If Buildings Could Talk: How Information Technology Can Increase Energy Efficiency and Demand Management in Buildings

W. Michael Warwick
Pacific Northwest National Laboratory
Portland, Oregon

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Pacific Northwest National Laboratory
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Executive Summary

DOE's Office of Building Technology, State, and Community Programs (BTS)[1] has helped the United States achieve significant improvements in domestic energy efficiency. This success occurred during periods when electric utilities were regulated and energy markets were stable and predictable. Times have changed. The energy industry is undergoing a fundamental change as markets replace regulation. Early experience with competitive energy markets has been marked by periods of price volatility and supply constraints. Although price volatility is a hallmark of commodity markets, it is foreign to regulated retail electricity markets. In response, regulators are struggling with ways to provide retail customers with information about changes in energy prices in real-time and tools to protect themselves from very high prices. Retail customers are struggling to address a future where not only are electric rates uncertain, the most important predictor of future energy bills are peak demand charges and fees for ancillary services that are unfamiliar. Larger energy consumers are attempting to assert control over their power bill by embracing self-generation.

Deregulation and periodic energy crises are forcing consumers to become educated about the energy industry. Nevertheless, their actions remain largely reactive and uncoordinated with the actual operation of the electric power grid, which does not provide retail customers with timely price information. Retail consumers are also becoming more "connected" through increased access to and use of computers and communication technologies, often called Information Technology, or IT. IT has the potential to integrate energy use practices with the needs of the power grid. Interaction between consumers and the power grid will enable homes and buildings and the equipment in them to become more energy efficient and will make more efficient use of the power grid. Increased "grid awareness" coupled with IT capabilities presents a new frontier for energy efficiency in buildings. This frontier holds out the promise that "connected" buildings and "smart" appliances will lead to more efficient energy markets and improved grid operations and, consequently, lower prices and less price volatility. Informed interactions between the supply system and demand components will also create a more resilient electric grid that is more robust and secure against brownouts, blackouts, and hostile attacks.

[1] Reorganized as the Office of Building Research and Standards (BRS) April 2002.

Introduction

DOE's Office of Building Technology, State, and Community Programs (BTS) has had numerous successes and is responsible for significant improvements in energy efficiency in the United States. Some of the successes include setting minimum efficiency standards for a wide variety of appliances and equipment, including air conditioners, heat pumps and refrigerators, weatherization of 5 million homes, and innovative technology breakthroughs such as the electronic ballast, high-performance refrigerator compressors, and low-emissivity windows. These successes occurred during a time when electric energy for homes and buildings was provided by a single local utility with regulated prices that were stable and predictable. The utility knew who its customers were and could forecast their power needs. It built power plants and transmission lines specifically to meet those needs. Retail customers knew who provided their energy and what future costs were likely to be.

Today, the environment is very different. Legislation has opened the door to competition in wholesale electricity markets. Local utilities are increasingly dependent on power purchased from remote sources that is transported over transmission lines owned by neighboring utilities. This trend toward increased interconnectedness of utilities is accelerating. It has been accompanied by increased wholesale price volatility, leading to less stable and less predictable retail rates.

At the same time, homes and buildings are increasingly interconnected to markets, customers, suppliers, and information sources using information technologies (IT) [2] and the Internet. Both the utility industry and electricity consumers are looking for ways for the IT network to intersect that of the electric power grid. Utilities are exploring ways to use IT and the Internet for automatic meter reading, electronic billing for electricity, and in some cases, direct control of customer loads, such as residential water heaters or commercial air conditioners. Retail electricity consumers, especially larger commercial and industrial customers, are searching for ways to coordinate operations with utilities to both reduce use when market prices are high and provide some services to the grid that would otherwise come from generators. Ultimately, interactivity between homes and businesses and the power system offers a pathway for individual homes and businesses to better manage their own energy use and thereby improve the quality, reliability, and security of electric power service to all customers.

So what does this have to do with DOE's building mission? Electric appliances, equipment, and lighting in buildings are evolving from static pieces of equipment to devices that can use embedded intelligence to interact with each other and the world beyond. Isolated appliances performing routine functions are giving way to "smart appliances" with greatly expanded capabilities. Similarly, stand-alone building systems such as lighting have the potential to "speak to" the HVAC, building envelope, security, and energy management systems. Individual pieces of equipment as well as entire building loads have the potential to dynamically interact with the upstream supply of power. The technological capability to do

[2] IT is short for Information Technology. Definitions of IT are almost as widespread as the technology itself. For purposes of this paper it will be defined simply as computers linked through a communications network to facilitate the gathering of actionable information to guide local decisions. This definition implies certain key assumptions. It is technology independent. Computers, in this context, include any equipment capable of receiving, processing, and acting upon information. This could be a general-purpose personal computer or a simple, single-purpose chip. The communication network could be a conventional computer network, landline phone system, cordless or radio phone network, or even a pager. Most importantly, the process is "intelligent." It has a purpose, namely to collect specific kinds of information to make operational decisions. In this context, IT is "intelligent" technology.

this is within reach. Utilities are evolving from mechanistic, hierarchical, and inflexible systems toward an organic network that continuously interacts with its customers. The economic rewards of increased interactivity are significant both in terms of avoided utility construction and power costs and environmental impacts. The feasibility of having controllable equipment working with the electric grid is dependent on developing new building technologies and electric grid interface capabilities.

Background

To understand the potential benefits and the critical issues facing buildings, IT, and grid interactivity, it is important to understand the changing business climate of the electric power industry. The Federal Energy Regulatory Commission (FERC) regulates wholesale natural gas and electricity markets. FERC has deregulated these markets in response to Federal legislation adopted since the 1970s. Wholesale deregulation includes “unbundling” transportation and other “ancillary” services from the energy commodity. As a result, where there used to be a single electricity or natural gas “product,” there are now multiple products, each with prices that are set in competitive markets. Commodity markets are typically marked by periods of price volatility. That has been the case with wholesale electricity and natural gas markets as well. The States regulate retail natural gas and electricity markets. Roughly half of the States have plans to allow electricity customers to choose among alternative electricity and natural gas suppliers. High wholesale prices ultimately translate into retail utility rate increases for customers of regulated retail utilities and they translate directly into power bills for customers in deregulated states. Uncertainty about future power prices is unsettling to many retail electricity customers who don’t know how to assess the long-term costs and benefits of energy-efficiency investments.

Power use varies over the course of a day or year, largely as a function of demand for space conditioning in buildings. Power supply and delivery costs vary in response to consumer power demand. This reflects the fact that the most efficient, and hence least costly, power plants are used first and plants that are more costly to operate are used sparingly, typically just to meet peak demands. This can be illustrated through a graphic the industry calls a load duration curve. A load duration curve is developed by rank-ordering electricity demand for each hour over a year. There are 8,760 hours in a year, so this means that the hour with the highest demand has rank 1, and the hour with the lowest demand is rank 8,760 (Figure 1).

A load duration curve provides visual confirmation that peak demand periods are relatively extreme compared to “normal” demand. They are also relatively short lived, typically between 200 and 400 hours a year. Power systems need to be able to meet peak demand; therefore, peak demand dictates the number of power plants and the size of transmission and distribution systems. As the load duration curve illustrates, the result is a significant amount of idle capacity throughout the power system, including idle power plants, transmission line capacity, and distribution line capability. This spare capacity is a result of a “just in case” philosophy that is a legacy of utility regulation and its requirement that retail utilities provide adequate reserves to ensure reliable service to all customers.

Utility reserves are equivalent to inventory in manufacturing or retail businesses. Modern supply chain practices embrace a “just in time” philosophy that minimizes inventory, as it is considered a costly, unnecessary, and non-productive asset. The “just in time” supply chain philosophy took root in modern enterprises due to the use of IT to communicate customer needs and preferences directly to manufacturers and retailers. The widespread availability of IT provides a similar communications pathway between utility system operators and consumers. Unfortunately it is under-developed and thus far rarely used.

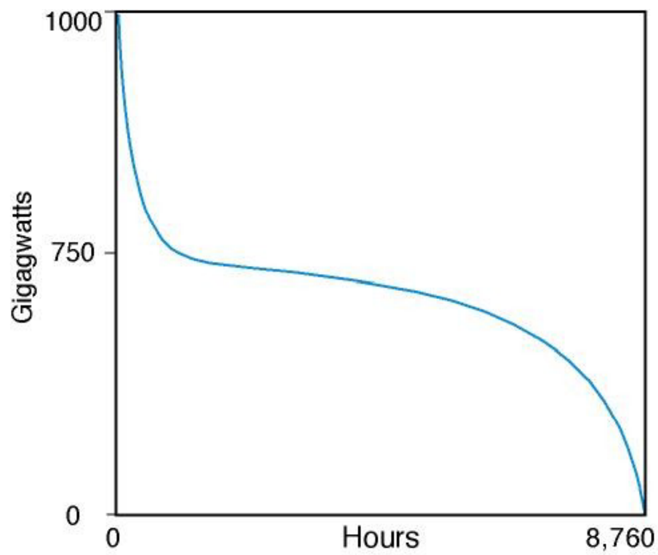

Figure 1. A Typical Load Duration Curve Showing a Rank Ordering of Hourly Loads from Peak (highest load hour) to Lowest for All 8,760 Hours in a Year. 1,000 Gigawatts is expected to be the total generating requirement for the nation by 2015. This load-duration curve for the nation is an artifice, as the nation's generators and consumer loads are not all interconnected.

Ironically, electricity grid operations are highly dependent on IT. This is because electricity supplies need to match consumer demand exactly, from moment to moment. If they do not, critical features of electrical service are impacted because electrical systems react to changes in generation and demand in real time. For example, when loads exceed generation, voltage throughout the system drops in response. This causes lights to dim and motors to slow and run hot. Thus, all consumers suffer. The balancing act between loads and generation can work both ways. Instead of meeting increasing consumer demand with more generation, balance can be restored by equal reductions in building loads, such as interrupting the heating cycle of home electric water heaters or commercial HVAC equipment or by supplying power *to the grid* from distributed energy resources (DER). Essentially, one set of customers makes room for another and is compensated for doing so.

The treatment of "load as a resource" is a new twist on an established practice to reduce generating peaks. It is now being explored as a way to "make room" for demand peaks on transmission and distribution lines as well. If utilities made full use of demand management of appliances in homes and equipment in buildings, it could significantly reduce the need to build new generating plants, construct new transmission lines, and expand distribution systems. Conceptually, the load duration curve could be "flat" (Figure 2).

EIA projects national power needs of approximately 1,000 Gigawatts by 2015.[3] This is on the present base of roughly 750 Gigawatts. A Gigawatt is 1,000 Megawatts. A nuclear power plant is typically rated at about 1,000 Megawatts, so a Gigawatt is roughly equal to one new nuclear power plant. Even a small reduction in future power requirements translates into significant economic and environmental savings.

[3] Energy Information Administration "Annual Energy Outlook 2002," Table A9.

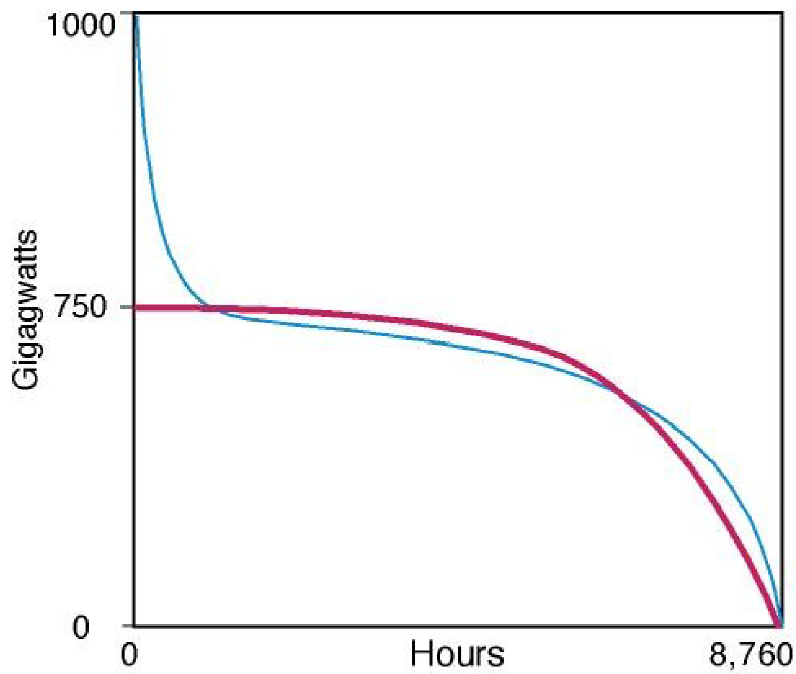

Figure 2. An Interactive Grid with Active Load Management Could "Flatten Out" the Load Duration Curve

From an economic and environmental perspective, a "flat" load duration curve is an ideal. It may be one that is impractical to achieve. Nevertheless, it provides an alternative scenario to continued business as usual based on "just in case" planning and operation of the electrical grid. More importantly, increasing interest in "load as a resource" to solve localized transmission and distribution constraints is leading to both a revival in demand management as an operating option and to potentially more widespread and rapid distribution of this capability in homes and buildings.

Buildings, IT, and Grid Interactivity

Interaction between consumers and grid operators/operations is not new. Utilities have implemented rates or programs that involve time-of-use (TOU) metering, demand management, and, most recently, demand bidding, all in an effort to reduce demand during peak energy usage periods. Briefly, TOU metering involves the use of a meter that tracks energy use during different time intervals with a charge that varies based on the time of use. Residential and commercial customers are expected to react to high prices by reducing their demand, although the response is voluntary. The high cost of TOU meters has limited their installation to high-use customers.

Load control programs rely on either a contractual obligation or utility control of end use equipment to curtail specific loads on command from the utility. Typically, a large customer will contractually agree to reduce demand by say, 5 Megawatts, but not have to specify what loads they will curtail. Smaller customers, such as residential and small commercial customers usually have a utility-controlled switch installed on a specific piece of equipment, such as an air conditioner, pool heater or pump, or water heater.

Demand bidding is a very new approach that combines elements of both time-of-use metering and load control. Its biggest launch was during the California power crisis, although similar programs were adopted in the northeastern states last year in anticipation of supply and transmission shortages. Demand bidding provides customers with an opportunity to offer to curtail use based on a payment to the customer. The customer establishes the payment through a bid. The utility or system operator selects bids based on price, with the lowest bid being accepted first. Performance is monitored and rewarded using a real-time meter. Again, the cost of the equipment needed for these programs limits participation to high use customers. Unfortunately, these programs are so new there is little data to evaluate them. The cool summer and economic downturn last year damped participation in the northeastern states. Similarly, ample power supplies sharply limited the need for demand relief in California.[4]

Although TOU rates and demand management programs are well established, their record of success is mixed and their future is uncertain in a deregulated world.[5] Nevertheless, it is clear that potential exists for improved electric system efficiencies from direct interaction between the power system and electric appliances, homes, and commercial buildings. What is not clear, at this stage at least, is how this interactive grid would come about. Why would consumers adopt "grid smart" technologies? Potential benefits to the power grid can't be realized without commensurate benefits to consumers, economically and through equipment and building efficiencies. Participation by residents and building owners is critical, because nearly 70% of the nation's electricity is used in buildings. Past programs have mostly excluded residential customers, but they account for about 45% of electricity use. Inclusion of electricity customers is critical both for equity reasons and to tap into demand management capabilities needed for transmission and distribution system demand relief.

Accordingly, let's take a look at the customer side of the power meter. In order for residents and building owners to embrace grid interactivity, it needs to allow them to do one or more of the following:

- Avoid cost, such as directly reducing energy use, demand charges, or maintenance expenses.
- Provide incentive payments, in addition to any electricity bill savings.
- Increase the energy efficiency of electrical equipment through operational changes (rather than through equipment replacement).
- Increase the energy efficiency of building operations (or otherwise improve building operations, for example by increasing comfort, tenant satisfaction, and/or employee productivity).
- Improve power quality and/or service reliability.
- Improve energy security.
- Lead to reduced costs of installing and operating new technologies by sharing costs and benefits with others, such as joint use of equipment by adjacent homes or businesses or shared power from DER, especially renewables.

Let's look briefly at each of these.

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[4] A good description of the California programs can be found in, "Overview of California ISO Summer 2000 Demand Response Programs," by John H. Doudna, P.E., of the California ISO.

[5] Although it is still beneficial to reduce demand, deregulation spreads these benefits across multiple parties, effectively diluting them. For example, peak load reduction doesn't benefit power suppliers, because they are able to charge top dollar for power on peak. Avoiding these purchases would benefit all retail customers, on average, but each customer may purchase their power from different suppliers, so they would be difficult to organize and reward for curtailing peak demand. There are similar benefits from reducing peak use of transmission and distribution systems. Again, transmission operation is in the hands of an ISO or RTO, not the utility, so these benefits are also Balkanized. Moreover, they tend to be both localized and insufficient to justify the needed investment to reduce them, at least, by themselves.

Cost avoidance. As wholesale prices trickle down to retail rates, they will bring "price signals" in the form of new rate structures and pass-through power costs that will reflect differences in the cost of power in the form of time-of-use rates and real-time pricing (RTP). In other words, deregulation of prices at the wholesale level will show up in retail customer power bills, *even without retail deregulation*. Accordingly, retail customers may want to embrace grid interactive technologies to reduce these impacts on their power bills. For example, residents can put controls on electric water heaters so they don't operate during high-cost periods, especially if those occur during the work or school day when no one is using hot water. Consumer actions that curtail use during high-cost periods or shift use to lower cost periods save money over the business as usual case. There are direct benefits to the consumer by avoiding use during high costs periods. There are also additional indirect benefits to *all* consumers if peak demand is reduced *in aggregate* due to consumer response to TOU rates. Load shifting may also reduce total energy use. For example, postponing the reheating cycle on a water heater after morning baths to the evening also avoids the standby heat losses that would otherwise occur during the day.

Incentive payments. Generators are paid to provide power and ancillary services to the power grid, including payments to operate power plants in specific areas that have transmission constraints. In other words, power system operators are willing to pay generators to provide both power *and* transmission services. If load is treated as a resource, then customers can offer to provide the same services to grid operators. The FERC has directed transmission-owning utilities to form and join independent organizations to operate transmission lines as an integrated network, rather than the existing patchwork of lines operated by individual utilities. These so-called Regional Transmission Organizations (RTOs) have been encouraged by the FERC to solicit bids for "demand relief." Several RTOs are operating and others are being formed. Most of these intend to operate a demand relief market where customers can bid demand relief. Generally, these are targeted at large commercial and industrial customers, but aggregators can participate as well. For example, an agent could coordinate the operation of residential water heaters or air conditioners to offer a large "block of demand" relief to the RTO, rather than each household having to do so on their own. Perhaps participants in weatherization programs could be equipped with control technologies on their appliances to participate as a block in demand bidding or other programs. Another approach is for customers with distributed energy resources (DER) to sell power back into the grid. This is particularly valuable for relieving transmission constraints. Generators that provide this service often receive fairly high payments.

Equipment efficiency improvements. Equipment that is smart enough to interact with the power grid should be smart enough to operate at optimum efficiency. For example, a water heater may be able to "learn" how residents use hot water and then set back its thermostat during low-use periods and boost its temperature just prior to periods of intense use. This kind of intelligence would reduce energy use for water heating and standby losses as well as reducing peak demands on the power grid. The reduced energy use translates directly into utility cost savings as well as lower electric bills.

Building efficiency improvements. Building Energy Management Systems (EMSs) are intelligent by design. Access to real-time prices from energy, ancillary service, and transmission congestion markets can be used to "fine tune" operations to reduce energy use or change energy use schedules. For example, a building schedule may call for a constant temperature of 72 degrees during the summer. On system peak days, when power prices peak, temperatures could be allowed to drift upwards a degree an hour from noon on. Similarly, the EMS may be able to control other, less visible energy uses. For example, it may be able to "sense" that offices are vacant and turn off the lights and equipment in those offices. In both cases, these actions save energy and money and help the power grid. If the building is offering these actions in the demand relief market, the building owner may even receive a check in addition to the energy bill savings. A key feature of this kind of intelligence is that it could be tailored to each situation, day by day. In other words, the temperature step-up strategy may only be used a few very hot days a year. Currently, EMSs tend to be programmed, like home thermostats, to follow a schedule that is not tied to power prices that vary in real-time. A price-driven conservation schedule would reduce tenant complaints as it would only affect building operations during rare, high-cost periods.

Power quality and reliability improvements. IT is now ubiquitous. IT devices are distributed throughout our homes and offices making it increasingly difficult to provide them with the high-quality power they require. A power outage anywhere in the system is likely to impact many homes and businesses. The problem is that the power system cannot be economically upgraded to provide high-quality power to everyone and it is expensive to provide back-up power supplies for each and every IT device. As noted in a companion white paper on peak demand by Jonathan Koomey, outage risk is greatest during periods of high system demand. If "smart" buildings are able to reduce system peaks, this should also reduce outage risk. Further, "grid aware" buildings and equipment should be able to tell when the system is under stress and take protective action. For example, key power system characteristics begin to exceed established ranges prior to system failure. Voltage may drop or vary widely or the 60-cycle (Hertz) frequency may slow. "Smart" buildings and equipment could use this information as a trigger to begin shutting down sensitive electronic equipment or to automatically initiate back-up copy routines. If the system does fail, building occupants are supposed to shut off electric equipment to facilitate service restoration. This rarely happens in practice. In contrast, "smart" equipment could automatically turn itself off when power is curtailed and delay starting up when service is restored. This would both hasten service restoration and protect the equipment from the power surges that typically accompany restoration of service after an outage.

Energy security improvements. The nation's electricity grid is fragile. Power lines are vulnerable to attack because of their location and design. A coordinated attack could bring down the power system in such a way as to delay service restoration for days or weeks. The combination of "smart" buildings and equipment along with DER could protect against region-wide power outages. For example, DER devices could communicate their location and status to the power grid so that grid operators could remotely disconnect lines in their area and automatically reduce building and equipment loads to a level that the DER devices could support. This could, in effect, result in scattered "islands" where electrical service would continue, albeit at very low levels. Available power could be diverted to support critical infrastructure, such as traffic and railroad signals and thereby prevent the kind of widespread disruption terrorists could be trying to achieve. The presence of active "power islands" would also facilitate restoration of the power grid once repairs were underway. A similar strategy could be executed by "smart" equipment within a building or facility that was under localized attack as well.

Sharing of costs and benefits. The last example highlighted the "mutual aid" model of cooperation among neighboring electricity customers. Acquiring "intelligence," especially as it relates to interactions with grid operators, may be expensive. Similarly, some energy resources, such as DER, may be able to support critical IT infrastructure or provide emergency power for more than one customer. Accordingly, customers may choose to "aggregate" themselves so that adjacent buildings can share some or all of the resources needed to interact with the power grid in the most optimal fashion. In the past, customers have collaborated to "share" demand relief "pain" and benefits. For example, two buildings may agree to limit their combined demand to a set level, say 10 Megawatts, or 5 Megawatts each. If one building can only cut 4 Megawatts its partner may be able to reduce its demand by 6 Megawatts, meeting the 10 Megawatt target. "Smart" equipment in each building could communicate with each other as well as with the power grid to optimize joint operations to meet this objective. Similarly, one building may have a DER and be willing to share it to provide protection to critical IT infrastructure (or sell surplus power). This could be especially important for buildings that have on-site renewable energy potential, such as the "120% building." Imagine two buildings on a north-south axis, with the southern-most building shading its northern neighbor. The two building owners could collaborate on the installation of a photovoltaic array on the southern building, but share the output. In this case, the electricity from the PV system would need to be coordinated with the power demands of both buildings and the surplus, if any, with grid operators. Again, "smart" devices can facilitate these kinds of operations.

How Would IT Increase Energy Efficiency?

"Smart" buildings and equipment can increase energy efficiency at the individual equipment level, at the building level (by how "smart" equipment interacts with the building and other "smart" and dumb equipment), and on a "system" basis by reducing the amount of energy required to meet the needs of all customers. The primary mechanisms for achieving these results include:

- Energy efficiency per se, namely increasing the efficiency of converting energy into useful work or service.
- Peak load curtailment, or simply not using energy during peak demand periods. As noted above this may or may not require customers to sacrifice some service or service quality. Ideally, "smart" buildings and equipment can identify unneeded or underused services to curtail thereby avoiding the need to sacrifice service and saving energy at the same time.
- Peak load shifting, simply re-scheduling an energy-using activity to a lower demand or price period. Most of the time, peak shifting of heating or cooling activities results in a slight increase in total electricity use, even though the electricity used later may be more efficiently produced (by plants that use less fuel to generate power). This is not always the case. If there is a significant difference in the ambient temperature as a result of the time shift, then there may be an increase in efficiency. For example, it may take less electricity to cool something at night than during the afternoon hours due to the cooler temperature of the inlet air. As noted previously, thermal losses may also be reduced.
- As noted above, peak-sharing activities can be coordinated so that they are not scheduled to occur at same time. That way on-peak demand is reduced. This kind of sharing can occur within a building, across buildings, or even within an appliance. For example, refrigerators could be designed so that the defroster and icemaker do not operate when the compressor is running.

- Supplemental generation or waste heat reuse. On-site generation can be used to reduce demand for grid-supplied power or, if excess, to supplement power from power plants. Similarly, waste heat from power generation or other activities may be re-used to replace energy used for heating or, if it is hot enough, to drive a thermal engine or chemical process for cooling.

The heart of this paper is how "smart" devices might employ these mechanisms and how they might coordinate with the power grid. This issue is the primary challenge the building equipment and appliance industries, utilities, and society face in designing and implementing an "interactive" grid. We can group these challenges into the following related topics.

- First, there is the question of the building/grid interface itself. Where is it? Who controls it?
- A second, closely related issue is whom the building/grid interface serves. Is it an intelligent agent in an appliance or at the building level? Who owns it and any resulting benefits?
- Third is a very important, but fairly esoteric technical question about the kinds of services "smart" devices might be expected to provide to the power grid. Are services limited to demand management or do they include other valued ancillary services? The answer to this question leads naturally to ones about the necessary scale of grid interactivity. For example, a handful of buildings cannot provide sufficient demand relief to avoid new utility infrastructure or affect short-term utility operations, especially if these buildings are scattered hither and yon.
- Forth, and finally, there are larger social issues that are raised by prospects of grid interactivity.

What and Where is the Demand Management "Gateway" and Who Controls It?

There are critical technical issues that need to be addressed to design and implement the interactive grid. The first is how the interactions will occur. Specifically, how will the grid and points of control, whatever they are, interact with each other? At the most basic level, this is a *communication technology* question. At a higher level, it may be an *economic and program design* issue. Specifically, if residents and building owners are to be rewarded for interacting with the grid, how do we determine those rewards and who pays them? Central to this challenge is the need for some kind of *decision framework*, the "smarts" in smart appliances.

"Smart appliances" which interact with the power grid individually, are one extreme. This solution may require extensive infrastructure, depending on the scope and scale of grid interactions. Another option would be to aggregate end uses and customers behind a communications "gateway" that would interact with the power system. This approach could significantly reduce the infrastructure burden, but it requires a whole new "appliance." Aggregation models assume that the power grid may benefit from "load as a resource" services equivalent to those of power resources but that the grid isn't capable of conducting the number of transactions necessary to gain the benefit. This could be especially true for services needed in real time.

There may be significant costs associated with interacting with the grid, especially if the interaction requires real-time metering. Small customers generally cannot bear these costs, but they may be able to if the costs are spread across a larger aggregation of customers for example, in a new Building America residential development, among Rebuild America partner commercial buildings, or among, say, 7,000 weatherized homes in Philadelphia. Finally, there is an underlying assumption that system operators need to deal with market participants that are reliable, stable, and financially sound. Aggregating small customers into a large trading block may address some of these issues and may result in more benefits to the power system and to customers. Each interaction or aggregation scheme raises different issues, as discussed below.

"Smart" Appliances Interacting with the Grid or Higher Level Interface

"Smart appliances" represent the far end of the interactive grid spectrum. Under this scenario, each electricity-using device is implanted with a "brain" that could tap into information or instructions through the Internet or other communications network to respond to grid conditions. For example, a refrigerator may be able to "learn" that the power system is reaching its peak and could choose to defer its defrost cycle or even reset its internal temperature to prevent the compressor from turning on until the internal temperature dropped to a point where frozen foods would begin to thaw.

One of the advantages of empowering each power-using appliance to direct itself is that the programming challenge is much smaller and well suited for mass-produced computer chips that could sell for a few dollars. Another advantage is that if each end use makes its own operating decisions, there is little or no need for the user to do so. In other words, it all happens in the background. The combination of low cost and ease of use could make "smart" appliances very attractive to a mass market, including appliances typically purchased by, or for, low-income residences. The presence of "grid-enabled" equipment should facilitate aggregation of this equipment within buildings or even across buildings, if desired. Thus, there is no need to force a choice between a system designed around aggregation and one using grid-enabled appliances.

There are some potential downsides to grid-enabled end uses:

- First, control operations would need to be standardized or easy to customize. In other words, if each utility or grid operator had unique specifications for load-supplied resources, the chips in each piece of equipment would need to be individually programmed. It would be preferable if these grid control operations were standardized instead. Facilitating the development of national standards is a natural federal role.
- Second, the present utility control system is not capable of interacting with the millions of end uses that could potentially be equipped with energy smarts. Further, the system is not designed to deal with transactions as small as those that would originate in an appliance. Consequently, the designers of future power systems need to be partners in the design and development of grid-enabled end uses. In other words, without engaging the power industry early in the process, appliances with "smarts" may not be used by grid operators.
- A third challenge is the need to coordinate interactions among independent agents. For example, if all refrigerators turned off, or on, at the same time, other power system control problems could result. If "on/off" commands were coupled with "fuzzy" logic, this would be much less of a problem.

Another option would be for appliances to have limited intelligence. As was noted previously, appliances, HVAC equipment, and lighting systems could just be equipped with chips that merely sense power system conditions based on variations in line voltage and frequency and respond accordingly. This kind of end use would not need to actively communicate with the power grid.

The Association of Home Appliance Manufacturers (AHAM) has developed a high-level standard for communicating with and among "smart" appliances. This draft standard, *Connected Home Appliances – Object Modeling (CHA-1)*, provides a framework for developing both smart appliances and higher level gateway devices that can communicate with any appliance developed to the standard using an appropriate communications protocol. AHAM has not specified a communications method or protocol at this time. This is a good first step toward the development of grid aware and smart appliances, but it is still just a first step.

"Smart" Buildings Interacting with the Grid

Another scheme is for individual buildings to interact with the grid through some kind of interface. This interface is often called a "gateway," which is a useful term for isolating the IT aspects of the consumer-grid interaction from the electrical ones.[6] The gateway may also be proprietary and it may be used to aggregate customers through intermediaries. The key distinction is that buildings with their own gateways may be able to act more independently of both intermediaries and other buildings. To some extent, building EMSs play this role already, although their ability to interact with real-time directives from the power grid is not fully realized. Further, they do not yet control all electricity uses or aspire to do so. Nevertheless, they do provide a useful analogy to assess the needs of a gateway and the associated barriers.

Interactive grid gateways will need to have capabilities similar to an EMS, including the ability to change the operation of building systems in response to changing market conditions but within constraints that maintain the functionality of the building, such as reasonable comfort and lighting levels. The benefit of a single-building gateway approach is that demand for this capability could generate a new, mass-market product that could be substantially lower in cost. This has not been the case with EMS technology for a variety of reasons. One view of the market is that the gateway may be used to access non-energy services, such as cable TV (CATV), broadband, and telecommunications services that could be used to pay for its cost as part of a service bundle.[7] Microsoft, CATV equipment suppliers, and the CATV and telecommunications industries have, at various times, indicated that a consumer gateway was a key element in their strategy to generate subscriber revenues from bundled services.

The downside of a gateway device, as its promoters are finding, is that costs are prohibitive until it becomes a mass-market item and, at present, there is insufficient demand for bundled services to create the necessary market. Unfortunately, like videotape formats before it, each promoter of gateway products envisions a proprietary interface. This lack of standardization creates additional barriers to the development of a mass market. Finally, a building-level gateway may be challenged to provide measurement and verification of services sold back to the grid if these need to be audited or the costs and benefits allocated back to building tenants. This may attract the unwanted attention of regulators that view the gateway as the equivalent of a power meter. Discussions with retail utilities reveal continued

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[6] The term "gateway" appears to be in common usage (not trademarked) and has been or is being used by a number of firms to describe a point of access and control by firms like IBM, Microsoft, and cable TV companies. The Japanese electric utility industry has developed a proposal for similar devices to be located at the distribution level. They call their interface a loop controller.

[7] This discussion benefited from communication with Ron Chebra of the Automatic Meter Reading Association.

interest in this area, but grave concerns that regulators will intrude into efforts regulated utilities may take to enter this market, even if those are undertaken by an unregulated subsidiary.[8]

Buildings Interacting among Themselves

The notion that buildings will interact with the grid, individually or through individual aggregators, is a common one.[9] One perspective, interestingly one put forth by Japanese electric industry researchers, is that customers will interact in unison with each other on a distribution line-by-distribution line basis. Essentially, each distribution line becomes a mini-utility. The term "micro-grid" has been used in the U.S. to describe a similar concept, although usually at a much smaller scale, such as a handful of adjacent homes. Both views assume that some customers on each distribution line generate a significant fraction of their own power as well as some of the power needed by other loads on the line. An alternative deployment is to aggregate buildings that are not adjacent to each other.

Aggregation schemes typically utilize an interface that is owned and operated by the aggregator. The benefit of this approach is that it doesn't require new technology. The downside is that it is relatively expensive to implement and leaves the customer with a system that is largely proprietary, is complicated, and requires skilled operators. To take full advantage of the ability to interact with the power grid, these systems also require the advice of local market experts, at an additional cost.

Scope and Scale Issues

Given that demand management is functionally equivalent to many generation and transmission services, how many of these are reasonable, or practical, to supply? This is a critical issue for how "smart" equipment is designed and operated and how connected it needs to be. For example, the refrigerator mentioned previously that shut off in response to voltage or frequency fluctuations didn't need an Internet connection to provide a valuable service to the power grid. It also wouldn't necessarily be compensated for that service, although the equivalent service from a generator would. One reason is that the interruption would be momentary and would have little or no impact on the customer. Providing other services to the power grid could require noticeable interference with energy use practices and customer comfort. It is reasonable to assume that customers will require compensation to provide these services. In order for them to be an effective and equivalent alternative to similar generation-supplied services, grid operators need to be assured, <u>in advance</u>, that a sufficient number of customers are available to provide the needed service and reliably do so when requested. (Otherwise, power system planners won't include these capabilities in their plans and power system operators will ignore them in their operations.) Depending on the nature of the generation or transmission service, this could require hundreds of participants concentrated in a small area or hundreds of thousands scattered across the United States.

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[8] Private conversations with a local utility made this point in no uncertain terms, despite the fact the local regulator is not particularly aggressive.

[9] Enron, Celerity, and Silicon Energy see a role for aggregators as middlemen. They install equipment and interact with the grid. Their profits are based on a share of savings or the extra they earn by selling the customer a product at a fixed price and playing the spot market to earn additional revenues.

Each of these alternatives requires a different kind of communication and control capability. Demand bidding for some ancillary services could require two-way communication in real time. Simple peak relief responses could be verified as part of the monthly meter-reading schedule. Passive responses would not need to be verified at all and thus, would require no communication capability. If "smart" equipment is not able to supply very many generation and transmission services, it may not significantly change the kind and number of new power plants and transmission lines and the associated economic and environmental costs. In other words, if the impact of "smart" appliances is fairly limited, it may not be worth developing grid capabilities in the first place. That said, the development of "grid aware" appliances and buildings still has intrinsic value as a way for equipment and building owners to protect themselves from erratic power supplies, volatile power markets, and potentially debilitating attacks on electricity supplies.

Socio-Economic Issues

There are a host of socio-economic issues that also need to be addressed.

What Replaces the "Regulatory Compact" with Consumers?

Regulation represented a bargain between the utility and its customers, commonly called the regulatory compact, although no such specific language exists. In essence, the utility was given a monopoly on customers and sales and guaranteed prices that were sufficient to cover its costs plus a profit. In exchange, utilities were expected to provide universal service to *all* customers at prices that were affordable, equitable, and did not discriminate. The interactive grid may result in customers who are able to interact with the grid and receive payments for doing so (thereby reducing their cost of power) and others who don't or cannot (low-income or rural customers, for example). Is that discrimination? Is it equitable? Similarly, if grid reliability is maintained by curtailing service to customers or end-uses, is that service truly "universal?" These issues will be of great interest to regulators and consumer advocates, both of whom will expect any new technology to be as equitable, universal, and reliable to customers as what it displaces.

What Is the Role of Regulators of all Sorts?

Electricity is regulated, in part, because it is a necessity. If customers come to depend on competitive suppliers and the associated IT they provide and maintain, who will watch over the market to ensure that the public is being protected?

Which is More Robust to Potentially Disruptive Technologies, a "Dumb" or "Smart" Grid?

IT and technical innovation is changing more than the electric grid. DOE not only anticipates, but also actively encourages some technologies that are likely to have "disruptive" impacts on the power grid, similar to the impact the cell phone had on the telephone industry and the Internet is having on commerce and commercial activity. Examples include fuel cells, mobile power in vehicles, super-conducting wire, "wearable" power systems (now being developed for the military), the development of plentiful domestic energy supplies (hopefully at low cost), and facilitating the shift to a hydrogen economy. Breakthroughs in the cost of any of these will have an impact on the way electricity is produced and distributed. That impact may make some, or all, current and new investments in the electric grid obsolete. A program to invest even more to make the grid "smart" may be questionable in the face of pending technology developments. Is it questionable? Or will buildings always benefit from being linked electrically to networked resources and to share future surplus generation from these new technologies?

Relationship to the BTS Program

There are several specific issues concerning how implementation of an interactive grid would impact current BTS initiatives:

- How might IT-enabled buildings and an interactive grid support BTS' vision of "net zero energy" and "120%" homes and buildings? Is the vision easier to achieve with a smart grid, smart buildings, and smart appliances?
- Which building end-uses are most amenable to IT enabling? Which end-uses provide the most value? Which might provide the most value/least risk to aggregators or distribution utilities?
- How might an "intelligent" grid with interactive appliances and equipment affect test procedures for appliances and the development of new minimum standard levels? Is it possible that a modestly efficient, grid-interactive appliance might use less energy than a more efficient "dumb" appliance over the course of a year, in terms of source energy? How about for peak power?
- Are low-cost, grid-interactive components a natural fit for Building America design concepts, which emphasize a number of attributes in new construction at minimal additional cost?
- Is it possible to make existing components "smart" through the installation of "at plug" intelligence? Can that be done at low cost? If so, might the technologies be applied to the BTS Weatherization-Plus program?
- Should BTS consider including a call for "intelligent" appliance concepts in a competitive solicitation?
- Should one or more roadmaps be considered? If so, how should stakeholders outside BTS's traditional circle be identified and included?
- If "smart" appliances facilitate aggregation of homes to take advantage of benefits that might be offered by utilities, should they be included in the Weatherization program to bring these benefits to low-income and elderly program participants?
- Should BTS accelerate development of a mass market for "smart" interfaces through its market transformation channels? Should future market transformation initiatives include specifications for "smart" features and interoperability with "smart" gateways?

The actual impact of an interactive grid that is not yet a reality is by definition in the future. In order for it to become a reality, it will require RD&D to begin now and increase fairly rapidly in the mid-term. Fortunately, there is plenty of time. Although EIA projects a need for roughly 250 Gigawatts of new generation by 2015, plans to construct most of that capacity have already been announced. Industry sources anticipate the bulk of the required capacity will be on-line by 2004. It is unlikely any action can be taken to defer or avoid construction of these plants. Unfortunately, there are no similar plans to expand transmission capacity to handle projected power transfers. Given that transmission line construction has a long lead time, 5 to 7 years, it is highly likely that the nation will face critical, but localized, shortages of power by the end of the decade. Widespread penetration of "smart" appliances between now and then will certainly provide homes and businesses with a modicum of protection against periodic power shortages or price spikes and may even alleviate their number and duration.