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Harvey Michaels and Kat Donnelly

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292 Main Street, E38-104, Cambridge, MA 02139-4307
617-253-8921
web.mit.edu/ipc/www

Architecting the Consumer Side of the Grid for Energy Efficiency[1]

Harvey Michaels
Research Scientist and Lecturer
MIT Department of Urban Studies and Planning
hgm@mit.edu

Kat Donnelly
Ph.D. Student
MIT Engineering Systems Division
KDonnell@mit.edu

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[1] This research was carried out as part of the Energy Innovation Project, based at the MIT Industrial Performance Center and led by Richard Lester. We are grateful for the support for this work provided by the Doris Duke Charitable Foundation.

Architecting the Grid for Energy Efficiency

Harvey Michaels and Kat Donnelly, Massachusetts Institute of Technology

SUMMARY

Building energy efficiency has become an important part of the determination as to whether Smart Grid and Advanced Meter Infrastructure (AMI) investments are cost-effective for utilities and their ratepayers, and as well, beneficial for society as an approach to help balance electricity supply and demand, and mitigate atmospheric carbon.

Policies that impact commercial and residential buildings – responsible for over 70% of electricity consumption – are especially attractive to target since many opportunities that are cost effective today aren't being exploited. Further, today's power generation and transmission capacity is under 50% utilized, yet fully needed to meet an increasing concentration of demand during a limited number of peak hours, largely driven by the market share growth of weather-sensitive air conditioning. Finding ways to enable building energy demands to be more responsive to utility system loads may optimize our utilization of electric system capacity, supporting future growth less need for expensive and hard-to-site new facilities.

By providing utility capability for direct load control, and possibly hourly measurement that supports dynamic pricing, the *Advanced Grid* may enable significant electricity peak demand savings. As well, the granular data on energy use produced by these systems may have the benefit of helping consumers more precisely target energy use to their needs, resulting in significant energy savings.

While the opportunity is clear, it is also the case that Smart Grid and AMI network architecture choices made today, which are strongly guided by the policies of state and federal regulatory authorities, will influence the future impact of the Grid on energy use in buildings. For this reason, the *MIT Energy Innovations Research Project* chose to examine Grid network architectures that may be transformational to society's use of energy in buildings. Through analysis of literature, consideration of the results of early trials, and advisory team interviews and forums, our research explores the roles for utilities, consumers, third-party providers of services and technology, and policymakers in the build-out of consumer-side smart grid infrastructure.

This paper considers key issues that impact efficiency and demand response via the *Advanced Grid*, such as: should utilities offer dynamic pricing, and/or control customer systems directly? And should utilities be required to provide access to their customers to the *Advanced Grid's* frequent and granular measurement of energy use, and possibly allow the consumers to direct this information to Web applications, third parties, or community initiatives if they choose?

A key step to addressing these questions is a comparison of the architectural options of *utility-controlled* and *consumer-controlled* energy networks. With *utility control*, the intelligence of devices is derived from a central control point via a private utility network. With *consumer control,* these devices use a control system that is located in the home or business, or on the Internet but ultimately managed by the needs of the consumer. For both of these extremes, as well as intermediate

possibilities, we consider how choices impact the aggregate efficiency and demand response, as well as support/limit innovation in supporting a responsive energy future.

This paper argues that architectures enabling innovation and efficiency *should* include consumer-controlled energy networks. Such networks create strong benefits from dynamic pricing and supportive advanced meter derived data, web-enabled thermostats and other devices, and improved Web applications. Together these elements support coordinated consumer-managed systems addressing individual tastes and objectives, while fostering a more energy efficient society.

Regarding marketplace and technology innovation, we find that sustained innovation is most likely if the *utility creates the enabling conditions* for a market-based innovation ecosystem. To accomplish this, it will be necessary for utilities, regulators, and policymakers to focus on *consumer-centric architectures* for appliance control, *public architecture* for advanced meter communication, and *collaborative architecture* for content. With these architectures, innovative firms will most likely find the strategies that appeal to various consumer needs and tastes, while building value with the efficiency, demand, and carbon impacts that they produce.

To make progress, the utility industry clearly needs regulatory standards and incentives conducive to their investment in such technology and data infrastructures. This will certainly include Advanced Meter Infrastructures (AMI) which, at minimum, are capable of hourly reads and at least daily communication of these reads to the utility. Further, federal policy to promote widespread adoption of hourly read meters and default dynamic pricing may be necessary to generate significant economic and carbon benefits to the country.

I. Introduction

Smart Grid or *Advanced Grid* refer to communications and control systems supporting utility generation, transmission, and distribution. Increasingly, the Grid is also seen as a potential enabler for many consumer-side energy applications and services, anticipating that consumer response and behavior change will be an important part of energy demand management. Together, an effectively integrated and optimized combination of in-building network technologies with other Smart Grid components is needed to lower peak building energy demands, and may also lower the total energy requirements of homes and buildings.

These communication platforms can also be used to deliver new information, connect to home and building automation systems, and support new services for consumers. In addition, these systems can allow utilities to directly control building loads.

Case studies and early pilot programs have shown that a consumer-centered enabling-technology approach by itself has the potential to produce 12% to almost 30% overall energy, demand, and consumer cost savings.[2] As experience continues to grow from early deployments, there is a greater understanding of the extent to which Grid architectures could increase the responsiveness of building energy use and displace the need for other energy resources. [3]

However, as we will describe, Smart Grid architectural and design choices we make today will have long-term energy use consequences, while also raising new questions about the innovation ecosystem that will emerge. There is a growing recognition that the utilities will need to partner with consumers to achieve the benefits of Smart Grid. We need therefore to consider how utilities, as guided by the policies of state and federal regulatory authorities, may significantly impact the outcome of Smart Grid as measured by societal-level resource benefits, as well the implications for greenhouse gas emissions, investment risks, and potential for innovation by the marketplace.

MIT Energy Innovation Research

This paper presents findings from the ongoing MIT *Energy Innovations Research Project.* [4] The energy use innovation ecosystem on the consumer side of the meter was chosen as part of this study for three reasons:

- The consumer side has significant potential for energy reductions and peak-demand shifting;
- The domain of interaction between large, incumbent energy service providers and small entrepreneurial businesses are an important part of our national innovation system, and
- The energy consumer has a key role at the center of this innovation process.

Through analysis of literature, consideration of the results of early trials, advisory team interviews, and discussions at a project forum held in July 2009, our research explores the roles for utilities,

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[2] Jim Butler, Cimetrics; Stephan Samouhos, MIT, case study presentations at MIT October 2009.

[3] Leeds, David, GTM Research, 2009.

[4] This research was carried out as part of the Energy Innovation Project, based at the MIT Industrial Performance Center and led by Prof. Richard Lester. We are grateful for the support for this work provided by the Doris Duke Charitable Foundation.

consumers, third-party providers of services and technology, and policymakers in the build-out of consumer-side smart grid infrastructure. [5] The objective of this research is to consider the most important factors that will influence this build out in the next five to ten years given the goals of (1) maximizing efficiency and demand response benefits, and (2) creating an innovation ecosystem to support the continuing flow of innovative new technologies, products, and services.

Clearly, the interactivity of utility, consumer, and marketplaces needs to be optimized for the energy benefits of the Smart Grid to be achieved. As expressed by Richard Tabors:

> *As in any market, but particularly in one as complex as electricity, the value derived from that exchange will depend in large part on how the interactions of supply (utilities) and demand (household and commercial consumers) are defined and carried out. The process of designing an appropriate marketplace will require an exploration of how these elements overlap, and where the exchanges of information, money and energy are best carried out.*[6]

In early discussion with project advisors, the focus centered on comparisons between *utility-controlled* and *consumer-controlled* energy networks. With *utility control*, processes that may regulate thermostats, water heaters, and other devices are derived from a central control point where the control strategies reflect the needs of the utility provider. In the *consumer control* scenario, the consumer uses information and control systems to optimize end-use needs (especially air conditioning, heat, hot water) based on weather, schedules, and time differentiated costs. For *consumer control,* we examine both behavioral responses of information, as well as the potential for control systems *ultimately managed by the consumer*- located in the home or business, or reached via the Internet, mobile phone, or cable/DSL network.

For both of these extremes, as well as intermediate possibilities, we consider:

- How do choices impact the aggregate energy efficiency and demand response?
- How will choices support/limit innovation in supporting a responsive energy future?

Outline of the Paper

The paper is divided into the following five sections, each of which attempts to answer the questions outlined below:

II. Definition and Policy Issues related to the Consumer-Side of the Smart Grid: Consideration of consumer-side architectural options may prove vital to the commitment to Smart Grid in the near future: policymakers, efficiency advocates, consumer advocates, and business strategic interests have expressed reservations about consumer side of Smart Grid investment. Are energy impacts an important part of the determination as to whether Smart Grid investments are cost-effective for utilities? What do intervening parties perceive as benefits or concerns for going forward?

III. Information-Derived Potential for Energy and Demand Savings from the Smart Grid: We consider the opportunity for energy impact that relates to Smart Grid architectures. How can consumers, especially households, reduce their use and peak demand? What are the characteristics of dynamic pricing and will consumers respond? How does diagnostic information impact consumer energy

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[5] Summer Project Forum participants shown in Appendix.

[6] Tabors, R. (2009). The Smart Grid's Ultimate (and Sustaining) Enabler. *Smart Grid News*. Retrieved from http://www.smartgridnews.com/artman/publish/Business_Markets_Pricing_News/Three_Pillars_of_the_Smart_Grid-636.html

behavior? What are the visions of the future of energy information and behavior change?

IV. Consideration of Architectural Options: With this background, we consider elements of Smart Grid architecture, along with technology and policy choices:

> *A. Controlling appliances using Utility-controlled vs. Consumer-controlled Architectures:* Should the utility control devices, or can we anticipate that consumer systems will adjust their devices effectively in response to price? What will ever increasing sophistication and granularity of information mean in terms of opportunity, and what privacy concerns will it create?
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> *B. Communication: Utility Meter Network vs. Public Network Approaches:* Somewhat independent of the question of utility vs. consumer-controlled appliances, is whether utilities should provide utility-proprietary meter network connectivity, or alternatively communicate price and control information via Public Internet using open standards hardware and communications platforms. We consider combinations of meter, utility network communication and IP communication technologies to produce the benefits of Smart Grid yet address data security concerns.
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> *C. Content Provisioning:* A third architectural issue is the provision of information; again the main question is whether the utility or the market via the Internet is the provider of information. Who owns the data and how is data exchange controlled? Should the meter directly provide content to the consumer? Should utilities develop software-based intelligence systems for their consumers on the Web?

V. Utility Strategic Considerations: Having examined the societal benefits of these architectural options, we then consider some of the utility industry's strategic considerations that relate to its financial performance. We consider how regulatory standards might impact Smart Grid architectures and how supportive utilities may be in quickly implementing them.

Key findings and recommendations are presented in Section VI.

II. Definition and Policy Issues related to the Consumer-Side of the Smart Grid

We can define elements of Smart Grid associated with networks for electricity distribution (excluding longer distance transmission) as composed of three distinct networks that may be of unitary design, interlinked, or perhaps operate independently:

- *SCADA:* "System Control and Distribution Automation" is an upstream utility system network that serves to monitor and control electric generation, transmission, and distribution assets to improve system efficiency and performance, and provide resilience to failure.

- *AMI:* "Advanced Meter Infrastructure" automates the meter reading process with a fixed network of communicating devices within meters, as well as upstream meter data management systems. AMI increases the frequency of reads typically from monthly to at least hourly, supporting dynamic pricing, and possibly communicates two-way between the utility and meter for demand response (DR) services and other purposes.

- *LAN:* "Local Area Networks" within buildings provide information and control services related to energy consuming equipment (includes HANs – "Home Area Networks"). This is composed of communications (powerline or wireless) between devices such as thermostats and a router, as well as some form of managing software process (in-home dedicated server, utility managed off-site, or Internet service). Frequently, the system includes some form of consumer display device (sometimes located on the thermostat) or process for viewing information on a multi-purpose display (TV, computer, phone).

This paper focuses on the latter two, AMI and LAN, and their implications on building energy efficiency and demand response. Meanwhile, a combination of SCADA and AMI system upgrades are expected to be beneficial to utility operations. While critical for the electric industry to advance both functions, we specifically examine architecture to achieve the potential energy efficiency and demand response benefits that have been established as a priority of recent federal energy legislation, as well as state regulatory and FERC's policies.[7] This is especially important since, while the Smart Grid is on a fast implementation path and large amounts of money are being expended on it, it is unclear the extent to which consumer-side functionality will be installed:

- Today, approximately 130 million electric, gas, and water meters exist in the US, including 27 million one-way and two-way communicating meters[8]. Of these, 7.7 million are what is now defined as Advanced Meters with fixed networks potentially capable of measuring energy use at least hourly to support dynamic pricing programs.

- The US DOE recently awarded $3.4 billion in Smart Grid stimulus funds. While a large portion of the money was awarded to transmission and distribution hardware systems, some will go towards

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[7] 2007 Energy Information and Security Act, FERC Demand Response Policy

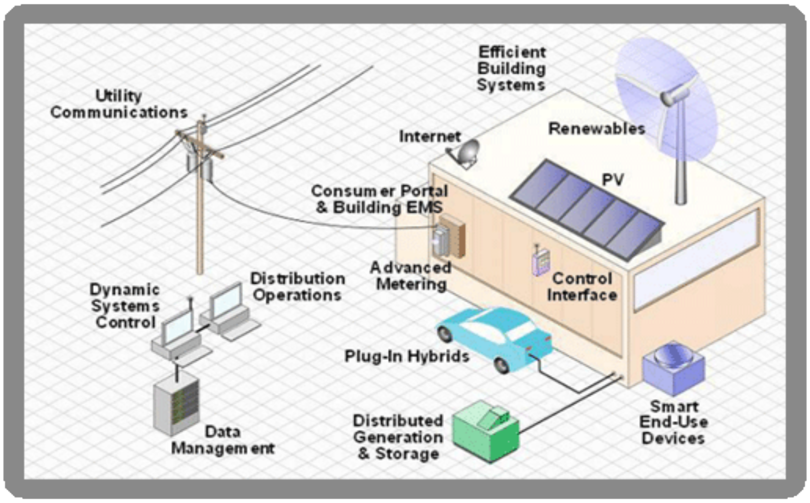
[8] Wolf, G. (2008). It's So Much More Than a Smart Meter. *Transmission & Distribution World, 60*(4), D8-D11. (Document ID: 1477853431).

AMI and consumer-facing hardware, such as in-home displays (IHDs) and programmable communicating thermostats (PCTs), with a small portion funding dynamic pricing pilots.[9]

Consumer-side Grid Architecture: Our analysis focuses on three elements of utility consumer-side systems: meter, communication, and in-home architectural options. Currently, the utility owns the AMI system and places it on the outside of the building, but the enabling-technology that delivers the information and signals, as well as automation to the consumer may be partially or completely within the building. The energy-managing elements are part of a Local Area Network (LAN), or for homes, a Home Area Network (HAN).

In larger buildings, energy management and control systems activated through Local Area Networks (LAN) have long been used for managing energy costs, provided by companies such as Johnson Controls and Schneider Electric. Similarly, it is posited that a well-designed Home Area Network (HAN) can provide consumers with tools to reduce their net energy use and shift peak period demand, but innovation is needed to achieve the cost-effectiveness that this market demands.[10]

Recent government stimulus and Smart Grid pilot project activity have supported HAN innovation. An emerging industry of HAN vendors includes established companies, such as Cisco, Microsoft, Google, and GE, as well as start-up companies, including Tendril, iControl, EnergyHub, and others. While some energy management related enabling technologies have been available in retail stores and on the Web for sale directly to consumers, these companies sell primarily to utilities for provision to their consumers, and therefore the current market relies upon regulatory incentives or federal funding. Venture capital firms continue to search for the next generation of systems that will break cost barriers, work within new communication protocols, and increase both effectiveness and ease of use.



EPRI, Smart Grid Resource Center, 2009

In 2014, $152 billion of the global smart grid market is projected to be comprised of devices, hardware, software, and communications equipment. These products will form the infrastructure and critical communication systems [that] will build, link, monitor, manage and secure the smart grid. Of course not every hardware or software company will have the resources or expertise to compete in this market, but those with the resources and a flexible knowledge

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[9] 2009 American Recovery and Reinvestment Act Selections for Smart Grid Innovation Grant Selections, US Dept. of Energy, October, 2009.

[10] PG&E. (2009). Home Area Network Overview, Presentation, Pacific Gas and Electric, January, 2009. Retrieved from http://www.edisonfoundation.net/IEE/reports/index.htm

base should at the very least explore new product opportunities…[11]

Critical Consumer-Side Grid Policy Issues: Despite the promise, some policymakers, efficiency advocates, consumer advocates, and business strategic interests have expressed reservations about the consumer side value of Smart Grid investments, especially AMI and in-home enabling-technologies. Some of the objections that have been raised include:

<u>AMI economics depend on predictions of demand response to be cost-effective for utilities.</u> The full system cost of AMI is typically $150 to $220 per home for fixed network systems capable of hourly reads. Business cases seek to justify this capital expenditure based on operating benefits such as reduced meter reading costs, better load forecasting and control, and improved consumer services. But in many cases, the net present value of these operational benefits are inadequate to justify the cost, and at other times achieve a very slim positive benefit. Therefore, assessment of the systems capability to achieve energy resource benefits may prove critical to the business case and the regulatory decisions to proceed with AMI. [12]

While consideration of all operating benefits may show at times a small surplus, the potential demand response value often makes the AMI investment appear to be highly cost-effective. Business cases often target up to 0.5 peak kilowatt (kW) reduction per participating consumer, which avoids $25-$75/kw annual peak capacity costs.[13] Over the twenty-year life of the equipment, this benefit alone justifies the complete system cost, but a prospective analysis in a regulatory process is hampered by uncertainties in both the impact and the customer participation level.[14]

Therefore, utility business cases need clear delineation of features and benefits among multiple objectives for decision-making.[15] For example, we will discuss later whether Programmable Communicating Thermostats (PCTs) and In-Home Displays (IHDs) are needed as part of a utility plan to reduce peak system loads: San Diego Gas and Electric's (SDG&E's) is including 56,000 PCTs for small and medium business consumers.[16] We will also discuss whether reliance on public Internet for some communications will permit selection of lower cost one-way, low bandwidth AMI systems for the needs of dynamic pricing and demand response.

<u>Consumer advocates are concerned about cost and fairness.</u> Consumers and other stakeholders are raising concerns about the long-term benefit of AMI infrastructure. Consumer advocates who participate in regulatory proceedings, such as the Attorney General's office in Massachusetts, consider the prudency of all utility capital investments that will be recovered through rates.[17] Because of the perceived uncertainties of building energy efficiency and demand response benefits, consumer

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[11] Zpryme. (2009). Smart Grid: United States and Global Hardware and Software Companies Should Prepare to Capitalize on This Technology. December 14, 2009 Press Release. Retrieved from http://zpryme.com/news-room/smart-grid-united-states-and-global-hardware-and-software-companies-should-prepare-to-capitalize-on-this-technology.html

[12] Conversation with Ralph Abbott, President, Plexus Research, 2008.

[13] Jeff Schlegel, regulatory consultant, at MIT October 30, 2009.

[14] AMI Business Cases, as filed by California utilities in 2007 and 2008.

[15] Plexus. (2006). Deciding on "Smart" Meters: The Technology Implications of Section 1252 of the Energy Policy Act of 2005. Prepared by Plexus Research, Inc. for Edison Electric Institute. Washington, D.C.

[16] San Diego Gas and Electric, Advanced Meter Proposal, 2008

[17] Brockway, N. *Advanced Metering Infrastructure: What Regulators Need to Know About Its Value to Residential Customers.* National Regulatory Research Institute. February 13, 2008

advocates often question Smart Grid investments. If these AMI investments do not produce enough offsetting system savings, rates will increase. In fact, a recent surge of opposition to AMI installations has been seen in California, Connecticut, Maryland, and Texas.[18] In addition, since the benefits may result from a change to the form of rates to time-differentiated pricing (dynamic pricing), there is concern that lower income ratepayers may be less able to participate in the benefits by adjusting their use, creating social equity concerns. [19]

Our examination considered the opportunities to mitigate Smart Grid system costs, especially by considering reliance on public networks and market forces for some of the components proposed for such systems. For example, one role of public utilities is to provide universal access. As a result, utilities and regulators have at times shown preferences for providing information on meter network-tied in-home displays, rather than over the Internet to home PCs served by consumer broadband. *As we will discuss, making this choice has both a cost and functionality penalty for the household with PCs and broadband access.*

Our examination also considered whether the benefits of Smart Grid are in fact distributed in an inequitable manner. As we will discuss, our current failure to measure electric use at the consumer level as we price at wholesale creates winners and losers: the losers, those who are more sensitive to electric use, subsidize the winners, consumers who use more energy on high-wholesale-cost hot summer weekday afternoons. Implementing time-differentiated pricing with Smart Grid advanced meters typically means an increase in the retail price of electricity on hot summer weekday afternoons and as a result increases the cost of operating central air conditioning systems. In many climates, central air conditioning is more common on newer and/or more expensive homes, therefore, such pricing may increase costs in those homes, and reduce electric prices for others. This could suggest that some of the benefits of dynamic pricing may in fact distribute progressively and increase fairness.

The subsequent sections discuss how these issues might be resolved.

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[18] Smith, R. (2009). Smart Meter, Dumb Idea? New devices promise to cut energy use by giving consumers more information. Critics say they aren't worth the cost. *Wall Street Journal, Business Section*. Retrieved from http://online.wsj.com/article/SB124050416142448555.html

[19] Wald, M. (2009, December 13, 2009). 'Smart' Electric Utility Meters, Intended to Create Savings, Instead Prompt Revolt*. The New York Times*.

III. Information-Driven Potential for Energy and Demand Savings from the Smart Grid

In this section, we consider the opportunity for energy impact that relates to Smart Grid architectures, based on a combination of what we know from pilots and experiments, as well as observations of what more needs to be learned.

There is great potential for using information to help us increase the energy efficiency of buildings: examinations of building energy systems show that, in today's practice, we frequently fail to align our delivered end-use (especially air conditioning, heat, and lighting) with the time and place that we require them. In homes as well as large facilities, buildings use energy for light and comfort unnecessarily when unoccupied, or to inappropriate levels where occupied. While local controls such as clock thermostats, occupancy sensors, and photocell dimmers exist, they are far from ubiquitous, and at times inoperative or ineffective at reducing the *sloppiness* of our energy use, often estimated as wasting 30% of total building energy. [20] It is therefore critical to consider the potential of systems for optimizing consumers' end-use needs based on information, consumer preferences, weather, schedules, and time differentiated energy costs.

As well, especially in the cooler areas of the US, the last few decades have seen dramatic growth in central air-conditioning market share.[21] A conversion of a home to central air conditioning on average increases its contribution to system peak from one kW to over five kW. Demand response opportunities in an individual home may seem small, as compared with the opportunity for control systems in industry and offices, but these small load reductions typically add to a total home potential of two to four kW per home on peak, as well as 5-10% energy savings:[22]

- Central air conditioning systems in homes that are unoccupied during peak times can reduce their contribution to system peak by adjusting the thermostat intelligently.
- Electric water heating can easily be shifted to off-peak. This could become more ubiquitous in the future using intelligence built into the water heater.
- Refrigerator defrost cycles occur randomly; in the future they may have built-in intelligence to respond to price.
- Laundry appliance, dishwasher, and pool and spa pump usage can often be dramatically reduced and shifted by consumers who understand that prices vary by time-of-day, season, and weather conditions.
- Even on hot summer afternoons, substantial lighting is running in kitchens and family rooms, which may be switched off in response to price signals.

Extrapolating to 50 million air conditioned homes, 2 KW per home would mean 100,000 MW reductions in peak load, about 10% of our current installed plant capacity.

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[20] Jim Butler, Cimetrics; Stephan Samouhos, MIT, case study presentations at MIT October 2009

[21] FERC. (2008). Federal Energy Regulatory Commission Assessment of Demand Response & Advanced Metering, Staff Report and Excel Data, December 29. 2008.

[22] Siddiqui, O. (2009). EPRI, Edison Electric Institute, Global Energy Partners, Brattle Group. Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S. (2010 to 2030). (Report No. 1018363).

Below we describe three overall strategies for creating efficiency and demand response with distributed information and intelligence-driven energy management:

- Utility control of peak building energy use (load control/demand response),
- Time-differentiated dynamic electricity pricing, and
- More frequent and granular energy consumption data to support operational improvements and behavior change.

1) Load control/demand response: Using utility network communications, the Smart Grid may curtail consumer loads during critical system hours. It is estimated that 5.8% of our peak loads are currently controllable and up to 20% could be controlled.[23] This approach, historically called load management, is now often called *Demand Response (DR)* - connecting system requirements directly to consumer endpoints. For small consumers, utility load management programs have for many years successfully shed loads on utility peaks. With radio and powerline signals, these programs cycle air conditioners, raise thermostat set points, or shut off water heaters as examples. AMI systems provide a lower cost and more ubiquitous system, potentially aiding expansion.

2) Dynamic pricing: AMI deployments are increasingly focusing on the ability of AMI to support time-differentiated (dynamic) prices, such as critical peak pricing (CPP) rates, which charge their highest rate for a few hours on a handful of days per year when loads are highest. A study comparing 15 recent dynamic pricing experiments found that critical-peak pricing tariffs, under a variety of price structures, induce a drop in peak demand that ranges between 13 to 20 percent. [24]

As an analogy to clarify the benefits of pricing signals, consider the economics of food in an alternative world – where supermarkets don't have cash registers, but instead charge by weighing shopping carts as they leave the store. The price per pound of food is used, instead of the price of individual purchases, to charge supermarket consumers. In this world, the price of a can of caviar is the same as a can of tuna of the same weight, even though it costs the store fifty times more. Consumers without accurate price signals fill up their shopping carts inefficiently by buying more caviar than they would if they understood the true cost. Stores lose money on caviar and that loss is passed on to all consumers. As a result, everyone pays more.

In our world, conventional electric meters are like weighing the shopping cart. Inevitably, installing meters capable of time-based reads, like supermarket cash registers, and differentiated pricing, tie electric retail prices to true costs, increase system efficiency and lower average costs for everyone.

In 2004 through 2006, a California statewide working group of utilities and government policy organizations conducted a pilot of critical peak rates for all consumer groups. The positive results of the pilot led to the rollout of advanced meters and time-based rates for all consumers. Notably, critical peak rates created an average 12.5% peak demand reduction.[25] Similar results were seen in smaller pilots in Texas, Missouri, New Jersey and Ontario. At the 12.5% level, the critical peak rate "creates" the equivalent of ½ KW coincident peak load reduction for the average residential household on the rate (including non-responding consumers). In aggregate, this suggests a national impact of over 50,000MW of peak reduction.

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[23] FERC, DR Assessment 2008 and DR Potential 2009

[24] Faruqui and Sergici, 2009.

[25] Charles River Associates. (2005). Impact Evaluation of the California Statewide Pricing Pilot.

3) Granular energy use information: With the availability of hourly electric reads, early research shows that, in addition to pricing, the information of AMI may by itself be a valuable source of behavior change. With feedback about energy consumption, an interested energy consumer can better manage their energy and money. There have been over 40 studies that have identified how direct and indirect feedback on energy use can reduce energy consumption. Direct, real-time, feedback through in-home energy displays and other enabling-technology can have positive effects on consumer electricity efficiency, reducing average participant usage by up to 15%. [26] Inferential analysis supported by granular data continues to advance; for example:

- *End use disaggregation* analytics separate energy use into meaningful components. A recent California study indicated that disaggregated end use information was, in fact, more impactful than real-time feedback. [27]
- *Benchmarks:* New companies such as O-Power (formerly Positive Energy) focus on providing consumers with benchmarks to understand their relative energy use, and are comparing these consumers with a similar social or demographic group. Early indications are that 5 – 10% energy savings may result from these benchmarks.[28]
- *Collective Action*: With ubiquitous metering, there is the potential opportunity to leverage the benefits of shared information resulting in greater individual behavior change. Anecdotal trials suggest that group dynamics hold a tremendous potential, with several models under consideration, including competitions and group rewards or recognition. [29]

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[26] Summarized by Darby,2006 and EPRI, 2009

[27] Herter, K., 2010

[28] OPOWER. (2009). The Home Energy Reporting System Fact Sheet.

[29] EPRI, 2009.

IV. Consideration of Architectural Options.

In this section, we discuss three architectural dimensions of AMI:

1. *In-facility Local area networks: thermostats, appliances, controls.*
2. *Utility-facility Communication.*
3. *Content Provisioning.*

1) Controlling appliances with Utility vs. Consumer-controlled Architectures: _AMI provides operating benefits including reduced meter reading costs, outage management, and granular visibility on distribution components including transformers. However, in many cases, energy efficiency, including but not limited to peak demand reduction, is important to making the business case for proceeding with Smart Grid. Automated control of appliances and thermostats is one approach to creating a sustainable energy impact in energy efficiency. In fact, Home Area Network (HAN) enabling technologies are now viewed as an important element of achieving the highest peak demand savings. In the summer of 2003 the California Statewide Pricing Pilot found that *average peak savings were 34.5% on households with enabling technology* such as communicating thermostats, appliance cycling devices, and in-home displays. [30] This is substantially higher than the 12.5% achieved by pricing-induced behavior alone, and as a result some utilities and regulators have reworked AMI plans to include control strategies to capture these potential benefits.[31]

At the ends of the spectrum, two disparate approaches are under consideration to more intelligently manage devices in the home: utility and consumer controlled architectures. The following outlines each of these systems and concerns that have been raised about them.

Utility-controlled architectures create resource benefits, particularly lowering system peak demand, with controls operated by the utility on their customers' air conditioning, water heaters, pool pumps, and other equipment. The infrastructure of AMI/Smart Grid however provides a lower cost, and more ubiquitous capability to achieve utility-controlled demand response as compared with the systems used historically.

Benefits of the utility-controlled approach:

- A deterministic demand impact, since these are implemented by switching capabilities controlled by the utility, as compared to the potential uncertainties of a consumer decision in response to price.
- Typically, the in-home control equipment in this paradigm is provided by the utility to the consumer at no cost, increasing near-term penetration rates, and does not require the consumer to have any form of Internet access. [32]
- Since the system is utility managed, attribution of the demand impact to the utility infrastructure investment of such control is very clear, simplifying the evaluation of benefits for incentive ratemaking.

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[30] , Statewide Pricing Pilot Summer 2003 Impact Analysis, Charles River Associates, Table 1-3, 1-4, August 9, 2004.

[31] Pacific Gas and Electric announced reconsideration of its AMI plan with this objective in June 2007.

[32] While the consumer is not charged, the costs are embedded in rates paid by all consumers.

<u>*Issues with the utility-controlled approach:*</u> The utility controlled approach anticipates in the years ahead that generation, transmission, distribution, and end use equipment will, in effect, collaborate directly as part of a single system, without any direct consumer involvement. There are concerns with this approach regarding consumer choice and privacy, with detractors envisioning a scary *Big Brother-like* network as a natural extension of this approach. As a result, in 2008, the California Energy Commission needed to scrap a plan to require programmable communicating thermostats (PCTs) in new construction, following a public outrage at a perceived trend towards utility access to home controls and information.[33] The PCTs were to have radio capabilities to respond to utility signals to increase home temperatures during system peaks, and report home temperatures and compliance back to the utility. To this point, it is unclear as to whether these fears will subside, as society's concerns for other information-related technological changes have over time, or force an end to this paradigm.

By comparison, **Consumer-controlled architectures** are composed of consumer purchased and configured building (LAN) or home (HAN) network devices that optimize appliances to meet the consumer's objectives for comfort or function, while minimizing energy costs and/or carbon footprint. Often, these devices connect to public networks, and interface with the consumer through Internet applications (often called control panels or dashboards) provided with the devices, or offered by third parties such as Google, Microsoft, or even the utility (but under consumer control). Utility AMI systems that support time-based pricing are beneficial, as they can add value to these systems if properly implemented. Direct interface with the meter network is not absolutely required, as price information can be made available over the Internet or intercepted by an in-home display.

<u>*Consumer-controlled benefits*</u>: Supporters argue that the consumer-controlled approach has the following benefits as compared with utility-controlled demand:

- Compared with utility control, consumer control has a similar theoretical potential to create demand impacts, but with price as the arbiter there is a boundary providing greater privacy to the consumer.
- Consumer control is more likely to generate energy savings as well as peak demand savings. Since total dollar savings is a common consumer goal, the system is more likely to save significant energy throughout the day, week, and seasons, while utility controlled systems are typically focused on the peak hours of the year.
- With time-based (dynamic) pricing, there is a more obvious connection to hourly meter read capability of AMI than with demand response, justifying the utility's investment.
- It is argued that time-based rates are inherently more fair and inevitable: without them, some consumers, such as those without peak-contributing central air conditioning, are paying too much and are subsidizing AC consumers. [34]
- Home area network (HAN) devices leverage existing networks already in the home such as Internet, mobile, cable, and in-home power lines for communication and control are more likely paid for directly by the consumer, rather than the utility (although all utility costs are indirectly borne by consumers through rate-setting). As a result, the utility total cost of the system may be less.

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[33] Barringer, F. (2008). California Seeks Thermostat Control. *New York Times* Retrieved from http://www.nytimes.com/2008/01/11/us/11control.html

[34] Faruqui, *The Ethics of Dynamic Pricing,* 2010

Issue with the consumer-controlled approach: The consumer approach is more reliant on the market to develop options, and the consumer to both purchase and use them, to get the desired energy and demand impacts. As a result, it is necessary with this approach that the utility provide a system to accelerate adoption, similar to the objective of other efficiency programs. Several, including Commonwealth Edison and Duke Energy have announced significant customer and market partnership programs.[35]

Potential 5-10 year innovations in consumer-control architecture: Just as the capabilities of Internet and electronics have continued to progress for a variety of consumer applications, one would anticipate that a decentralized ecosystem of competitive applications will continue to adapt to the improving understanding of consumer preferences. Some directions that have been already considered or are under development include:

> *Improved control precision:* In time we can anticipate improvements in sophistication of control. For example, in addition to the control of heating, air conditioning, hot water, and pool pumps, we can anticipate that in time refrigerator/freezers could modify their use pattern by linking their internal control logic to a home network signal of high cost, a scenario already being beta-tested in select households. In addition, comfort settings are increasingly more automatic, and mitigation is possible by pre-overcooling of the home, for example, prior to anticipated high cost periods to allow the system to coast.[36]
>
> *Thematic control:* A trend to establishing default settings in complex electronics is to offer the consumer a few high-level thematic choices. Browser Internet security settings set many parameters based on a consumer's selection of low, medium, or high security. Some automobiles have tunable transmissions that allow power vs. economy settings. Similarly, we can see the trend towards thematic options in home controls, allowing consumers to select their preference for maximum economy, low carbon footprint, or full-but-not wasteful comfort.
>
> *Adaptive control:* Many software systems improve their functionality for the consumer through automatic response to user experience. For example, voice recognition systems adapt based on the history of corrections, as do many other functions on websites, word processing, and mobile phones. In time the response of household and business energy systems to dynamic pricing can be designed to adapt to user corrections, reflecting preferences more accurately through learning, and over time requiring fewer corrections. As an example, if a more general thematic setting such as "super green" had been selected, but the consumer at regular times adjusted the heating or cooling for increased comfort, the software system can learn and tune the controls to more accurately reflect these preferences in the future.

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[35] Vardell, 2008.

[36] Galvin Electricity Initiative, 2007.

<u>2) Communications</u> - Utility Meter Network vs. Public Network Approaches: Somewhat independent of the question of utility vs. consumer-controlled load is whether utilities should provide proprietary meter network connectivity, or alternatively communicate via Public Internet.

Meter Network Gateway concept (FERC 2008)

With the meter network approach, the utility provides the meter-to-display and meter-to-control devices, and in most models subsidize them substantially for provision to consumers, with the costs recovered through rates. In early trials of Smart Grid-enabled controls, most systems offered a paradigm of utility-controlled smart thermostats, with on-device displays, firmware, and utility-network connectivity. In-home display pilots have been typically deployed in the kitchen or dining room, providing basic information on metered electricity use and prices in *real time*.

However, if the meter network is going to manage the devices, it needs to have greater bandwidth, two-way capability, and more upgradeability than systems installed to date to service these needs over the next 20 years (a typical meter network system life). As a result, a meter network gateway system may have $50-$200 per home additional costs for these system capabilities, excluding the costs for any utility-provided HAN devices.

With the public network approach, the home network components communicate through a market-provided home network wireless router to connect with the home computer or other market-provided processor, which in turn connects with the public Internet, as do other devices like printers and computers on a home network today. Alternatively, home powerline and/or wireless broadband may support the home area network.

Consideration of AMI high bandwidth and two-way communication capability: With the consumer-controlled approach focused on dynamic pricing with Internet-provided communications and information presentment, one-way hourly meters may be sufficient for this purpose, as there is no need for control capabilities to be built into the AMI network itself. Further, bandwidth needs are less, potentially reducing the AMI cost and increasing the number of options available. Also, since the consumer buys the display and control equipment, these costs are less for the utility. As a result, if AMI system costs are substantially higher for high bandwidth two-way capabilities (considering the cost of communication devices and upstream software and control systems), these may not be justifiable costs based on efficiency and DR considerations.

Benefit of containing the requirements for AMI: Certainly, the higher the stakes in terms of initial cost, and the greater the technology expectations placed on the system, the more difficult it will be for AMI to move forward. Not only will the higher costs produce near-term rate impacts that might be politically unacceptable, the breadth of current and near-term future solutions will slow the AMI procurement process. In addition, the higher requirements expand concerns for upgradability, obsolescence, and standards. Therefore, to achieve the necessary opportunities for AMI-enhanced energy use, *minimizing the technology requirements is an important focus of policy and regulation*.

<u>3) Content</u>: Meter Information and Analysis: A third related architectural issue is provision of information; again the main question is whether the utility is the provider or the market: who will design and deliver information that consumers need to better manage their homes and buildings?

<u>Meter-to-Home Network Communications:</u> In the last section, we discussed Internet options that reduce the necessity of utility-to-meter communication. Nonetheless, it is valuable for the meter systems to provide at a minimum hourly reads directly to the home for use by consumers with their web workspaces. Several AMI systems offer technology in the meter that broadcast short-interval reads directly to the home. These short-interval reads *on demand* (when the consumer can use them) are a key ingredient in measuring differential energy use, supporting the measurement of load, and cost, of any device in the home.

At the low marginal cost of $10 or less often cited, it should be justifiable for AMI systems to have functionality to support high frequency reads *on demand* to home networks. With short-interval meter data available to the home router, and then routed to a Web-based application, diagnostics and inferential analyses can be performed for a variety of functions. For example, applications using this data may be able to determine appliance energy use, determine when heating or air conditioning systems are in need of service, and evaluate options to reduce costs or improve device performance. For interested consumers, a Web audit on a cell phone could support the consumer walking around the home, switching loads on and off, and seeing what the impact of the switched load – costs per hour during peak or off peak periods, carbon footprint, etc. As others have written,

> *The biggest challenge will be to assure that the electric company meter hanging on the outside wall of buildings will be linked real-time with the consumer-owned building management system inside the wall. The ubiquitous IP-based commonality now becoming standard will make that easy to achieve at the right time. The immediate challenge is to make sure that the utility industry moves away from small-scale proprietary systems and embraces broader, interoperable IP-based protocols and approaches.* [37]

This raises some important questions. First, should consumers receive their content from the Public Internet, or the utility private network? Many pilots have examined the benefits of in-home displays as part of the AMI network, but it may be more beneficial to tie displays to public networks. With IP connection, the consumer's display of choice can be a home computer, or a log-in from a computer at work, or web-enabled cell phone (i.e. iPhone). Web systems are low cost, flexible, and easily upgraded, promoting open, non-obsolescent consumer connectivity. Compared with the static content and quality of meter network-tied in-home displays, utilities or third parties such as Google or Microsoft can offer a richer, more interesting interface for working with consumers on the public Internet.

Second, should Utility content architectures support data exchange with other public Websites**?** The open HAN direction discussed above will support a growing set of energy Web content choices in time. This will include portal content providers such as Google (Powermeter) and Microsoft (Hohm), as well as the Web control panels for the thermostat and other devices in the home. In this model, the utility Website provides meter data and potentially collaborative Web content site with models and functionality that can be drawn upon by the portal or control panel sites, ideally with a standard data exchange format. The consumer would need a security password to allow the public portal or control

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[37] Galvin. (2007). Galvin Electricity Initiative, <u>The Path to Perfect Power: New Technologies Advance Consumer Control</u>.

panel Website to connect to his data. This model is similar in architecture to the download of consumer-intimate financial data from bank websites to Intuit's Quicken and TurboTax applications.

Some question exists about whether the utility can refuse to make the consumer energy data available to other Websites, or be able to charge for the access. To date, most rulings by state regulators have determined that billing data availability by utilities is consumer-owned and within their purview to regulate, although the costs to create and support data access can be passed on to the consumer with a shared rate-based approach or event-specific charge. This argument is grounded in the view that the consumer information gathered and managed by utilities is done as a publicly mandated and ratepayer-funded activity. And further, the public interest in energy efficiency seems that regulators should encourage easy access to the consumer's data for the objective of maximizing energy benefits and market innovation.

V. Strategic Considerations for Utilities:

The previous sections have examined Smart Grid architectural options from an energy and market perspective. We now examine some of the utility industry's strategic considerations, namely financial performance. Aligning utility financial incentives with Smart Grid performance will be key to the success of this endeavor.

Utility cost coverage of Smart Grid investments: Regulators will decide which expenses can be covered as an approved investment in utility rate bases. Typically, their decision is based on the business case offered based on minimizing consumer bills. Ideally, regulators should approve architectures considering all benefits associated with the Smart Grid investment, including energy, demand, and carbon. However, many AMI proceedings have used business case analyses that exclude potential energy benefits, considering these to be speculative, and limit the decision analysis to operating benefits of the advanced metering infrastructure.

Research conducted for the Federal Energy Regulatory Commission identifies the demand-response potential of AMI and dynamic pricing, including a model based on compilation of many dynamic pricing pilots that indicates a very consistent energy impact. Savings are substantial enough, in practically all cases, to justify the near-term upgrade to AMI capable of hourly meter reading needed to support dynamic pricing. This includes cases, such as in Massachusetts, where utilities have recently installed monthly AMR systems.[38]

Utilities need cost coverage for research and pilots. Despite the clear outcome of dynamic pricing, the scenarios regarding the potential benefits of control and information will benefit from experimentation and pilots. Utilities should be encouraged to conduct such pilots, as many are doing so using the available Smart Grid stimulus funds. However, technologies chosen today for pilots are not likely to be the "right" pieces for a full scale program, since there will be much advancement in the communication capabilities of appliances and routers in the next few years.

We therefore need to view these pilots *as simulations* of the future scenario, rather than the model for the future. While companies in the utility HAN segment provide the convenience of a bundled solution of hardware and software, and/or a general contractor role for the conduct of pilots, longer term

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[38] FERC (2008). Federal Energy Regulatory Commission, Assessment of Demand Response & Advanced Metering, Staff Report and Excel Data, December 29. 2008.

scalable solutions will need to consider technology trends that may offer more functional and lower cost devices, and market trends that may make these technologies more routinely available, or possibly built-in to appliances, computers, and other systems.

Utility need for performance incentives consistent with architectural requirements: In recent years, an elegant utility model has emerged that is described in the EPA's and DOE's National Action Plan for Energy Efficiency (NAPEE). Among its goals are:

- *Aligning Consumer Pricing, Incentives, and Financing to Investments in Efficiency*
- *Establishing State of the Art Billing Systems*
- *Implementing State of the Art Efficiency Information Sharing and Delivery Systems*
- *Implementing Advanced Technologies (AMI/Smart Grid)*[39]

NAPEE calls for the utility industry to be fully engaged to accomplish these things, including an objective to establish utility profit incentives for maximizing efficiency and demand response. Utilities have responded, including the formation of the Institute of Electric Efficiency within the Edison Foundation, and research being conducted by the industry's Electric Power Research Institute.

Without such profit incentives for efficiency and demand response, utility shareholders will likely see earnings reduced if utilities take effective actions that result in lower electric sales and revenues. Yet in most states today, utility earnings and electric sales are coupled. Regulatory models that decouple earning and sales, and/or incent effective efficiency and demand response activities, are clearly important to align utility interests with effective customer-side-of-the-meter architectures.

Need for public research standards to evaluate benefit measurement: Measurement of reduction in energy use and demand are necessary to determine prudency and incentives for these regulated investments. Further, individual regulatory bodies in states set the standards for evaluation that utilities will use to establish that its Smart Grid implementation produced quantifiable reductions in energy use and demand as compared with a future benchmark use. While it may seem difficult to measure reductions in energy use and demand from a moving future baseline in statistically valid ways, there now is a body of successful research experience to provide a framework going forward.[40]

This process may be more achievable, obviously, with utility-controlled architectures, where the relationship of utility action is directly measurable. With consumer-controlled architectures, it is possible, but difficult, to construct an evaluation process that will prove that the utility's activities were necessary to accelerate the market's movement towards a smart energy future. Therefore, the strategy for how savings will be measured is critical to the program's ultimate design: a key objective of pilots needs to be measuring impact. This will require rigor in research planning of treatment and control groups, measurement, and ongoing process and impact evaluations. Further, since the full-scale ultimate program may use different technologies, it will be important to project the changes in cost and benefits moving forward, with particular focus on *market transformations:* longer-term shift in market-provided devices, which may have been accelerated by utility's investments and activities. [41]

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[39] US EPA & DOE (2008). _National Action Plan for Energy Efficiency Vision for 2025: A Framework for Change_.

[40] IEE. (2009). Summary of IOU-Administered Residential Customer Dynamic Pricing Pilots & Programs by State. *The Edison Foundation: Institute for Electric Efficiency*.

[41] Vine, E. (2006). The Integration of Energy Efficiency, Renewable Energy, Demand Response and Climate Change: Challenges and Opportunities for Evaluators and Planners. *Lawrence Berkeley National Laboratory, International Energy Studies, 2006-10-10*(LBNL-62728). Retrieved from http://ies.lbl.gov/node/304

VI. Summary of Findings and Recommendations

Speculating forward to approximately the year 2015, current trends suggest that a combination of meter systems, web-enabled thermostats and other devices, and improved Web applications may form a coordinated system supporting a more energy efficient society. In our review of the nature of energy and demand savings from the Smart Grid, we see the potential for energy benefits for both large and small consumers, but the most substantial opportunity appears to be for smaller consumers and households with central air conditioning.

This paper examines utility vs. public/consumer approaches to various aspects of consumer-side Smart Grid architecture. Our conclusion is that utilities, regulators, and policymakers should focus on the *consumer-centric architectures* for appliance control, *public architecture* for AMI communication, and *collaborative architecture* for content. Some of the elements are summarized on the following table[42]:

	Consumer Control	**Utility Control**
Control	Consumer decisions/control	HAN optimized by utility - Consumer opt in/out
Pricing	Time-based - dynamic pricing.	Incentive for participating.
HAN	Owned/purchased by consumer. Possible utility incentives	Provided by utility/ recovered as part of regulated filing.
Gateway	HAN via internet, mobile phone, cable	Meter via proprietary system.
Data	To consumer via internet To utility via proprietary system hourly reads once/day; low bandwidth.	To consumer and utility via proprietary system Two way and high bandwidth – Large amounts of data.
Utility Cost	*Less Expensive*	*More Expensive*
Impacts	Creates *efficiency and DR.*	Primary impact *is DR.*

Regarding innovation, our findings to date are that our objectives are best met by an ecosystem where the *utility creates the conditions for and seeds an effective ecosystem* for innovation, *which the marketplace then populates with novel ideas and innovative companies*. In this model, the marketplace will generate the innovations that appeal most to the consumer's preferences. This is accomplished through leverage of the utility's metering infrastructure, with appropriate open access and information sharing. And clearly, the regulatory standards placed and incentives offered to the utility industry will be the drivers of effective change and advancement.

In summary, we believe the following must guide the country's development of Smart Grid:

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[42] Terry Vardell and Michelle Davis, Duke Energy, *Analysis of Smart Energy Now pilot,* July 2008.

We need to focus on consumer-controlled architectures for device control. The market and consumer-led opportunities for innovation are exciting and substantial. We can see glimpses of ever-improving diagnostic and control methods that will dramatically reduce our energy requirements. Achieving our energy and greenhouse gas goals may require that we focus on market-led innovation in how we manage our homes and buildings.

We need to focus on open and public network approaches to communication. Public network-connected devices are likely to produce more effective energy management, while utility-specific standards for communication protocols may reduce choice and innovation.

We need to encourage a broad ecosystem of content providers, including utilities. The ability of Web software systems to interact with all of the consumer's technologies and information may create an ecosystem that supports the intelligent management of appliances and systems in our buildings, increasingly effective at saving energy and demand, and adaptive to consumer preferences. The consumer-managed approach and IP-based communication options recommended above support this direction. For example, in-home displays if provided by utilities should receive their content from the Public Internet, not the utility private network. And in time, one would expect consumers to rely on their own displays, including computers and phones. However, utility AMI systems that broadcast short-interval reads directly into the home for use by consumers and their web workspaces will support innovation. These short-interval reads *on demand* are a key ingredient in measuring differential energy use, supporting the measurement of load, and cost, of any switchable device in the home.

In short, we need to move forward now with AMI and dynamic pricing. This paper's findings support one overarching conclusion, which is that there is substantial and critically important opportunities for innovation on the consumer side of the meter. However, a precondition for much of this innovation is the installation of meters capable of hourly reads. We will need advanced metering to price electricity on a time-differentiated basis. In addition, there is an issue of fairness. Our failure to measure electric use at the consumer level as we price at wholesale creates winners and losers, where the losers subsidize consumers who are insensitive to costs and the timing of electricity usage. Finally, the load duration curve continues to get "peakier" as air conditioning market share grows, making the fairness problem worse.

A federal policy to promote widespread adoption of hourly read meters and default dynamic pricing would be likely to generate significant economic and carbon benefits and should be pursued in the national interest. To date, federal policies have been more focused on regulating AMI, rather than promoting it. A federal policy to move us to ubiquitous hourly read meters and default dynamic pricing is in our national interests for the economic and carbon benefits it will create. Therefore, we recommend a priority to Federal and state energy policy-making to resolve the architectural and strategic concerns that will allow us to unlock the potential of innovation on the consumer side of the meter.

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Appendix A –

MIT Energy Innovation Project

Workshop on the Innovation Ecosystem on the Customer Side of the Meter

Hotel Marlowe, Cambridge | July 24, 2009

Andrew Bowman
Director, Climate Change Initiative
Doris Duke Charitable Foundation

Darren Brady
Senior Vice President and
Chief Operating Officer
EnerNOC, Inc.

Paul De Martini
Vice President Advanced Technology
Southern California Edison Company

Katie Donnelly
Program Officer, Climate Change Initiative
Doris Duke Charitable Foundation

Kat Donnelly
Ph.D. Candidate, Engineering Systems Division
Massachusetts Institute of Technology

Ahmad Faruqui
Principal
The Brattle Group

David M. Hart
Associate Professor of Public Policy
George Mason University

Erfan Ibrahim
Chief Technical Officer
Electric Power Research Institute

Marija D. Ilic
Professor of ECE and EPP
Carnegie Mellon University

Richard K. Lester
Professor of Nuclear Science & Engineering
Director of the Industrial Performance Center
Massachusetts Institute of Technology

Roger Levy
Senior Advisor, StrateGen
Lawrence Berkeley National Laboratory
Demand Response Research Center

Carlos Andres Martínez-Vela
Director of Innovation Policy
John Adams Innovation Institute

Harvey Michaels
Energy Efficiency Research Director and
Lecturer
Environmental Policy and Planning and MITEI

Mark Moskovitz
Partner
IBM Business Consulting Services
Strategy & Change Practice
Energy & Utilities

Geoffrey G. Parker
Director, Tulane Energy Institute
Associate Professor, Economic Sciences
Tulane University

José Ignacio Pérez-Arriaga
MIT Visiting Professor
IIT/Institute for Research in Technology
Universidad Pontificia Comillas

Rohit Sakhuja
Executive Director
Energy Innovation Project

Ted E. Schultz
Vice President
Duke Energy

Hemant Taneja
Managing Director, General Catalyst Partners

Adrian Tuck
Chief Executive Officer, Tendril Networks, Inc.

Mason Willrich
Chair, California Independent System Operator