances and/or home energy management systems will have to be able to operate at some level of autonomy, with minimal to no interaction with the consumer. The extent to which the manufacturers are able to design and implement a user-friendly, autonomous interface will determine how valuable this technology is to the consumer. Appropriate notifications and alerts will have to be carefully thought through, engineered, and designed considering human factors and behavioral economics.

Water heater demand response programs over the past several years given us some insights into residential participation, behavior and value-added. For example, the Oconto Electric Cooperative has actively controlled large capacity residential electric water heaters for over 35 years to aid in managing the utility peak load. The utility has in excess of 2,300 water heaters in the program representing 49% of their residential customers. The demand response program has resulted in a ~13% reduction in the utility peak load with an overall economic benefit to the customers over $265K in 2011.[3] Additionally, the Bristol Tennessee Essential Services (BTES) utility has engaged 15,000 of their 28,000 residential customer base (53%) to participate in their water heater demand response program.[4] This program has successfully cycled water heaters off for 6-8 hours depending upon the season resulting in ~6% annual reduction in peak load (or 1.5 MW of system capacity). Therefore, for some utilities, a water heater demand response program has experienced considerable engagement by their residential customers with significant benefits to both the utility (peak load reduction and cost savings) and to the customers (monetary incentives) with little apparent customer disruption.

Residential Consumer Interface Behavior

Consumer perception of smart grid interaction and how it affects their personal lifestyle will shape the future success of implementing a holistic residential smart appliance solution. While consumers will need to be educated about the advantages, monetary rewards, and how minimally and seamlessly it benefits their life, the bottom line will be how well the system functions autonomously, with very little

[3] Letter from Jan Sanchez, VP Member Services to the U.S. DOE commenting on Request for Information: EERE-2012-BT-002-RIN1904-AC78, July 12, 2012.

[4] Letter from Dr. Michael Browder, CEO, Bristol Tennessee Essential Services to the U.S. DOE commenting on Request for Information: EERE-2012-BT-002-RIN1904-AC78, July 11, 2012.

required interaction from the consumer. In 2010, a speaker at a popular gaming conference[5] drew the conclusion that this next generation of consumers who were raised with an electronic gaming mentality may not need financial incentives to use tools like this. Rather, they will simply be rewarded with a "high score". Their own high score, or the better score by a friend or colleague, is the continuing motivation to best it. Virtual incentives are amplified with the consumers' willingness to invest their time in competing to best their competitors (virtual or real). Folding a homeowner or car owner's energy performance into their Facebook account is a very real possibility. A developer may need to look no further than to generate a Facebook user app (and posting your personal appliance 'demand response score' each day) that ultimately has the power to completely transform how the world sees and manages its energy use.

Any holistic smart grid solution will include studies on how consumers will react to the 'smart grid' as well as considering the future implications of the smart grid on human behavior. The California Energy Commission (CEC) has added a programmable communicating thermostat standard to their building codes. Actions such as this have the potential to affect how customers make decisions, and shape social behavior. But having a programmable thermostat installed by regulation does not imply that by having this type of information collected and available, that it can actually be used to help consumers can make more informed decisions when purchasing appliances. Smart appliance stakeholders, however, should make attempts to glean as much information as possible from regulatory actions such as the CEC programmable thermostats. This information, along with additional research is needed to help determine the value thresholds for influencing consumer participation with smart appliances.

Smart Grid – Residential Demand Response Economics

Consideration must be given to the economics for all stakeholders in interacting with the smart grid and, in particular, issues around dynamic pricing and the market competition that impact these prices. Consumer utility rates are tied very closely to cost of generation, transmission and distribution, and a need for real-time/dynamic/time of use rates exists. Regulatory support will be needed to help address this.

Regulatory barriers will be different across states and arguments will have to be made to encourage the necessary changes, especially if the requirements placed on the utility by regulators constitute a cost recovery barrier. Furthermore, the business cases for utilities functioning as an aggregator (efficiency gains versus lost revenue) must be assessed, as well as a business case for the third party aggregators. Historically, third party aggregators (ESCOs) deliver only a small fraction of savings of the energy consumed, but through effective integration could be relied upon for consistent and perhaps considerable peak load savings. Discussions along these lines should consider:

- Whole home energy management aggregators bidding into wholesale markets
- The effect on the market as more and more residential smart devices are introduced
- The optimal response for aggregators (e.g., 5 min, 30 min, 1 hour, or?).

Residential Demand Response Device Manufacturer Economics

Manufacturers of residential demand response devices (e.g., appliance, HVAC, water heating, other equipment) will have to see long term financial benefits in smart grid-enabled equipment to justify their research and development investments. The business case must be solid. The manufacturer is being forced to walk a fine line between what consumers are willing to spend for a grid-friendly appliance (and

[5] DICE 2010; Talk: Beyond Facebook; Keynote Speaker, Carnegie Mellon Professor Jesse Schell

how much a consumer will save by using it in terms of a payback period for buying the technology) and the cost to develop, design, test, and implement a smart appliance solution. Manufacturers will have to look at the cost of R&D and the future marketability of these smart appliances. So while the premise may be sound, specifically, the following need to be addressed for consumers who may have *interest* in saving money on their electric bill for manufacturers to justify their own internal investments in smart appliances to their management and shareholders:

- To what extent are consumers willing to invest in more expensive technology, and over what payback period?
- Does this willingness cover a wide range of residential consumers, or is it more of a niche market?
- Will there be utility incentives available (or allowed by the regulators) to offset the premium cost of demand response appliances?

Assessing Residential Loads and Demand Response Viability

The two biggest loads in homes are the HVAC and the water heater. Additionally, most homes have refrigerators and dishwashers. Other significant electric appliances include ranges, dryers and possibly clothes washers. Residential loads appropriate for demand response/control will need to be determined based on penetration, load and flexibility for use as a demand response appliance. Although, most consumers will likely leave the controls set at industry defaults, the consumer ultimately will have the option to select which appliances are controlled, and when. Additionally, a delayed start (to wait for lower rates) could be selected (such as starting a dishwasher or clothes washer), or, the user may have an option for a smart appliance to register and schedule a future run-time with the utility. In this approach, a closed loop control system would allow the appliance (dishwasher, dryer, electric vehicle charging station, etc.) to register a potential load with a utility as a request, and then run at a negotiated time. If a sufficient percentage of the aggregate load is managed in this way, the utility could forecast and control dynamic loads for minutes and hours into the future. The implication here is that a more demand response-interactive appliance could help define the dynamic load on the grid, and ultimately interface with the utility to negotiate best timing to connect with the grid based on price—all without any significant consumer interaction. Essentially, three interactive load models should be considered:

- The traditional system on/off response;
- the grid-enabled appliance that controls certain features in response to a price signal; and
- 2-way communication, ‘bid into the grid’ interaction.

Ultimately, studies are needed that assesses the functionality of residential appliances, and how adaptable they are for use in a demand response control environment. The study should look at what technologies represent “low hanging fruit” (easily adaptable) and which technologies will require substantial research and development investments.

Toward a Unified DR Grid Friendly Appliance Standard (Connecting Residential DR Appliances with the Smart Grid)

The basic communication protocols, both wired and wireless, already exist for connecting residential smart appliances or home energy management systems with smart meters, and the smart grid. Smart meters use ZigBee chips, and it does not appear that they will be changing to a different protocol anytime soon. But despite the plethora of today’s networking protocols, the question is not so much which wired or wireless communications protocol should we use, rather, “what should the data transmission protocols be that will enable success?” Ultimately, the key to residential smart grid appliance systems success will be implementing a single, unified data communications standard that defines smart grid data sets, and how they are maintained. The standards need to be applied across all of the primary stakeholder interfaces, where communications and dynamic, real-time interactions are the key to success.

So while any number of home appliances could be connected within the home (e.g. via 802.11b/g/n Wi-Fi, Bluetooth, CAT6, Universal Serial Bus, etc.) to an in-home network or home energy management system, and connected to the internet via internet protocol, a unified standard is still needed to define what, when, and how the information is accessed, requested, transmitted, and received.

Selectable user options and convenience items can be defined by the manufacturer as marketing tools and selling points. These options and tools will likely be proprietary in nature, but will not detract from the primary standardized data protocol for interaction between appliances and the grid. Manufacturers can provide user-selectable tools that determine how quickly and how often the consumer is alerted to a demand response ‘event’ and whether or not a signal be sent to the appliances to generate a consumer interactive decision point. The consumer will need to have the ability to set the level of autonomy of the system. Manufacturers will have proprietary user interfaces and interactive designs that implement the most desirable features for the consumer. This might include interactive, touch screen appliance displays, smart phone applications, desktop computer widgets, or even a simple hardware-type slider device. Home energy management systems can be as simple or complex as the homeowner desires (and is willing to pay for), with online device controls, and periodic home energy use reporting, including suggestions on how to obtain further energy savings based on historical savings and projected electricity markets.

The user interface is but a small piece of the smart appliance puzzle. Smart appliances will have to be able to communicate autonomously with a real-time grid demand response/trending databases, which contain a host of relevant information including price trends and anticipated peak/low demand windows. These data can be used by a smart appliance to make autonomous decisions that will help maximize the consumer benefit. Without standards, costs will remain high, and consumer adoption will be low.

Several options should be explored with regard to the development of a grid friendly appliance standard, with focus on what needs to be standardized, who should standardize it, and at what level. Determining what should be standardized should include a broad range of stakeholders, from regulators to manufacturers to utilities. Key aspects of standardization should focus on critical component interfaces, data protocols and price signaling, standardized databases, and component testing. Who should be standardizing can range from local municipalities (i.e., via building codes) to the federal government, or more practicably, industry standards (IEEE, ISO, ASME, etc.).

Pricing Signals and Consumer Response

Resolving the use of retail versus wholesale price signals is a huge issue and critical to getting sufficient acceptance of stakeholders. One possible approach is to design a protocol that could accommodate both. Another would be to create an extensible protocol that starts with wholesale pricing initially but can accommodate moving to a retail model when it can practicably be supported.

Another big issue is whether or not LPM is a sufficient pricing signal. In the wholesale market, load resource balance is achieved through day-ahead, hour-ahead, etc. pricing. But at some time resolution less than an hour, totally different resources, priced-separately, are used to deal with system stability. Moving to a single, standardized signaling protocol will not only help enable DR interaction, but also needs to provide system stability.

Pricing signals, then, become one of the primary areas of concern in moving forward with a unified demand response residential appliance standard. Several additional questions will need to be addressed by stakeholders:

1. If the wholesale market doesn't use one price signal to satisfy a stable system is it reasonable to expect a single price stream to work in home appliances? Or, for adequate control, are more than one orthogonal type signals required?

2. If at least one of the orthogonal signals were the actual price the customer incurs per kWh, would the revenue meter (smart meter) be the mechanism to enforce economic load shifting?

3. If we have more than one control signal do we need to standardize an economic method to enforce behavior to respond to this signal?

4. Can the whole home under a HEM be a better resource for demand response than individual products in the home?

5. How much load response does the system need? How much load response is available? How much can grid load really be influenced by an HEM or smart appliance and how many customers are required to make a difference and of those how many will choose to over-ride?

As an example, assume hourly prices are a firm price for any given hour within a 24- to 48-hour widows. And prices are forecasted (and made known to the appliance via a signal) for the next 24 to 48 hours. Assume a second signal can be sent to the appliance within any hour to modify behavior of the appliance…say a signal that ranges from 0% (representing the low end of your flexibility range (but not 0 kWh energy consumption) to 200% (which means do whatever you want to do), with 100% means do whatever you were planning to do. An appliance that can operate in this manner (for example with a display showing a 0% to 200% range) needs to have internal logic that determines the nominal (100% level) behavior for the hour, and alternatives, if any, for higher or lower average power levels. Thus anytime the appliance changes behavior (at the request of the grid or an override by the user) away from 100%, it would be possible to calculate and display the increase or decrease in kWh the appliance provided.

Other suggested schemes for a user interface may display a range of settings from 'most' (flexibility/ efficient/convenience) to 'least' (flexibility/efficient/convenience) with perhaps a mid-point representing a nominal or average behavior of use of the appliance.

No matter the representation on the appliance display, the aggregated increase and decreases on an absolute value basis could be recorded in a monotonically increasing register within the appliance; this register becomes a proxy for the in-hour response of the appliance to grid signals. Optionally, the customer could allow the register to be read by the utility service provider once a month via the signaling method. Thus a simple tool, if standardized, could be created that allows the service provider to compensate a customer (equitably among all) for the flexibility the customer permitted.

Barriers

The broad set of consumers are not easily motivated (in adequate numbers) to get involved, and each are motivated differently. Consumers do, and will in the future, need help understanding the value proposition of using a smart appliance or home energy management system (HEM), whether it be financial value, or convenience/service value or even driven by wanting to be 'green'. Today's rates and tariffs are confusing to the customer and are extremely inconsistent. Rates are computed very differently and the consumers will have a hard time sorting this out. Typical consumer commodity purchases show consumers are nearly always first-cost-driven, but when it comes to purchase of electricity it is something for which many consumers cannot even name the unit that relates to how they purchase electricity. And, to further complicate the issue, electricity is a commodity (and in fact a necessity) that is purchased *after* it is consumed.

For example, the raw survey data from the Exelon/ComEd final reports (public EPRI reports 1024865 and 1023644), although not an area of focus in the report, seemed to indicate that pilot consumers lacked an understanding of their rate. Many customers, including virtually all of those in California and Texas, now have access to time-varying prices, but very few know about them. Arizona Public Service (APS) and the Salt River Project (SRP) have shown that explaining this option to customers at the time they sign up for initial service results in very high uptake – close to 40% voluntary opt-in. Furthermore, there appears to be a lack of consumer understanding that electricity consumption impacts the environment. Consumers (public EPRI report 1024566) didn't seem to make the connection between their actions and the need to build more power plants.

A grid friendly appliance or HEM needs to be easy for the consumer to adjust to their personal settings whenever and where ever they want. However, if we assume that consumer understanding of their electricity rates are too burdensome, the appliance or system will have to be smart enough to communicate with the consumer to make the decision process as simple as possible. The level of automation and consumer choices may move from the standardized communication protocol into more proprietary, simplicity-based, user interfaces. This is an example of where consumers may be willing to pay more for a higher level of automation in the demand response interaction. The premise here is that automation is a result of user motivation as opposed to utility control ("inform and motivate" versus "command and control"). (see EPRI whitepaper 1020432)

Privacy is a current issue and will likely be a concern for many consumers if the utility has access to individual energy monitoring/control programs. Consumers need to be assured their system only sends appropriate consumption information and that their system in turn receives the information necessary to make predetermined adjustments. A standardized, secure communication protocol is needed to protect personal, private information, if it has the potential of being transmitted. However, many existing websites are leveraging their user's private information as a requirement for using their content (e.g., Facebook, Google, iTunes, etc.), while allowing them to opt-out (which takes a measured and overt action by the consumer) of certain portions of the data usage. This in itself would seem to indicate a willingness of the consumer to forego some privacy concerns in return for the greater benefit of using the product.

In addition to basic privacy issues to be addressed for consumers, the potential for mis-use of the system by an attacker should not be ignored. While much scrutiny is being devoted to protecting generation and distribution assets from hackers, a determined attacker may choose to go after the customer grid-enabled system and simply inject false messages and commands, thus disrupting the balance of both the load (consumers) and the generation side of the system in addition to potentially causing havoc with consumers use of the appliances. Some attention should be given to possible mitigation and isolation of potential vulnerabilities to reduce disruption. Such an attack could be mounted on a neighborhood up to regional basis, with severe social and monetary consequences.

Some Conclusions

This paper is intended to provide some thought provoking topics on issues that need to be addressed for moving toward an integrated, residential smart appliance solution as an interactive part of a demand responsive smart grid. Hopefully it will also generate interest with stakeholders to continue working through some of these critical issues and continue moving forward with exploring the possibilities and potential of interactive residential appliances and demand response.

Controllers for user interface devices will have to be designed to allow consumers to communicate with smart grid-enabled appliances and assess their function to modify and increase their efficiency, but with some level of autonomy. However, there is a cost related to each device and specifically the technology each requires to communicate with the system. For manufacturers to be willing to invest in research and development of products supporting smart appliances and interactive demand response, there will need to be a clear picture of the potential financial rewards.

Similarly, the utilities and aggregators will be very interested in how implementing a solution gets paid for, and will want to understand what the implications are for smart residential appliances changing electricity market prices. Getting a significant percentage of the consumer base involved will be challenging. It will be a sales job, for sure. Utility incentives for pilot programs may help, but ultimately, consumers will have to be convinced that the benefit outweighs the burden, both from a fiscal perspective and from a usability/functionality improvement in life perspective.

Lines of responsibility will need to be drawn, and substantial collaboration efforts will be required to standardize the most critical aspects of a holistic smart appliance solution. This is no easy task, given the wide range of interests and stakeholder engagement. However, acting now to begin building consensus in the most key areas will help move forward the possibility of integrating demand responsive residential appliances onto the smart grid.