Leveraging Advanced Metering Infrastructure To Save Energy

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Revision

The original edition of this report did not include all six use cases for Southern California Edison; the utility initially reported only one use case (TOU rates) in the survey. SCE subsequently provided data clarifying how it uses AMI in support of the other five use cases. We have updated table 1 to reflect this change.

About the Authors

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Executive Summary

KEY TAKEAWAYS

- Advanced metering infrastructure (AMI) has grown rapidly and is in place in many states, covering nearly half of all meters in the United States. It is a key element of grid modernization.
- Providing customers with AMI data alone generally does not result in energy savings. AMI data need to be paired with customer engagement tools; pricing strategies; and programs with incentives and services that enable, motivate, and support customers to take actions and make changes to modify their energy use.
- Utilities are largely missing the opportunity to utilize AMI data to improve their energy efficiency and demand response offerings, in part due to regulatory, administrative, and technological barriers.
- Opportunities for leveraging AMI for energy savings include time-varying pricing (TVR); more granular energy usage feedback, including time and locational value; customer targeting and technical assistance; programs that align payment with metered performance; and more actionable insights from evaluation, measurement, and verification.
- Utilities can leverage AMI to support energy efficiency by investing in complementary systems and workforce, prioritizing the customer experience, and piloting new approaches and ways of leveraging AMI data.
- Regulators can encourage utilities to better leverage AMI by quantifying and incorporating benefits from saving energy in the AMI business cases in regulatory proposals, then adjusting shareholder compensation based on performance in realizing those benefits. They can also establish clear and reasonable protocols for data access, set performance standards for metered energy savings, and encourage innovation and pilots that could leverage AMI but might involve technology or business model risk.

BENEFITS OF ADVANCED METERING INFRASTRUCTURE

Advanced metering infrastructure (AMI) consists of meters, communications networks, and data management systems that collect, transmit, and record electricity consumption data in daily or shorter intervals. AMI is considered a foundational element of electric grid modernization by many within the electric utility industry. More timely and more granular data can be used to influence customer behavior and energy consumption when used in ways that engage, motivate, and reward customers. For utilities and grid operators, AMI provides a variety of operational benefits, including reduced costs for metering and billing, faster responses to outages, and improved safety.[1] The operational benefits of AMI compared with traditional manual metering have typically been the primary rationale used

[1] See US Department of Energy, *Advanced Metering Infrastructure and Customer Systems: Results from the Smart Grid Investment Grant Program* (Washington, DC: DOE, 2016), www.energy.gov/sites/prod/files/2016/12/f34/AMI%20Summary%20Report_09-26-16.pdf.

by utilities and regulators to invest in these systems.[2] The capabilities of AMI as an information resource and tool for customers to reduce their costs and achieve other benefits generally have been underutilized, as indicated by our utility surveys and interviews with industry experts.

Moreover, to the extent that AMI has been considered a means of influencing customer energy use, it has most often been viewed as a tool for affecting the timing of energy usage (e.g., for load shifting and demand response). Nevertheless, there are important ways that AMI can enable and support customer energy efficiency savings via several use cases. These strategic uses include:

- Enhancing the quality of insights on energy use from near-real-time feedback
- Providing time-varying pricing that reflects fluctuating energy costs at different times of day and year. Near-real-time feedback, combined with communications and possible automation, can better inform and motivate customers to respond to pricing signals and change their energy use accordingly.
- Targeting customers for programs best suited to their energy use profiles
- Promoting grid-interactive efficient buildings that extract more grid value from customer programs by providing more flexible demand[3]
- Supporting energy procurement and meter-based pay-for-performance (P4P)[4]
- Producing granular data needed for advanced measurement and verification of customer energy and demand savings (M&V 2.0.)
- Enabling conservation voltage reduction (CVR) on electricity distribution networks to reduce demand and energy use

This report places a special focus on the potential application of AMI tools to realize customer energy efficiency. Another potential benefit is use of AMI data for utility system planning, particularly for distribution systems. However we found no significant examples of the impacts of this use case on energy efficiency in our research.

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[2] Traditional metering is based on meters that are read manually, usually at monthly intervals. The data must be entered or uploaded to utility records and billing systems; they cannot be transmitted automatically via the various communications technologies employed with AMI.

[3] Grid-interactive efficient buildings (GEBs) are grid-connected buildings with information, controls, and communications technologies able to respond to signals from the grid to modify energy demand.

[4] P4P rewards energy savings on an ongoing basis as the savings occur, rather than providing up-front payments based on deemed or custom measure calculations. Meter-based P4P programs determine performance payments according to savings quantified using meter data, including daily or hourly data from AMI where available. See C. Best, M. Fisher, and M. Wyman, "Case Study: Policy Pathways to Meter-Based Pay-for-Performance in CA, NY, and OR," *Recurve*, September 3, 2019, www.recurve.com/blog/policy-pathways-to-meter-based-pay-for-performance.

POTENTIAL ENERGY SAVINGS FROM AMI-LEVERAGED ENERGY EFFICIENCY

The energy savings possible through different uses of AMI to advance energy efficiency vary. The results for some applications have been well documented; these include (as percentages of total annual electricity use in kilowatt-hours):

- Near-real-time and behavioral feedback: 1–8%[5]
- Pricing with time-varying rates: 1–7%
- Conservation voltage reduction: 1–4%

Other uses of AMI have a high potential to improve energy efficiency programs and evaluation, thereby contributing to and supporting customer savings. For example, in program design AMI data can be used for customer targeting and recruitment. In program evaluation, AMI can provide accurate and timely data to facilitate P4P approaches as well as allow rapid feedback to management for program improvement.

PRACTICES TO LEVERAGE AMI TO SAVE ENERGY

Leveraging AMI to save energy requires active efforts from utilities in their roles as energy efficiency program administrators, grid planners, and grid operators. Utilities are also the primary entities identifying AMI technologies, selecting vendors, and investing in these resources on behalf of the system and their shareholders. Utilities need the support of regulators and stakeholders to implement AMI in a manner that optimizes customer as well as operational benefits.

Utilities and program administrators need to break down traditional internal business and operations silos to manage and use AMI to its fullest capabilities to benefit customers and system operations. Utility and regulatory practices that support robust AMI utilization include:

- Crafting effective communications that inform, engage, and motivate customers
- Quantifying and incorporating benefits from energy savings in business cases
- Adjusting shareholder compensation for AMI based on performance in delivering customer benefits from AMI investments
- Setting clear and reasonable performance standards for data access and energy savings
- Encouraging innovation and pilots that leverage AMI, including innovative rate designs, new means of delivering energy use feedback, and new program design tools that use AMI data, such as P4P and targeting.

[5] Feedback devices and programs show wide variation due to different designs such as opt-in versus opt-out. See R. Sussman and M. Chikumbo, *Behavior Change Programs: Status and Impact* (Washington, DC: ACEEE, 2016), www.aceee.org/research-report/b1601.

CONCLUSIONS

We find that many utilities are underexploiting AMI capabilities and attendant benefits, thus missing a key tool to deliver value to their customers and systems. This is due in part to organizational barriers including silos and workforce challenges, data access and sharing issues, and difficulties communicating the benefits and costs of AMI to key stakeholders. AMI data can help utilities and third parties create better, more compelling, more cost-effective demand-side offerings. AMI also can enable energy efficiency to expand its role as a grid resource by providing temporal and locational value of energy savings in highly granular form. Utilities can learn from the experiences of other utilities that have been successful in rolling out AMI and associated pricing and customer programs. They must actively engage their customers and offer them a range of services to support their energy-saving investments and actions. AMI itself is just a tool that can enable energy markets to support energy efficiency and clean energy goals. When used effectively by utilities or third-party service providers, AMI can improve grid performance, save energy, and reduce customer bills.

Introduction

Advanced metering infrastructure (AMI) has increased the availability of more granular and more readily available data on customers' electricity usage. Traditionally, consumption information was available at best on a monthly basis, with a one-way flow of data from the customer to the utility. Now, with more granular information and relevant insights about their energy usage, customers can become active participants in lowering their own bills; improving their health, productivity, and comfort; and providing value back to other participants on the grid. These data are a critical building block of a more active marketplace for demand-side resources in which customers, working with or through third parties and utilities, support the integration of renewables into the grid, foster reliability, and build resilience (Relf, York, and Kushler 2018).

Interval data can come from multiple sources, including AMI, communicating smart thermostats, customer submetering devices and sensors, and other advanced metering functionality (AMF). AMI is the most prevalent source of interval data about customers' electricity use. It consists of meters that collect electricity consumption data in daily or smaller intervals, as well as the communications networks and data management systems to transmit, store, and process the data. AMI has expanded to more than half of all meters in the United States and is projected to reach 90 million units, or close to 60% of all meters, by 2020 (Cooper 2017).[1]

Current technology and policy trends have made AMI increasingly important. Decreases in the cost of renewables and distributed energy resources (DER), along with policy efforts supporting decarbonization, are boosting the value of flexible demand-side resources and hastening their deployment. To take advantage of this opportunity, utilities, markets, and customers require good information about what services demand-side resources can provide. Utilities need more granular load forecasts to support high-quality distribution and integrated resource planning that better anticipates grid needs. They also need customers to be able to see and respond to variation in the cost of delivering energy throughout the day and year, which requires time- and eventually location-based pricing or valuation.

AMI rollouts, sometimes included as a part of smart grid or grid modernization plans, tend to highlight operational benefits to utilities. However many also cite potential customer benefits, including bill and outage management and opportunities, through their actions, to save energy via efficiency and demand response. For example, in the smart grid business cases arising out of the American Recovery and Reinvestment Act of 2009 (ARRA), many utilities cited potential energy efficiency and peak demand benefits such as savings from feedback, time-varying rates, and actions taken through customer interaction with in-home devices (DOE 2019).

[1] EIA data for 2018 on AMI penetration show that penetration rates among residential and commercial customers closely track total penetration rates (EIA 2019a). AMI penetration rates for industrial customers show wider divergence from total penetration, likely a reflection of more-specialized needs and arrangements with their utilities.

In the years since ARRA, some efficiency program administrators have been finding it increasingly challenging to maintain cost-effective portfolios in the face of sustained decreases in average avoided costs as well as rising appliance and equipment standard baselines. With the rise in availability of more-advanced data analytics, utilities and implementers can use lessons learned from online and retail sales and advertising to more effectively target customers for energy efficiency opportunities based on not just demographics but also their interval usage. Such targeting and data analytics have the potential to increase savings and boost cost effectiveness (Borgeson and Gerke 2018).

Despite AMI's potential value to save energy, most discussion of its value focuses on operational benefits, and our research suggests that the value of AMI for customer energy efficiency programs and market enablement is underexploited. This creates two forms of potential risk for utilities. First, utilities with AMI that are held accountable for customer benefits and do not deliver may risk regulators' denying cost recovery for existing investments. Second, for those utilities without AMI, or for those that seek to invest further in grid modernization, the industry's poor performance in delivering customer benefits (or articulating how they will do so) may undermine these utilities' ability to gain approval for these large future infrastructure investments.[2] Recent rejections in Massachusetts, Kentucky, Virginia, and New Mexico are cases in point; the New Mexico rejection specifically noted that the AMI proposal from PNM (Public Service Company of New Mexico) failed to "take advantage of possible energy efficiency measures, identify sufficient operational benefits, or provide meaningful opt-out opportunities" (Massachusetts DPU 2018; Kentucky PSC 2018; New Mexico PRC 2018; Virginia Electric and Power Company 2019).

This report seeks to shed light on the ways utilities, program administrators, and third-party service providers are using AMI data in support of customer energy efficiency.[3] We begin by outlining the operational and customer benefits of AMI to identify the use cases for AMI to advance energy efficiency. We examine how and to what extent AMI data are currently used to drive energy savings in a variety of use cases. For promising use cases that are underexploited, we identify barriers to using these data in support of energy efficiency and discuss options to address those barriers from leading examples. Finally, using lessons learned from these leading utilities and market actors, we close by providing

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[2] US grid investment grew by 8% in 2018, with 60% of spending in the distribution grid, and analysts project continued growth in transmission and distribution to replace aging infrastructure, support renewables integration, and provide a source of growth for utilities with more limited capital investment opportunities due to flat load growth (IEA 2019; DOE 2015).

[3] This report addresses two primary types of customer action to modify energy use in order to reduce costs. *Energy efficiency* signifies measures and technologies implemented by customers that reduce the amount of energy used whenever a given device is operated. *Demand response* encompasses various customer actions taken to reduce or shift electric load in response to signals or requests from a utility or system operator. This typically is done to provide load relief at a time of high system demand. Demand response measures primarily shift loads and do not necessarily reduce energy use. Some savings may occur. However energy efficiency by definition always reduces energy use for a given application.

recommendations for regulators and utilities seeking to leverage interval data and communications technologies as a tool to enable all cost-effective energy efficiency.

Research Objectives and Methodology

The primary goal of this research is to show how utilities with AMI can better leverage its capabilities to increase energy efficiency program effectiveness, influence customer behavior to reduce energy use, support more robust energy efficiency markets, and deliver system benefits through energy efficiency. We set out to answer the following research questions:

- How do smart grid businesses characterize the energy savings case for AMI?
- Is there evidence that AMI deployment has saved energy or reduced peak demand?
- What missing opportunities are available to better leverage AMI data for energy savings? Could they use AMF technologies other than AMI?
- What are the barriers to better leveraging AMI data to save energy?
- What supportive investments and programs are needed to fully realize energy savings benefits from AMI?
- What rules can regulators adopt to help customers realize greater energy savings?

To answer these questions, we reviewed existing research and experience on AMI rollouts. Industry experts, including former regulatory staff and contacts from national labs, the US Department of Energy (DOE), and utilities, provided input on the history and current status of AMI, including barriers to and drivers of adoption. Through these resources we identified the range of AMI technologies and their potential implications for energy efficiency and customer benefits.

To characterize the current landscape of how utilities are leveraging AMI, ACEEE conducted a survey of the top 52 electric utilities by sales, the results of which are reported throughout this report. The data from this survey are also being used for ACEEE's forthcoming 2020 *Utility Scorecard*. Where information was available, we captured which utilities had the following programs or program measures in 2018:

- Real-time energy use feedback to customers
- Behavior-based programs with customer feedback and insights
- Time-of-use rates
- Program targeting, marketing, and technical assistance using insights from data disaggregation
- Grid-interactive efficient buildings[4]
- Conservation voltage reduction or volt/VAR optimization

[4] Grid-interactive efficient buildings are energy-efficient buildings with smart technologies characterized by the active use of DERs to optimize energy use for grid services, occupant needs and preferences, and cost reductions in a continuous and integrated way (Neukomm et al. 2019).

We identified seven potential use cases of AMI. In addition to the list above, our literature review and interviews identified additional use cases: more real-time, iterative measurement and verification (M&V), and performance-based procurement of energy, capacity, and grid services.

To assess whether these AMI use cases can lead to energy savings, we built on our initial literature review, examining publicly available demand-side management program filings and case studies from the literature on AMI for examples of these use cases. We conducted structured interviews with nine program administrators or implementers to understand program details and structures and to identify lessons learned and challenges faced.

Advanced Metering Infrastructure and Advanced Metering Functionality

The Energy Information Administration defines AMI this way:

> Meters that have the capability to measure and record usage data at hourly or shorter intervals, and provide usage data to energy companies and may also provide the data to customers at least once daily. Data are used for billing and other purposes. Advanced meters include basic hourly interval meters and extend to real-time meters with built-in two-way communication capable of recording and transmitting instantaneous data (EIA 2019b).

Before and sometimes concurrently with AMI deployment, some utilities use automated meter reading (AMR) systems. AMR also involves electronic meters, to eliminate the need for manual meter reads, but features only one-way communications, whereas AMI by definition includes two-way communications (DOE 2012). The DOE's review of the Smart Grid Investment Grants, which provided $3.4 billion in ARRA funding, builds on this definition, finding that AMI deployments around the country typically include the following:

- Customer-side smart meters that collect electricity consumption data in 5-, 15-, 30-, or 60-minute intervals
- Communications networks to transmit interval consumption data from the meter to the utility back offices
- A meter data management system (MDMS) to store and process the increased volume of data. The MDMS also integrates meter data with information and control systems, including head-end systems, billing systems, customer information systems, geographic information systems, outage management systems, and distribution management systems (DOE 2016, 10).[5]

To support new rate designs, these three elements are typically combined with customer-sited control technologies like programmable communicating thermostats and direct load

[5] The term *AMI* typically refers to a combination of these technology solutions deployed by electric utility investments. Gas and water utilities also deploy advanced metering, but less frequently than electric utilities. Webb (2018) found examples of natural gas AMI metering in only three states—California, New York, and Maryland—typically for dual fuel utilities, so this paper focuses only on leveraging AMI in electricity systems.

control devices, and with information technologies like in-home displays, web portals, and text/email alerts.

The Advanced Energy Economy offers a broader term than AMI, *advanced metering functionality* (AEE 2017b). AMF includes the following capabilities, many of which align with the energy efficiency use cases described in this paper, but it is agnostic as to which technologies are used and who deploys them.

- Collection of customers' usage data, in near real time, usable for settlement in relevant retail and wholesale markets for energy and ancillary services
- Automated outage and restoration notification
- Two-way communication between customers and the electric distribution company
- With customers' permission, communication with and control of smart devices
- Large-scale conservation voltage reduction programs or volt-VAR optimization
- Remote connection and disconnection of customers' electric service (while maintaining consumer protections)
- Measurement of customers' power quality and voltage

While no alternatives provide all the same functions as a widespread AMI deployment, other technologies can provide some aspects of AMF. These include the online portals for tracking solar PV output and consumption provided by solar companies, the separate networks and control centers managed by demand response companies, and home or building energy management systems. Similarly, smart thermostats and electric vehicle charging infrastructure can provide consumption data for a large end use, which can be aggregated by separate companies. Additionally, new companies are emerging that use radio-frequency sensors to capture data from legacy electric, gas, or water meters; these wireless energy monitors are being tested by one Midwest utility and may provide another alternative to AMI (Dan Forman, CEO, Copper Labs, pers. comm., June 18, 2019).

Further, although AMI can provide all of the advanced metering functionalities, some utilities with AMI rely on adjacent systems such as customer broadband or Wi-Fi to deliver some of those capabilities where real-time communications are needed. For example, Green Mountain Power's controllable heat pump water and space heaters communicate over customer Wi-Fi (Gold, Guccione, and Henchen 2017). Some AMI meters are installed with limited bandwidth for load management actions, and furthermore, some manufacturers have found it difficult or costly to register their devices on utilities' smart meter networks and therefore prefer a technology available in most homes.

History of AMI

Deployment of AMI began in the early 2000s as AMI technologies matured and their costs declined. Some of the earliest utility rollouts of AMI occurred during this period (Cooper 2017), although overall AMI penetration still was low. AMI received a large boost toward the end of the 2000s as a result of the Smart Grid Investment Grant funding included in the ARRA legislation of 2009. The number of meters quadrupled between 2007 and 2011, then investment proceeded at a slower pace from 2012–2016, doubling again during that period to reach nearly half of all meters, as shown in figure 1 (FERC 2019).

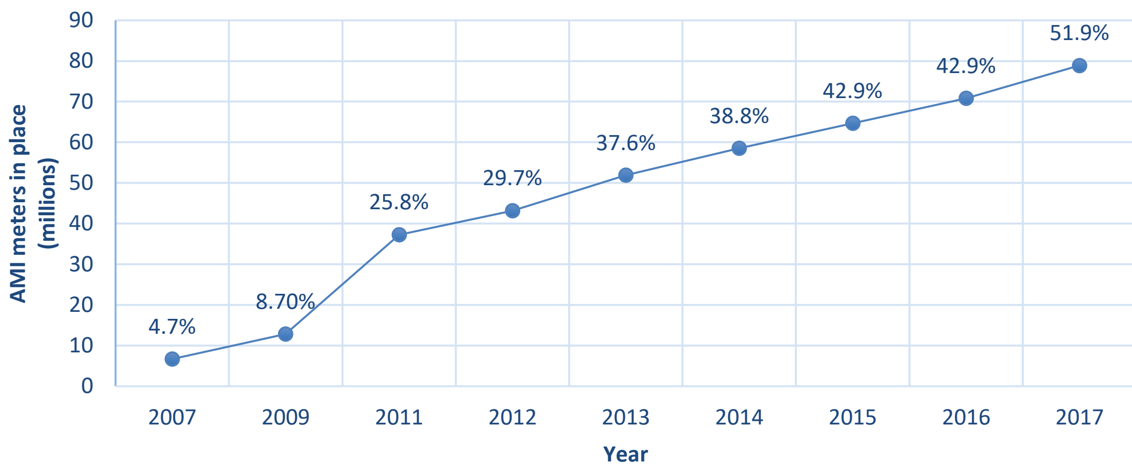

Figure 1. Estimates of advanced meter penetration rate (FERC 2019).

In 2007 there were about 6.7 million advanced meters in place, according to FERC. By 2016 this number had grown more than tenfold—to 70.8 million out of a total of 151.3 meters in the United States, a penetration rate of 47% (FERC 2019). And AMI continues to grow. The Institute for Electric Innovation estimates that AMI installations will reach 90 million by 2020, which will represent about 60% of all US households (Cooper 2017). Eventually virtually all customer metering is likely to be advanced, although this will take a decade or more, given past penetration rates.

A slight majority of the top 52 utilities in the United States had deployed AMI for most of their customers as of 2018 (EIA 2019a). A small subset (four) have penetration rates between 30% and 80%—possibly an indicator of a full AMI rollout in progress over several years or pilot programs in place. The remainder have AMI penetration of 17% or lower, with 10 of these at zero. These results show that utilities generally either have implemented AMI widely or have yet to do so to any significant degree.

A number of technological advancements have been critical for regulatory approval to support the growth of AMI, particularly customer communications through text messaging, online portals, paper and email reports, and, in early deployments, monitors and home energy displays (e.g., dashboards) that can provide energy use information in user-friendly, easily understood formats to customers. In addition, sensors, controls, and management systems can enable and automate responses using AMI data and customer inputs. AMI generates massive volumes of customer data. Consequently, advancements in information technology and management of large sets of data also have been necessary for the growth of AMI.

While AMI has grown rapidly in recent years and is well accepted in many states as a foundation of grid modernization, there are states and jurisdictions that have rejected AMI proposals by their utilities. Generally the reason cited is that AMI remains too costly relative to the benefits, or that utilities have not verified to the regulator’s satisfaction the likelihood of those benefits (Walton 2018). In a few cases customer suspicions of alleged negative health impacts of AMI, such as radiation, have hindered rollouts (Hess and Coley 2012).

Benefits of AMI

Typical benefits of AMI in utility business cases include a combination of operational gains that accrue to the whole system and benefits that customers can directly take advantage of. Operational benefits result in cost savings for utilities and may result in rate decreases for customers, depending on the scale of those benefits relative to the cost of AMI installation. In contrast, customer benefits can include greater control over their energy usage and bills, leading to increased satisfaction and the potential for customer cost savings (and possibly energy savings). Some customer benefits accrue to the system as a whole, such as system capacity and energy benefits, but customer action is required in order to realize those impacts. In this section we describe the key operational and customer benefits cited in the business cases for AMI in our literature review, and we note their connections to energy savings.

Operational Benefits

The inclusion of AMI in utility portfolios can lead to operational benefits that deliver reduced costs to the utility. DOE's 2016 review of the Smart Grid Investment Grant program in ARRA identifies four main operational benefits of AMI: reduced costs for metering and billing, reduced outage costs and less customer inconvenience, enhanced safety, and lower utility capital expenditures.

Lower costs for metering and billing come from the labor savings associated with fewer site visits to read meters and reduced truck rolls to check on lines, as well as lower labor costs from more accurate and timely billing, which reduces or eliminates estimated bills and reduces customer disputes (DOE 2016). AMI capabilities also can be used to provide customers with information on unusual usage patterns before they receive their bills, which may further reduce customer disputes. The Electric Power Board of Chattanooga (EPB) saved $1.6 million in annual O&M costs by using automated meter reading and remote services instead of on-site services (DOE 2016). Remote meter reading provides the most value for utilities with large AMI deployments and low customer densities (DOE 2016). However utilities that already have AMR, which provides one-way communication from the electric meter to the utility, may have already realized savings from fewer manual meter reads for service calls. Further, if AMR systems are not fully depreciated, the business case for AMI would need to include the costs of writing off any systems that have not reached the end of their useful economic lives (DOE 2012).

AMI can support outage notification and restoration by providing utilities with "the ability to detect, isolate, and respond to outages quicker than current capabilities" (NEEP 2017). Because utilities are able to detect and isolate outages faster with AMI, they can strategically dispatch repair crews, decreasing outage duration and customer inconvenience (DOE 2016). Utilities can also combine AMI capabilities with outage management systems (OMS) and geographic information systems (GIS) to create more detailed outage maps to share with the public (DOE 2016). Deployed in this way, AMI can increase system reliability and resilience for communities, especially in areas that are prone to severe weather events.

A qualitative benefit of leveraging AMI is increased safety for communities, businesses, and utility systems. "Sensors provide the opportunity for detection and reporting of methane leaks, corrosion potential, arc fault, and stray voltage" (NEEP 2017). With these data, utilities can troubleshoot problems remotely and more quickly respond to system emergencies. Utilities can also use automated data collection to better comply with safety standards, reducing risks from noncompliance (NEEP 2017).

With AMI, utilities can give their customers the tools they need for energy efficiency and demand response, reducing consumption and shifting energy use from peak to off-peak times (DOE 2016). While demand response can involve direct control of loads, utilities can also use pricing tools, like time-based rates and incentives, and informational tools, like customer bill alerts, to encourage more-efficient consumption. Where customer usage is effectively reduced or shifted away from peak times, utilities can deliver system benefits including fuel savings, market price suppression, and avoided line losses (Lazar and Colburn 2013). These benefits can lead to lower utility capital expenditures through reduced need to invest in capital-intensive infrastructure, and avoided greenhouse gas (GHG) emissions (DOE 2016).[6] Although these are system benefits, they require customer action that can also result in customer bill savings and other benefits associated with energy savings.

Another potential benefit is use of AMI data for utility system planning, particularly for the load forecasting aspects of distribution system planning and integrated resource planning. For example, Burbank Water and Power used AMI data to size distribution transformers and circuits more accurately by using actual peak coincident load on transformers instead of the worst-case scenario as an assumption (Hamer 2015). However we found no significant examples of the impacts of this use case on energy efficiency in our research, so we did not examine it in depth in this report.

CUSTOMER BENEFITS

Customer benefits include feedback and pricing that encourage or enable them to lower their bills, and improved satisfaction from better communication with their utility about billing, outages, and the sources of energy use in their home. In addition, utilities can deliver more-effective and better-targeted programs using AMI data, which can provide bill savings both from reductions in purchased energy and from rate reductions enabled by utility cost savings.

Tools like smart thermostats, web portals, and mobile apps coupled with behavioral cues can give customers more information and control over their electricity consumption, costs, and bills (DOE 2016). Utilities can leverage insights from interval data to present customers with their usage information in near real time through online portals and applications, as well as through phone calls, text messages, email, and even paper mail. AMI also facilitates the introduction of behavioral demand response, peak-time rebates, and other time-varying behavioral and pricing signals, enabling customers to respond more deftly to pricing and control signals. In addition, bill alerts can increase energy savings (Fulleman 2019), and

[6] We discuss how AMI is used to create time-based rates and give examples of time-of-use (TOU) programs in our section on Energy Efficiency Use Cases.

more accurate billing information can decrease complaints and help avoid bill arrearages (NEEP 2017). These features may be particularly useful to low-income customers.

These customer benefits require customer engagement and as a result may require additional back office tools to store and process data. Customer engagement systems and back office tools may raise initial AMI deployment costs, but without them AMI is unlikely to deliver on customer benefits. Green Mountain Power (GMP) qualitatively measures societal benefits of its AMI deployment, such as commercial and industrial outage cost reduction, decreased energy costs, and energy conservation connected to AMI-based web portals (NEEP 2017). As a result of system cost savings, GMP was able to lower customer rates. Additionally, GMP call center representatives report that customers gained a better understanding of energy usage from having access to granular data (NEEP 2017).

Customer-facing control and information technologies are typically required in order to realize the potential benefits from better customer decision making about their energy use (DOE 2016). Control technologies include programmable controllable thermostats and home and building energy management systems, and information technologies include web portals, smartphone applications, and in-home or voice-activated devices to make customer energy usage data more visible and actionable. Such technologies may be provided by utilities, by contracted agents of utilities, or by third-party solution providers interacting with customers; as a result, availability of granular data can create benefits for these market participants as well.

Now we describe the use cases of mechanisms for AMI that support energy savings. These use cases directly and indirectly lead to the operational and customer benefits we have just discussed.

Energy Efficiency Use Cases

ACEEE's survey of the top 52 electric utilities by sales collected information on how they are leveraging AMI to save customers energy. Where information was available, we captured which utilities had the following programs or program measures:

- Near-real-time energy use feedback to customers
- Behavior-based programs with customer feedback and insights[7]
- Time-of-use (TOU) rates[8]
- Programs using data disaggregation
- Grid-interactive efficient buildings
- Conservation voltage reduction (CVR) or volt/VAR optimization (VVO)

[7] Note that for the purposes of the initial survey, we focused on behavior-based programs that are energy efficiency measures. As a result, this data set does not consistently include behavioral demand response, which does produce some incremental energy efficiency savings (see Feedback section for details).

[8] For the purposes of the survey, we looked at time-of-use rates only; the rest of this paper considers time-varying rates, which include but are not limited to time-of-use rates.

Definitions of each of the above use cases are provided in Appendix B. Table 1 shows which utilities included the above program measures in their energy efficiency portfolios in program year 2018. Utilities with less than 25% AMI penetration are not included in this table.

Table 1. Prevalence of use cases for leveraging AMI to save energy among top 52 electric utilities by sales in program year 2018

Utility	Near-real-time feedback to customers	Behavior-based feedback	Conservation voltage reduction (CVR)	TOU rates	GEBs*	Data disaggregation
Portland General Electric	•	•	•	•	•	•
Southern California Edison	•	•	•	•	•	•
Commonwealth Edison	•	•	•	•		•
NV Energy		•	•	•	•	•
AEP Ohio (Ohio Power)	•	•		•		•
AZ Public Service	•	•		•		•
Baltimore Gas and Electric	•	•		•		•
Consumers Energy	•	•		•	•	
CPS Energy	•	•	•		•	
DTE Electric	•	•		•		•
PECO Energy	•	•	•			•
Salt River Project	•	•	•	•		
Duke Energy Carolinas (NC)		•	•	•		
Georgia Power	•	•		•		
San Diego Gas & Electric	•	•		•		
WI Electric Power	•	•		•		
Ameren IL		•		•		
Duke Energy OH		•		•		
Duke Energy SC		•		•		
PG&E		•		•		
PPL Electric Utilities		•	•			
Alabama Power				•		

Utility	Near-real-time feedback to customers	Behavior-based feedback	Conservation voltage reduction (CVR)	TOU rates	GEBs*	Data disaggregation
Duke Energy IN		●				
Florida Power & Light				●		
OK Gas and Electric				●		
West Penn Power				●		
Total	14	22	9	22	5	9

* Grid-interactive efficient buildings. Where utilities have a third-party program administrator in their service territory, some programs may be offered by that entity. For use case definitions, see Appendix B.

Portland General Electric

Portland General Electric (PGE) is one of only two utilities that reported using AMI for all six of the surveyed use cases. The utility maintains a separate AMI operations department that is responsible for collection, storage, and analysis of data, as well as export to other departments like billing and customer programs. PGE first implemented AMI for all customers in 2011. It reports that the company has improved on customer-facing applications for the data over time and is working to expand use cases for AMI, particularly in transmission and distribution management applications (Kirk Page, lead network data operator, and Erik Cederberg, AMI manager, PGE, pers. comm., November 25, 2019). These applications include two customer portals, EnergyTracker for residential customers and Energy Expert for commercial customers, which provide near-real-time data, data disaggregation for key end uses, behavioral tools like goal setting, and connections to Energy Trust of Oregon energy efficiency programs. The utility is testing time-varying rates through its Flex (a time-of-use rate) and peak-time rebate offerings. PGE also uses AMI for billing alerts, EM&V for demand response programs, and some small conservation voltage reduction pilots.

In addition to PGE, Southern California Edison also leverages AMI for all six use cases. Commonwealth Edison (ComEd) and NV Energy both leverage AMI for five different use cases. Seventeen utilities leverage AMI for two to four use cases, and six utilities report using AMI for only one use case. Utilities that have less than 25% AMI penetration are not included in this table. AEP TX and Oncor Electric Delivery have greater than 25% AMI penetration, but they do not include any of the listed use cases in their portfolios.

Of the utilities with 25% or greater AMI penetration, behavior-based feedback and time-of-use (TOU) rates were the most prevalent, with 22 utilities implementing each of these measures, respectively. Behavior-based feedback for energy efficiency, as described below, does not require AMI data but can use AMI data to enhance the customer experience. Similarly, while AMI enables more successful implementation of TOU pricing, AMI is not required for TOU rates since the periods and pricing are set in advance.[9] In contrast, AMI is

[9] Some form of sub-daily metering is required, but AMR can serve this purpose.

required for effective deployment of more dynamic forms of pricing, such as peak-time rebates and real-time pricing. Real-time feedback and CVR were also prevalent use cases, with 14 and 9 utilities, respectively, implementing these measures. Nine utilities responded that they use data disaggregation to target and market relevant programs to specific customers, and four utilities offer grid-interactive efficient building programs.

Our interviews reflected these trends. Most utilities whose representatives we interviewed have programs that provide customers with feedback, and many use AMI to support time-varying rates. For example, NV Energy provides AMI data to customers via a website and mobile device app. Customers can access a portal that integrates billing and other services, including energy efficiency programs. There also is an online home energy assessment that identifies savings opportunities based on a disaggregation tool using AMI data. In addition to the use cases included in the *Utility Energy Efficiency Scorecard* survey, we identified three additional use cases of AMI: procurement and pay-for-performance (P4P), evaluation measurement and verification 2.0, and system efficiency.

Building on these results, our literature review and interviews with experts for the current study revealed seven total use cases by which AMI enables or supports energy savings, especially energy efficiency, although some also support customer benefits through demand response.

- Feedback
- Pricing
- Targeting for program design, marketing, and technical assistance
- Grid-interactive efficient buildings
- Procurement and P4P
- M&V 2.0
- Conservation voltage reduction

Figure 2 depicts these use cases. Starting at left, the first two cases are directly customer facing. The four in the middle are use cases where a utility or program administrator can deliver savings indirectly, by improving the performance and potential value of customer programs. Conservation voltage reduction, as well as planning (which we do not explore in this paper), are utility-facing use cases for AMI data that can indirectly deliver energy efficiency, but through operations or procurement rather than customer programs.

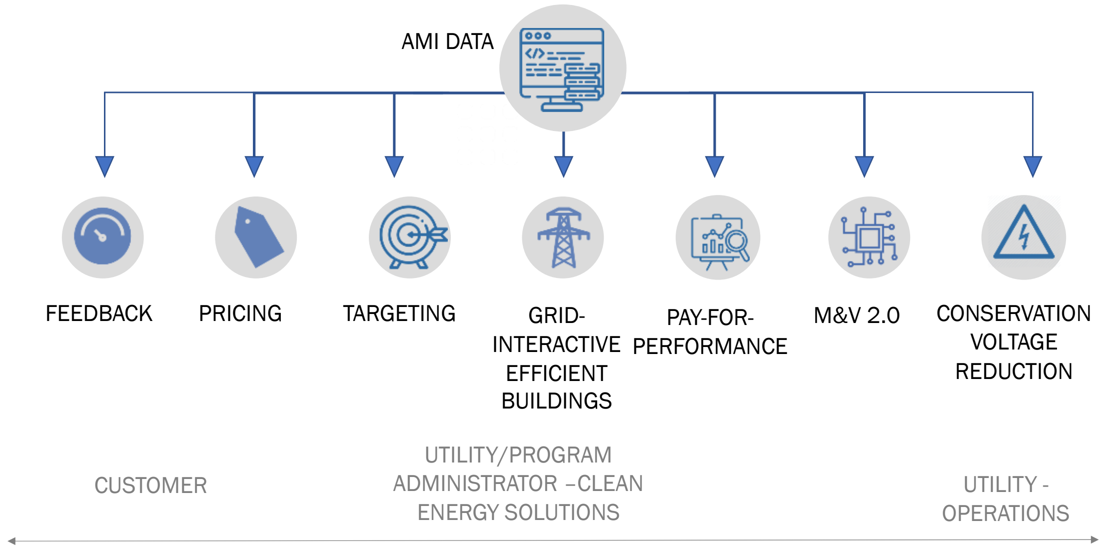

Figure 2. Use cases to leverage AMI for energy savings

Two of the use cases are driven primarily by customer actions: *feedback* of interval usage insights through information provision and *pricing* when customers respond to the more granular rates enabled by AMI. Utilities and third parties provide these informational, behavioral, and pricing signals, but customers are the primary actors. Other use cases are enabling mechanisms that work behind the scenes: usage segmentation and improved M&V are two ways that utilities, program administrators, and implementers can design more cost-effective, targeted programs. Other use cases focus on market animation and optimization of demand-side resources: using AMI data to enable procurement of and programs for those resources best positioned to meet system energy, capacity, and flexibility needs at least cost. Finally, AMI can support system efficiency through conservation voltage reduction, controlling voltage on distribution circuits and enabling some end use loads to draw less power.

We explore each of these potential use cases in the sections below, articulating how AMI can result in energy savings benefits. We document evidence of those savings where available from the literature or provided in our interviews with utilities and third-party service providers. In many cases, these use cases are largely underutilized by the utilities with AMI; as a result, much of the following section represents the opportunity rather than the reality on the ground today.

FEEDBACK

There are two principal types of feedback that can influence customer behavior related to energy use. Near-real-time feedback provides customers energy use data shortly after use is recorded. The exact interval between use and reporting varies according to technologies and practices in place but can be close to zero. Behavioral feedback applies the tools of behavioral science to enhance responsiveness to energy use feedback, whether by AMI or conventional metering. As we discuss below, providing customers near-real-time feedback based on AMI and using behavioral science tools can yield the largest impact on customer energy use.

AMI can provide highly granular feedback to customers on their energy use, which can both engage and empower them to take actions to reduce or otherwise modify such use. Rather than a single monthly reading that gets reported to customers about a month later (a lag due to manual reading of meters and monthly billing cycles), customers can receive near-real-time data on their energy use (depending on the meter's interval cycle and reporting technologies and methods). Data can be coupled and tracked with a variety of display technologies, such as a smartphone application or in-home display (smartphone apps being more prevalent). The AMI data also require appropriate software to convert it to information in a form that is readily understood by customers and that can motivate them to change their use. With timely data and clear reporting, customers can correlate different uses of electricity with the amount consumed. Such knowledge is fundamental to understanding and managing energy use within a home, business, or industry.

While energy use data alone can influence customer behavior, simply providing such data is insufficient to affect most customers' energy consumption. Experience shows that providing customers with personalized insights based on interval data (as a number of vendors do in their home energy reports or other communications) is much more effective at motivating customers and getting them to take actions to change their energy use. Such reports are a common application of behavioral feedback.

Studies on customer feedback suggest different degrees of impact. Buchanan, Russo, and Anderson (2015) conclude that there is limited evidence that feedback alone is effective in getting customers to reduce energy use. Karlin, Zinger, and Ford (2015), however, conclude that feedback is a promising strategy to promote energy conservation, but that this depends on how information is conveyed to customers (e.g., via social norms, anchoring, and other behavioral tools) to motivate them to take actions that affect their energy use. Sussman and Chikumbo (2016) find that most real-time feedback programs using opt-in designs report net electricity savings in the 5–8% range.

Program experience and studies of consumer behavior have shown that the best way to maximize the effectiveness of feedback is to provide it through an engaging medium, such as an interactive computer program, and in combination with additional strategies (Sussman and Chikumbo 2016). Strategies can include incentives, normative reporting (comparison with similar households, such as is provided in home energy reports), and personalization of information and messaging. To have the greatest impact, energy use feedback should be coupled with programs, services, and pricing that can motivate, assist, and reward customers for taking actions. In a pilot AMI program, CenterPoint Energy used a web portal to provide smart-meter customers with information on how to better manage their energy usage and costs, including education on steps to reduce peak demand. The pilot included prizes for successful responses. In 2011 the set of 198 participants reduced peak demand by an average of 5% during 10 events; some participants reduced consumption by as much as 35% (DOE 2016).

Mobile applications are another way to for utilities to provide feedback and can be an effective tool to engage customers. For example, DTE's behavior program uses a mobile application, Powerley, that gives customers energy usage insights and allows customers to set savings targets, interact with feedback tools, and see recommendations of energy efficiency measures targeted to their consumption patterns. Customers can request an Energy Bridge that uses AMI to collect one-minute energy usage information and gives customers real-time energy usage feedback through the DTE Insight app. Paired with home energy reports, in 2018 DTE's residential behavior change programs achieved 62.7 GWh of energy savings and reduced demand by 23.6 MW (DTE Electric Company 2019).

Survey research by the Smart Energy Consumer Collaborative certain types of residential customers are more likely than others to use AMI feedback to understand their energy use and take actions to change it, particularly segments the Smart Grid Consumer Collaborative terms "green champions" and "savings seekers" (SGCC 2016). This also applies to commercial and industrial customers. Most small businesses lack the expertise, time, and resources to actively manage their energy use (Nowak 2016). Larger customers—with higher energy use and costs—may devote necessary resources to actively managing energy use, such as a dedicated energy manager and technologies that can use both AMI data and related on-site metering of systems and equipment.

Program staff and third-party service providers we interviewed affirmed these observations. One provider noted that the level of customer engagement with AMI data and technologies is the key to energy savings from energy efficiency improvement and behavioral changes. Although we found a lack of evidence in the literature documenting a direct causal link between customer engagement and energy efficiency, the two behavioral program providers we interviewed cited internal evidence that those customers who are engaged are more apt to act on insights gained from AMI to save energy.[10]

Where AMI data are disaggregated, the insights from sharing a breakdown of large end uses can be a means to get customers more engaged because it makes the customer experience more relevant.[11] Another provider noted how AMI can be used to start a discussion with customers about their energy use and how they can make changes to save money, which can help create strong long-term relationships between customers and their utilities. Customer engagement tools and platforms (e.g., web portals and mobile apps) also can be effective for cross-marketing programs—linking use patterns with available incentives and services that may benefit customers. Such tools also can provide high bill alerts. Evidence from one randomized trial of a high bill alert email offering for 50,000 Xcel Energy customers in Minnesota found 0.4–0.6% annual savings per customer (Fulleman 2019). These customers did not receive other behavioral energy efficiency communications. While these savings are small in magnitude per customer, they can be large in aggregate in an opt-out design such as the one used in Minnesota. Further, there may be additional

[10] However, absent documentation, we note that there could be a reverse relationship, that saving energy causes people to pay attention to and engage with communications from the utility. There could also be a third variable explanation, for example that the type of people who pay attention might also be the type of people who would save energy anyway.

[11] This disaggregation is sometimes called nonintrusive load monitoring. We explore the value of this disaggregation for targeting and program design in the Targeting for Program Design, Marketing, and Technical Assistance section.

benefits from layering high bill alerts with home energy reports; internal analysis from eight different Opower programs found high bill alerts can boost Home Energy Report savings by 0.3% (JD Toppin, Global Practice Lead, OPower Solutions Consulting, pers. comm., December 4, 2019).

While AMI rollouts and associated efforts to engage customers have focused largely on the residential sector, AMI also can be used to engage and benefit commercial and industrial customers. Feedback from more granular data provided by AMI can provide insights on their energy use, just as for residential customers. As an example, Efficiency Vermont uses AMI in conjunction with a strategic energy management (SEM) program for commercial/industrial customers. The program model is for continuous energy improvement, a standard for SEM programs. Efficiency Vermont account management staff recruit cohorts of facility energy champions and their teams to participate in the program. SEM training includes an initial assessment of a facility energy management practice and then workshops on topics in energy management such as goal setting, energy efficiency topics, monitoring energy performance, and employee engagement. In addition, early in the workshop progression, a facilitated energy "treasure hunt" occurs to identify low- and no-cost savings opportunities, which are then pursued for implementation with help from the account management/energy consultant team working with the customer. These program elements are designed to engage customers and establish an ongoing relationship with them based on SEM. AMI provides vital, timely feedback that enables participants to monitor and validate results from actions they take to reduce energy use. AMI is an effective tool for EM&V and also is used to document savings and utility payments.

AMI feedback can also be used effectively for behavioral demand response programs, which use feedback to target reductions in peak power demand (kilowatts). This report does not focus on behavioral demand response, even though it requires AMI, because its primary function is to deliver peak demand reduction rather than energy savings. However a 2016 DTE program found 0.45% incremental electric energy savings in addition to 3.31% incremental coincident peak demand savings, demonstrating the potential for small additional energy savings beyond kW reductions from these programs (Kirchner 2017).

PRICING

While AMI data combined with customer engagement can better inform customers and may lead to direct savings, time-of-use pricing used in conjunction with these insights from AMI is often the key to unlocking the greatest customer savings and benefits (Faruqui, Sergici, and Warner 2017). Aligning rates with market and system costs that can vary widely by time of day and season provides signals and incentives to customers to modify their energy use.

Utility economists and analysts long have advocated for time-varying pricing as a means to optimize generation resources and grid performance. This type of pricing also would provide market-based price signals to customers, enabling them to reduce their costs by changing energy use behavior and making energy efficiency improvements. But until AMI technology matured and became cost effective, such arguments for more-advanced pricing remained largely rhetorical.

Costs of power production and wholesale electricity markets are dynamic. Prices for electricity can vary widely due to system power demand and the different costs of production and delivery among electricity suppliers. Generally, the highest prices for wholesale power occur during times of peak demand—times when the most expensive generating resources need to be used and grid constraints may limit bulk power transfers. Historically and currently, retail electricity rates for most customers are flat; they do not reflect wholesale market prices and time of use. The same rate applies regardless of when the electricity is used; there is no seasonal or daily variation.

Time-varying, or dynamic, rates have long been advocated and have been used in certain cases to better reflect the dynamic nature and costs of wholesale electricity markets. There are a few types of time-varying rates, outlined in Baatz (2017):

- *Time-of-use rates.* TOU rates may vary by time of day and season to align with daily and seasonal variations in power generation costs and market demand. TOU rates also send price signals to customers related to future investments. High rates that occur at times of peak power demand can encourage customers to reduce use during peak periods, thereby helping utilities avoid or defer investments in new infrastructure.
- *Real-time pricing.* RTP is a structure in which customer rates vary directly with real-time wholesale market rates.
- *Critical peak pricing.* CPP assesses a higher energy rate (often over $1 per kWh) during an announced event for a limited number of hours, on the basis of higher wholesale electricity prices and allocation of costs for capacity needed at peak load. The announced events are often limited to a certain number per year.
- *Peak-time rebate.* While not technically a rate structure, PTR awards customers with a rebate for energy saved during announced peak events, typically announced in advance. It provides a financial signal and incentive to customers as to varying costs according to time of use.
- *Variable peak pricing.* VPP charges customers a higher rate for a predefined peak period. The price component on-peak can change each day, with a constant off-peak price.

AMI enables the implementation of TOU rates while providing a way for customers to track their usage in the specified time-based intervals and understand how they can respond to the rate. AMI can also support a bill comparison tool and "shadow" billing, which helps customers predict what their bills would be if they switched to a different rate. However the periods and pricing are set in advance for TOU, not based on real-time prices, so AMI is not required (Colgan et al. 2017).[12] In contrast, critical peak pricing, peak-time rebates, variable peak pricing, and real-time pricing all rely on advanced metering data due to the nature of these rate structures and their dependence on timing of events or wholesale market fluctuations. These rate structures also require some means in place to notify customers of changes in prices, such as via text messages, mobile device applications, or in-home

[12] Colgan et al. (2017) note, "Meters with multiple registers can be read with conventional meter reading equipment," which is why TOU is possible without AMI.

displays. For time-varying prices to have an impact on customer behavior, their effect on customer energy bills needs to be reasonably predictable. Customers also need general education to understand how pricing is structured, how it may affect them, and how they can take advantage of such programs to reduce costs.

Some of the first time-varying rate experiments occurred in the 1970s (Faruqui and Malko 1983). However application of time-varying rates by utilities did not occur to any large degree until the early 2000s, triggered in part by California's energy crisis of 2000–2001 and the emergence and availability of AMI technologies that could be deployed at scale and reasonable cost. Numerous studies of time-varying rates provide overwhelming evidence that customers respond to changes in volumetric (kilowatt-hour) rates (Baatz 2017). For example, a meta-analysis of more than 60 residential pricing pilots from 57 utilities across nine countries and four continents concluded that there is compelling evidence that customers respond to price changes (Faruqui, Sergici, and Warner 2017).

Recent deployments at utility scale in the United States and Canada are demonstrating that customers are accepting and benefiting from time-varying rates. Rollouts of TOU rates in Arizona, Oklahoma, Sacramento, Ontario, and Fort Collins, Colorado, have been well accepted. Customers see opportunity to save money by changing their behavior (Faruqui and Bourbonnais 2019).

Results from the Smart Grid Investment Grant program, which was part of ARRA, demonstrate clearly the impacts possible from implementation of time-varying rates (DOE 2016). Table 2 presents examples of these results.

Table 2. Customer bill savings from selected time-varying pricing programs

Utility	Bill savings	Program year(s)
Baltimore Gas and Electric	• $9.08 average credit paid per customer for four energy savings days • $2.8 million in bill savings for all 700,000 participants in the Smart Energy Manager Program, which included behavioral demand response	2013
Burbank Water and Power	• More than $1 million in bill savings for all 25,000 participants in TOU rate program across all program years	2011–2014
Green Mountain Power	• For customers on peak-time rebate and critical peak pricing, average savings across 14 events of $2.52–$4.88 • Estimated total annual bill reduction of $50/customer	2012–2013
Oklahoma Gas and Electric	• Average annual savings of $191.78 for residential customers and $570.02 for commercial customers in the VPP pricing pilot program	2012

Utility	Bill savings	Program year(s)
Sacramento Municipal Utility District	• Average summer bill savings exceeding $77 on the TOU-CPP rate • Average annual bill savings of nearly $40/year for customers who checked out and used an in-home display from the utility	2012–2013

Source: DOE 2016

Reducing costs is clearly the primary motivation for customers to change their energy use in response to TOU pricing. The corresponding reductions in overall energy consumption and peak demand reveal the magnitude of the responses. Table 3 shows results from a previous ACEEE review of 50 studies of TOU and other time-varying pricing mechanisms (Baatz 2017).

Table 3. Average and median peak demand reduction and reduction in overall consumption from 50 time-varying pricing studies

Rate treatment	Number of studies	Average peak demand reduction	Average reduction in overall consumption	Median peak demand reduction	Median reduction in overall consumption
CPP	13	23%	2.8%	23%	2.6%
PTR	11	18%	2.3%	18%	0.6%
TOU	17	7%	1.2%	6%	1.0%
TOU+CPP	8	22%	2.1%	20%	2.3%
TOU+PTR	1	18%	7.4%	18%	7.4%
All	50	16%	2.1%	14%	1.3%

Clearly TOU pricing and other time-varying pricing mechanisms can be effective in changing customer use of electricity to optimize grid performance and yield cost savings to customers. To put the above savings in context, most state energy efficiency resource standards set annual energy savings targets in the range of 1–2% from all customer energy efficiency programs in a utility portfolio. The results shown in table 2 also reveal that while time-varying pricing does yield reductions in overall energy consumption (kWh), the biggest impacts are on peak demand (kW) reductions. In this way, time-varying pricing functions primarily as a demand response strategy—a means to shape demand and create a more flexible grid.

Customer responses can be automated with various information and control technologies. Such technologies include in-home displays, web portals, and text/email messaging that provide energy use data in formats that are visually appealing, easily understood, and able to guide customers toward beneficial actions to change their use. For example, web portals can provide customers both historical and near-real-time usage data. Home HVAC controls, such as a smart thermostat, can be programmed to adjust settings and operation of equipment such as central air conditioners to respond automatically to price or other signals from grid operators or third parties. This type of functionality can also be achieved without AMI, although AMI deployments can deliver much greater scale for customers served and impacts. Faruqui, Sergici, and Warner (2017) find a 69% reduction in on-peak usage where these rates are paired with AMI and other technologies—from 6.5% for every 10% increase in the peak-to-off-peak price ratio to 11% for every such increase.

AMI can also be used by utilities for prepay plans. These require customers to pay in advance of receiving electricity. Such plans are controversial as electricity is cut off when a customer's balance reaches zero. There usually is only a very short grace period (e.g., one day) compared with those under traditional billing plans.[13] Research by ACEEE and Slipstream found that customers reduce their consumption by about 9% on prepay plans, but the reason for these savings is unclear (Sussman 2019). The combination of enhanced feedback and threat of shut-off is particularly likely to reduce energy use, but other factors may also explain these findings. Although customers generally like prepay plans, such programs can pose risks to certain customers—those who are extremely budget constrained and vulnerable to loss of service.

Targeting for Program Design, Marketing, and Technical Assistance

With limited budgets and concerns about the rate impacts of programs, program administrators need to maximize the value of each program dollar spent, especially with continuing cost-effectiveness challenges at some utilities. Energy efficiency targeting is one means of improving program effectiveness (increasing savings, lowering the cost of serving or recruiting customers) by selecting customers with particular characteristics as the focus of marketing efforts. Borgeson and Gerke (2018) describe three strategies for targeting. Utilities can focus on customers who: (1) are able to participate (e.g., have the relevant end uses), (2) are likely to participate, or (3) are likely to save more than others when they do participate.

Some strategies do not rely on AMI, instead using other forms of data—monthly usage data, demographic information, past program participation, and other characteristics—to target customers. Examples from national labs, software companies, and utilities suggest that interval data can add value to program targeting by helping to answer whether a customer can participate, and whether she is likely to save more if she does.

Identifying Whether a Customer Is Able to Participate

Where interval data enable segmentation of end uses, they might be used to determine whether a customer can participate in a program; for example, for a residential pool pump program, interval data might locate customers who have a pool. This segmentation uses nonintrusive load monitoring (NILM), which employs data from a single point of monitoring, like a smart meter, to provide an itemized accounting of end-use energy consumption (Baechler and Hao 2016). NILM analysis compares these data with appliance signature databases that catalog physical measurements of appliance load (Armel et al. 2013).

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[13] Prepay plans also typically have certain blackout periods (times when power cannot be shut off), such as overnight, on holidays, and on weekends. Customers are usually shut off at the earliest time legally permittable under applicable regulations and rules.

Most AMI data are reported on a 15-minute, hourly, or daily basis, and at this level of disaggregation, some software vendors for NILM have faced challenges recognizing loads and identifying key events for complex equipment, like different phases of operation (Baechler and Hao 2016). Software vendors report significant improvements in performance since 2016, suggesting the importance of continued testing that measures how well NILM can recognize loads. The ability to disaggregate end uses increases with the granularity of the data. Hourly data can identify loads that correlate with outdoor temperature (like HVAC), continuous loads, and time-dependent loads (like pool pumps and outdoor lighting). One-minute data can identify as many as eight different appliance types, with increasing numbers of appliances for data in the multiple kHz or MHz range (Armel et al. 2013). Some devices, like the Sense Home Energy Monitor, are installed in the home and use a Wi-Fi network instead of an AMI meter to perform the disaggregation.

Despite these reliability challenges, the market for NILM is growing, with about 60 vendors offering these services as of 2016 (Baechler and Hao 2016). Because NILM techniques can identify some of the largest end uses, like heating and cooling, as well as unique time-dependent loads like pool pumps, they can be used to identify customer eligibility for some types of programs. These techniques can also be used to assess whether customers are good candidates for meter-based P4P programs (described below). For example, the Sacramento Municipal Utility District (SMUD) identified which buildings had good “fitness” for the Time-of-Week and Temperature model developed by Lawrence Berkeley National Laboratory (LBNL), finding that restaurants did well but that colleges and schools varied more, depending on whether classes were in session, which was not included in that model. Model quality is one contributor to the overall robustness of meter-based savings results (Berkeley Lab 2018). We found in our interviews that opportunities to use the outputs of NILM to improve energy efficiency program performance are generally underutilized, although some utilities and vendors are working together to pilot such use of these algorithms.

Identifying Whether a Participant Is Likely to Save More than Others

Usage data, especially interval data, can also be used to prescreen potential program participants on the basis of their usage patterns so recruitment efforts can focus on the most promising customers. In this way, targeting has the potential to improve cost effectiveness by increasing savings and reducing the likelihood that there will be customers who fail to achieve energy savings benefits from the program.

Most estimates of energy efficiency savings are based on average cases or at best a range. Scheer et al. (2018) investigated the metered savings performance of several energy efficiency programs across both residential and commercial sectors. In each case the authors identified characteristics derived from customers’ preprogram AMI data that were highly predictive of actual metered savings outcomes. Figure 3 shows results for customers in California’s Central Valley who participated in Pacific Gas and Electric’s (PG&E) Advanced Home Upgrade pathway (AHUP) of the Energy Upgrade California program. AHUP is a home retrofit program consisting of building shell and HVAC measures. The figure’s two panels show the distribution of metered annual MWh savings for customers in the top half and bottom half of two targeting criteria: summer usage and summer-to-shoulder kWh ratio. Customers in the top half of this targeting scheme saved nearly 3.5 times more than customers in the bottom half. Similar patterns were observed for every program studied (with different targeting schemes, depending on the program). This research clearly highlights the potential to improve savings and cost-effectiveness by basing targeted interventions on customers' usage patterns.

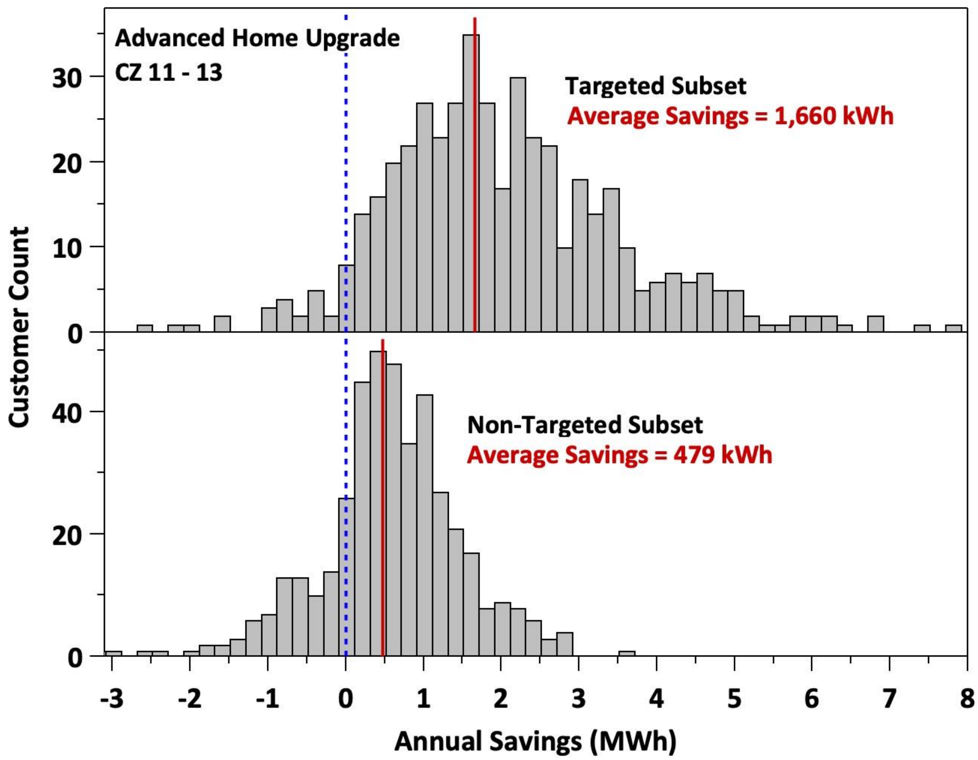

Figure 3. Distribution of pre/post annual cooling electricity usage for Advanced Home Upgrade participants in California's Central Valley. Top: top half of customers as gauged by the targeting criteria. Bottom: bottom half of customers as gauged by the targeting criteria. *Source:* Scheer et al. 2018.

Although monthly data can and should be used to target programs for which AMI data are not available, interval data allow more precise targeting and enable targeting schemes that rely on segmentation of usage, like discretionary kWh, peak-period usage, baseload kWh, load-shape characteristics, and more precise determinations of heating and cooling kWh. For HVAC programs, the PG&E team found that targeting based on total usage was less effective than using interval data, which enabled researchers to better isolate the portion of usage from cooling and derive additional parameters (Scheer, Borgeson, and Rosendo 2017; Borgeson and Gerke 2018). These techniques were not limited to residential programs; PG&E research also estimated the potential impact of targeting across a range of residential and small and medium-size business programs and estimated that such targeting would increase average participant savings by 53% and 76% (Scheer et al. 2018).

These research exercises informed targeting strategies that are now being deployed within PG&E's meter-based P4P programs.[14] These programs will provide in-field experience with targeting to maximize total savings and savings depth. In the meantime, it is clear that PG&E sees targeting as an important strategy, as described in its *Energy Efficiency Business Plan 2018–2035*: "AMI data offers PG&E the ability to better understand site-specific customer energy usage and to tailor offerings that benefit customers most in need of specific energy efficiency offerings . . . PG&E plans to target customers who are expected to yield the greatest energy savings, energy bill reductions, and/or grid-value" (PG&E 2018, 1–9).

For effective targeting, program designers will need to balance increased savings from more rigorous targeting criteria with increased pressure on program recruitment from a smaller segment of the population. Targeting may also raise equity concerns by eliminating customers with lower likelihood of savings; to mitigate these concerns, program designers will need to ensure that targeting strategies also focus on desired customer attributes such as disadvantaged community designations. It should also be noted that energy efficiency is often a priority or first-in-the-loading-order resource expected to deliver cost-effective savings that benefit the entire rate base. Targeting the customers who can drive the greatest value can enhance benefits for all customers. Finally, the value of targeting is dulled by traditional deemed approaches, which average savings across all customers and thus reduce the motivation and accountability for improved results from targeting.

Using Targeting to Improve Technical Assistance

Utilities can take insights about which customers are most likely to participate in and benefit from programs directly to the customers themselves in the form of improved technical assistance. Although these insights can be used in feedback as described above, they can also be used in customer interactions with utility representatives or contractors. If such insights are integrated with databases and the workflow of customer call center representatives, large account managers, and contractor trade allies, they can be used to help customers diagnose high bills and connect customers to utility offerings.

PECO offers an example of a utility using data from AMI to target customers and better market programs. It recently began an effort working with a third-party implementer to disaggregate end uses with AMI data in an e-audit tool and then use these data in email campaigns that target small and medium-size businesses. In addition, large account representatives use these assessments, including highly visual "heat maps" of buildings' energy use at different times of day, to facilitate conversations with customers about how they are using energy (Mike O'Leary, Manager of Energy Efficient Programs, PECO, pers. comm., August 29, 2019).

The targeting, marketing, and program design described above can be used by a range of market actors, including utilities themselves, other program administrators where third-party (e.g., Energy Trust of Oregon) or hybrid (e.g., NYSERDA) models exist, and program

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[14] PG&E did not self-report data disaggregation as one of its use cases in our survey, suggesting either that it has discontinued the practice or that the survey respondent was not aware of these activities within the company's large energy efficiency program team.

implementers who acquire savings on behalf of program administrators. In addition, the "platform" model of distribution utilities explored in New York's Reforming the Energy Vision process envisions other service providers using these data directly in the marketplace, perhaps absent "programs" per se (New York PSC 2016).

GRID-INTERACTIVE EFFICIENT BUILDINGS

Many states increasingly face growing peak electricity demand, transmission and distribution infrastructure constraints, and an increasing share of variable renewable electricity generation (Neukomm, Nubbe, and Fares 2019). These stresses to the grid create an opportunity to expand the role of flexible, controllable electricity loads to support reliability and lower system costs. Traditional demand response can serve this role, but so too can grid-interactive efficient buildings (GEBs).[15] These buildings are energy efficient, can be demand flexible, and can be optimized with multiple technologies (possibly including customer-sited generation and storage) for customer and grid benefits. GEBs essentially combine the AMI use cases discussed above: pricing, feedback, and targeting. The technologies required for GEBs also can enable other use cases, namely P4P and M&V 2.0.

To serve these multiple roles, GEBs require information and communications technologies—interval data from either AMI or building automation systems (to understand the best ways to respond to grid needs) combined with controls both for the building and for communications back to utility or aggregator offtakers of the building's services. These data and controls can be used to support GEBs in utility program offerings or can be a part of GEB projects implemented by third-party aggregators and building owners.

To date there are only limited examples of GEBs, especially through utility programs. ACEEE's recent brief (Perry, Bastian, and York 2019) on this topic concludes that no programs or pilots can be considered a holistic GEB program. However we identify a number of utility programs and pilots that promote aspects of the GEB vision for programs, as shown in figure 4.

[15] GEBs are grid-connected buildings with information and communications technologies able to respond to signals from the grid to modify energy demand. They actively use distributed energy resources (DERs) and optimize energy use for grid services. Utilities can use GEBs to manage grid operations and lower system costs while delivering customer value in the form of reduced bills, improved productivity, and enhanced comfort. The energy efficiency aspects of GEBs can also make large contributions toward meeting state, municipal, and utility energy efficiency and emissions goals.

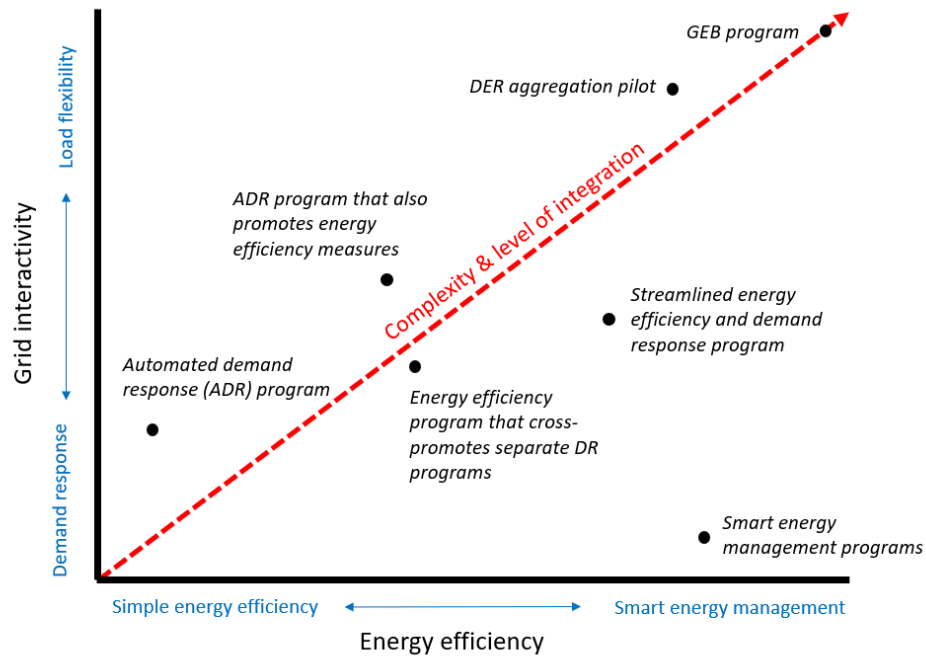

Figure 4. Various types of grid-interactive and energy efficiency offerings scaling up to fully integrated programs

In our survey, four utilities said they are running GEB programs, and these appear to be automated demand response programs (ADR) that also offer energy efficiency measures and integrated energy efficiency and demand programs that use smart thermostats to deliver customer and grid benefits. For example, PG&E's ADR program offers additional incentives to participants who install energy efficiency measures at the same sites that participate in demand response events. This program also requires participating facilities to undergo an on-site audit that identifies both demand response and energy savings opportunities (Perry, Bastian, and York 2019). While these programs do not require AMI, advanced metering can support GEB development through its ability to quantify and capture the time value of savings. This yields concrete value streams both to customers with GEBs and to grid operators.

One opportunity to better value the multiple services that energy efficiency provides is to base utility procurement on the actual performance of energy savings, capacity, or flexibility resources. Where these P4P models value peak savings, they typically leverage AMI data to measure the performance of demand-side resources.

PAY-FOR-PERFORMANCE

P4P, an emerging model for energy efficiency program design, rewards energy savings on an ongoing basis rather than providing up-front payments based on deemed or custom measured calculations. These meter-based P4P programs determine performance payments based on savings quantified using meter data, including daily or hourly data from AMI where available (Best, Fisher, and Wyman 2019). Meter-based P4P programs aim to produce a series of benefits for program administrators (typically utilities) and their customers (Best, Fisher, and Wyman 2019).

Some of the benefits of meter-based P4P are not AMI dependent. Monthly billing records can still be used to calculate avoided energy consumption. Using standardized methods of accounting for savings and delivering performance payments can help increase investor and utility confidence that energy efficiency is a quantifiable, reliable resource, which may help energy efficiency programs scale.[16] Meter-based P4P can also reduce the need to oversee program implementers by setting competitive procurement requirements and then letting implementers determine how to best incentivize customer adoption. Finally, these program designs can break down silos between programs and enable integration within customer offerings by letting a broader range of technologies participate if they can meet program savings requirements.

Currently, the meter-based P4P landscape includes some program administrators without AMI, like Energy Trust of Oregon and the NYSERDA–National Grid collaboration launching in 2020. Others, like PG&E, the DC Sustainable Energy Utility (DC SEU), and NYSERDA's collaboration with Con Edison, do leverage AMI. In interviews, NYSERDA cited additional potential benefits from meter-based P4P with AMI: alignment with greenhouse gas reductions and grid needs and continuous improvement in program design. AMI also enables program administrators with meter-based P4P to offer data to implementers to support program targeting that relies on usage segmentation, like peak-period usage, baseload kWh, and load-shape characteristics, as described above.

With daily, hourly, or 15-minute interval data, program administrators can set performance payments that scale based on the value offered to the grid or on GHG reduction at different hours of the day or different locations. This is currently being done in multiple PG&E residential P4P programs where savings achieved during the summer peak period are assigned a 3x payment kicker. Similarly, program administrators can offer localized incentives in night-peaking residential areas or midafternoon-peaking commercial areas on the same summer day. While utilities can use average load and savings shapes to value savings happening during system peaks, interval data offer a more accurate, granular understanding of the time value of energy efficiency and localized impacts on the grid. For example, figure 5, below, shows how a California home-upgrade program delivers significantly more annual avoided GHG emissions per MWh of savings than a commercial program (that consists of mostly lighting and refrigeration measures), given the time dependence of marginal emissions rates through the day on each day of the year. This value will be most important in states and service territories focused on carbon or on grid constraints, or where measured load shapes do not provide sufficient information.

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[16] One example of a standardized method used in meter-based P4P is CalTRACK (caltrack.org), which provides detailed, executable approaches to calculating changes in consumption. When operationalized with an open-source code base, it significantly improves transparency for market actors over traditionally custom-designed evaluations using professional guidelines like Uniform Methods or various state EM&V protocol documents.

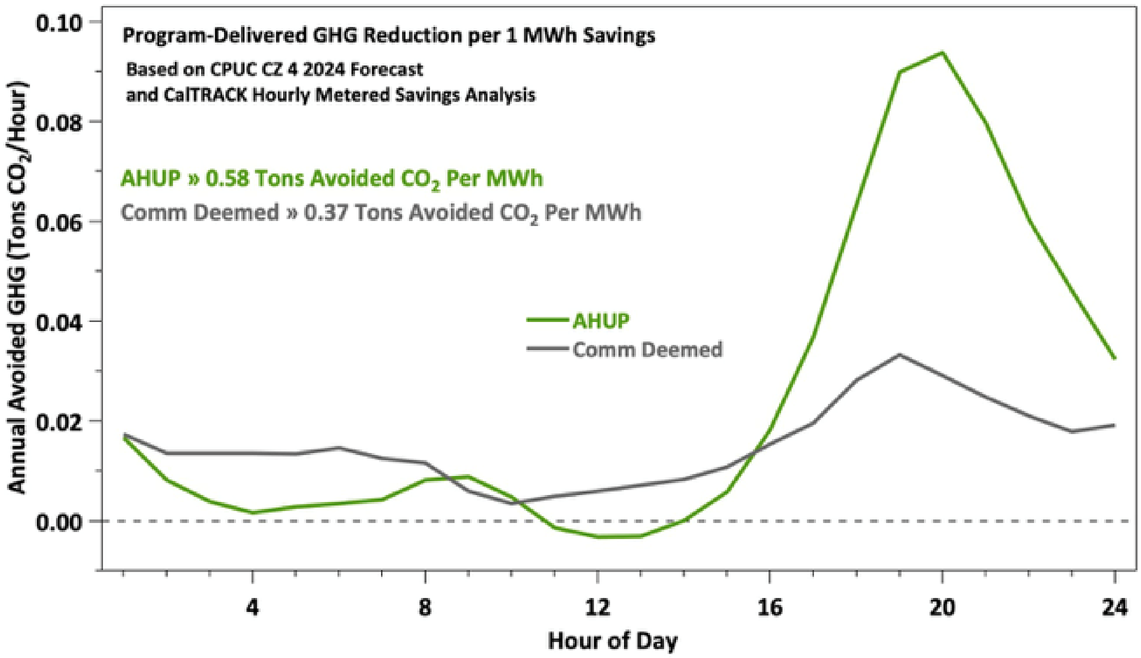

Figure 5. Avoided GHG emissions for 1 MWh of savings from Pacific Gas & Electric's Advanced Home Upgrade program and Commercial Deemed program. Each data point multiplies 365 hourly kWh savings measurements with associated marginal emissions to calculate annual avoided GHG at each hour of the day. *Source:* Golden, Scheer, and Best 2019.

Meter-based P4P with AMI allows program administrators to create actionable insights about how to improve programs while they are happening by tracking meter-based impacts close to real time rather than months after the end of a yearlong program. Interval data also generally allow for better modeling of energy consumption. With better models, evaluators, utility planners, and investors can have more confidence in the savings, and program administrators, and perhaps even policymakers can better forecast results before the end of program cycles in order to make key adjustments (for example, to targeting strategies and quality assurance requirements).

Even those programs that do leverage AMI for some purposes may not use its full functionality in initial pilots. Program implementers may roll up their AMI data to a less frequent interval, or they may select not to include use cases for AMI in early program designs to reduce the complexity of performance payment calculations. Establishing new frameworks such as P4P can be difficult, and more complex design elements can be introduced over time if necessary. Further, leveraging AMI in support of P4P requires data access for program administrators like NYSERDA and DC SEU as well as the implementers or "aggregators" who run the program. In addition, it requires investment in staff capacity on procurement, contract structuring, and the other tools required to structure performance payments and create the platform for a P4P marketplace. Finally, fully leveraging this use case requires commitment from evaluators and utilities to use the data to optimize programs in real time.

MEASUREMENT AND VERIFICATION

AMI creates new opportunities for measurement and verification of energy savings from utility energy efficiency programs. Most past methods of M&V have relied on monthly use data, customer surveys, statistical modeling, and possibly some on-site metering (primarily for large commercial and industrial customers). The lag time of one to two years from the end of a program year in determining impacts can result in inefficiencies and higher costs because of the slow feedback and delayed ability to detect problems. By contrast, AMI yields near-real-time measurement of actual energy use. Program managers can use such timely and highly granular customer energy use data to monitor program results closely to assess ongoing performance, detect problems, and take corrective actions as indicated.[17]

The advent of AMI and related information and communication technologies has given rise to M&V 2.0, a major advance in how program managers and evaluators measure and verify energy savings.[18] NEEP (2016) views M&V 2.0 as the ability to use granular data, analytics, and computation on a large scale to streamline the M&V process. These advanced M&V methods hold great potential to determine energy savings in near real time to benefit stakeholders. LBNL researchers (Franconi et al. 2017) cite numerous benefits from these methods, including:

- More timely and detailed information on program results
- Ability to inform ongoing building operations
- Early input on energy efficiency program design
- Consistency and improved accuracy of impact measurement
- Ability to assess impacts by location and time of day
- Increased confidence in M&V results

AMI data enable program managers, implementers, and evaluators to gain a more comprehensive understanding of a program and measure impacts, particularly energy use at different times of the day. It also is important that all users of AMI employ common data platforms that provide secure nodes for accessing data and ensuring consistency. The more continuous M&V possible with AMI data and advanced, automated analytics can be used to spot problems more quickly and make any indicated changes to improve program performance. Another benefit of early feedback is the ability to identify which types of customers are achieving better measured performance. Such data can in turn be used to enhance program targeting—concentrating efforts on those customers most likely to benefit from certain measures. Programs can use performance dashboards that draw on AMI data to show program results in near real time.

Use of M&V 2.0 methods does not appear to be systematic for any utilities or states and did not come up as a use case in any of our utility interviews. However LBNL is working with states and utilities across the country to formally test the value proposition associated with

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[17] Granularity of data can take several forms. For AMI and related building data, these primarily are measurement interval, volume, and end-use detail.

[18] See also Nowak, Molina, and Kushler (2017) for a discussion of definitions, recent trends, challenges, and examples.

these tools. Pilots are being conducted with Sacramento Municipal Utilities District, multiple gas utilities in California, Eversource and United Illuminating in Connecticut, Seattle City Light and Bonneville Power in Washington State, and BC Hydro in British Columbia (Berkeley Lab 2019). These pilots are largely ongoing, with limited published results, and tend to focus on comparing M&V 2.0 tools with traditional M&V methods. Early results for most projects find a good fit to the model for a subset (~50–75%) of buildings, with uncertainty exceeding ASHRAE guidelines in a significant number of buildings.[19] LBNL tends to find the most value in delivering early feedback on savings as they accrue and in identifying nonroutine events and underperforming projects (Berkeley Lab 2016b, 2016a; NEEP 2019). Efficiency Vermont is also testing the use of AMI data for M&V in a pilot comparing homes with energy efficiency measures against a control group. This effort will yield efficiency savings load shapes, hopefully with time-differentiated impact estimates for efficiency programs that can be used in valuing energy efficiency at different times of day and year (Fink 2017).

UTILITY SYSTEM EFFICIENCY (INCLUDING CONSERVATION VOLTAGE REDUCTION)

Much of the impetus for AMI is improving and optimizing grid or system efficiency. As discussed earlier, AMI can be coupled with pricing, incentives, and customer programs to modify system demands and reduce loads at the peak periods when meeting demand is expensive. By flattening demand through overall reductions or shifting loads from peak to off-peak periods, grid efficiency is improved and costs reduced.

AMI technologies can provide utility systems with data, control, and communication capabilities beyond customer power demand and energy use. One such capability is voltage monitoring, which measures voltage levels and some power quality parameters, enabling utilities to develop accurate voltage profiles across feeder lines. These profiles can be used to diagnose customer voltage issues remotely and to optimize voltage across the grid (DOE 2016).

This ability to monitor voltage can be used by system operators to implement CVR as a means to reduce distribution power losses. CVR involves measuring and analyzing voltages on distribution feeders in order to find ways to reduce voltages while still maintaining service requirements (including voltage and phase balance) at levels that allow equipment to operate without problems. Lower voltages can improve end-use equipment efficiency and reduce line losses on both the customer and the utility sides of the meter. Voltage optimization can also improve effective capacity (kW) and help with reactive power management (Schwartz 2010). The Central Lincoln People's Utility District in Oregon implemented a pilot CVR program that yielded a 2% energy savings for all customers (DOE 2016). On the basis of this result, the utility plans to implement the program system wide.

Dominion Energy offers another example of utility CVR. Since 2009 Dominion has installed more than 450,000 smart meters in its service areas in Virginia and North Carolina and has

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[19] AHSRAE Guideline 14, Measurement of Energy, Demand, and Water Savings, provides guidelines for minimum performance in reliably measuring the energy, demand, and water savings achieved in conservation projects.

used a subset of the information provided by these meters to implement CVR. Dominion has software that measures the energy savings from CVR, and the utility is now achieving an average of 2.9% savings year-round. Dominion has also been actively marketing voltage optimization services to other utilities, including PG&E, Hawaiian Electric, Nevada Power, Hydro Ottawa, and several municipal utilities. The company estimates savings on a circuit by alternately raising voltage and then restoring the voltage to normal and seeing how loads change in response. Savings vary from utility to utility and have ranged from 2–4%, with lower savings for circuits in the moderate climates along the Pacific Coast and higher savings higher in East Coast applications. The Potomac Electric Power Company (Pepco) provides another example of CVR energy savings. Pepco's impact analysis shows that a 1.5% voltage reduction on its Maryland distribution system provides an annual nonresidential energy reduction of 0.9%; for residential customers the savings are 1.4% (Sergici 2016).

Potential Energy Savings from AMI-Leveraged Energy Efficiency

As these cases demonstrate, AMI can be—and is—a powerful tool to help customers reduce their energy consumption and energy costs. As such, AMI also provides important benefits to grid operators, as discussed earlier. The energy savings possible through different uses of AMI to advance energy efficiency vary. Some have been well developed and documented; these include:

- Near-real-time and behavioral feedback: 1–8%[20]
- Pricing with time-varying rates: 1–7%
- Conservation voltage reduction: 1–4%

Other uses of AMI also have strong potential to improve energy efficiency programs and evaluation, contributing to and supporting customer savings. For program design, examples include the use of AMI data for customer targeting and recruitment. For program evaluation, AMI can provide accurate and timely data to facilitate P4P approaches, as well as allow rapid feedback to management for program improvement.

While AMI can be used as a tool for helping customers reduce energy use, as we have discussed, our research on past performance shows no obvious connection between performance in demand-side energy savings and penetration of AMI. There are leading utilities for customer energy efficiency programs with and without AMI. For example, Eversource MA and National Grid MA, which do not have AMI, held the top two spots in the 2017 *Utility Scorecard*, but in third and fourth place were utilities that do have AMI, PG&E and Baltimore Gas and Electric (BGE). Similar patterns exist throughout the spectrum of energy efficiency performance (Relf, Baatz, and Nowak 2017). Nonetheless, it is clear that many of these use cases are underexploited, and with better adoption and further evidence, a stronger statement may be possible about the relationship between AMI and energy savings. Further, as energy efficiency program delivery evolves as a climate and

[20] Feedback devices and programs show wide variation due to different designs, such as opt-in versus opt-out. See Sussman and Chikumbo (2016).

grid resource, the capabilities of AMI highlighted in these use cases will become increasingly valuable.

Barriers to Leveraging AMI to Save Energy

As illustrated above, AMI can yield significant potential utility and customer benefits, including energy savings and peak demand reduction. However our survey of the top 52 electric utilities by sales, as well as interviews across the industry, suggest that utilities are largely underutilizing this resource. Our interviews with program administrators and literature review further revealed common limiting factors for leveraging AMI.

There are myriad barriers to adoption of AMI in the first place, including the challenges of justifying these investments where AMR has already been deployed, issues with measuring some of the benefits of AMI, and communications challenges with regulators, consumer advocates, and customers (NEEP 2017). Unclear business cases for AMI adoption can lead to denial of AMI applications, as seen in recent rejections in Massachusetts, Kentucky, New Mexico, and Virginia. However this section highlights barriers to the use of these systems for utilities, regulators, and customers, as well as technological issues limiting their use by those groups.[21]

Utility

Utilities that do not perceive a need to know and understand their customers are less likely to implement programs that leverage AMI; unfortunately, our interviewees found this blind spot prevalent across the industry. When utilities neglect to do customer research using AMI, they miss out on the benefits of customer targeting, feedback, and more robust M&V. This barrier is driven by a few challenges. First, monopoly utilities with a guaranteed customer base may lack a core competency in customer acquisition and engagement, which may discourage some utilities from focusing on customer-facing offerings or using customer data to gain insights. Second, utility business models encourage utilities to focus on capital investments. Utilities may need to make up for lost revenues intended to cover fixed costs from reductions in sales through decoupling or lost revenue adjustment mechanisms (LRAM). They may also need additional earnings opportunities to make up for avoided capital investments due to lower sales and peak demand levels through performance incentive mechanisms.[22] Last, utilities are often reluctant to share data with nonutility vendors that offer additional services and products because these services and products may not offer value to their utility business model. Even where utilities are willing to share data, they may lack clear ownership and access policies around data collection, data storage, and customer data access portals.

In our literature review we found limited evidence for direct energy efficiency savings from AMI outside of feedback augmented by behavioral energy efficiency and demand response or automation technology, pricing, and CVR; many of the promising use cases were

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[21] We have outlined customer barriers here regardless of particular customer characteristics; however it is important to note that barriers may differ across the spectrum of customer segments.

[22] For more information on utility business model tools such as decoupling, LRAM, and performance incentives and how they encourage energy efficiency investment, see Molina and Kushler 2015.

enabling or indirect in nature, and many had limited examples. The lack of concrete evidence for savings directly stemming from AMI can make it difficult for utilities to build a good case for AMI deployment. Utilities rarely prioritize testing the success of measures or programs with and without AMI, so it is difficult to isolate the incremental value of AMI use cases. Further, regulators rarely require such detailed demonstration of benefits. Nonetheless, behavioral program vendors noted in interviews that where utilities have access to AMI, they typically do use it to provide more relevant insights to customers.

AMI deployments require utility investment and workforce development to implement the new technology, and this can challenge utilities without such infrastructure and workforce. Utilities should allow "sufficient time to plan AMI deployments including logistics, asset management, records management, workforce management, and integration with communications, MDMS, OMS, and other affected systems" (DOE 2016). When AMI is in place, utilities may have to hire staff with new skills or train existing staff in data science, marketing, communications, customer service, and engineering to incorporate these data into their work flow. According to a DOE case study, PECO invested time to coordinate internal and external communication systems and processes to aid workforce development and customer communication for their AMI deployment. Internally they "held regular meetings, developed standard messaging, and implemented a dedicated intranet page to help with workforce management and training" (DOE 2016). PECO also created uniform talking points, presentations, and other materials to share with the public and local media (DOE 2016).

Regulatory

AMI produces a much higher volume of customer data than traditional analog meters. Having additional data creates opportunities for energy savings but also raises data privacy and cybersecurity concerns. "AMI deployments raise new questions about the security of customer data, the types of entities that can access it, and how the data will be protected from cybersecurity breaches and other data privacy intrusions" (DOE 2016). Thus, standards, tools, and other techniques are needed to ensure that data privacy and cybersecurity are not compromised. Our interviewees stated that there is technology to support cybersecurity and privacy, but utilities and states struggle to create and apply clear rules that allow customers to easily access their data and vendors to provide energy services. Green Button is one such set of standards, although application can be inconsistent (AEE 2017a).[23] An additional challenge in creating these rules is consumer advocates' resistance to approving AMI programs or third-party access to data (Chris Villarreal, president, Plugged In Strategies, pers. comm., July 12, 2019).

AMI requires significant investment of ratepayer dollars. In most states, utilities request pre-authorization of these expenses, and consumer advocates and some regulators balk at the potential ratepayer impacts, especially where there are insufficiently beneficial business cases. Primary hesitations tend to consist of concerns about delivering uncertain benefits

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[23] Green Button comes in two forms: Green Button Download My Data, which allows customers to download their energy use data and upload it to a third-party application, and Green Button Connect My Data, which enables customers to automate the secure transfer of their usage data to third parties.

relative to costs and concerns about equity and uneven distributional impacts. However there are notable exceptions. For example, the Illinois Citizens Utility Board has supported AMI rollout and has endeavored to ensure that the AMI offered to Ameren and ComEd customers is used in service of energy savings, including by conducting research tracking the impact of real-time pricing across customer classes (Thill 2019).

Technology

Utility systems designed for small volumes of monthly data and systems without necessary integration can limit the potential of AMI data. To fully take advantage of large interval load data sets produced by AMI, utilities need to improve data processing and management, models for assessing system conditions and predicting demand impacts and energy savings, and some software platforms (DOE 2016). Many of these data processing capabilities are delivered through service-based solutions, which are often lower cost and cloud based. Utilities typically have a disincentive to use such resources, as they are usually not valued as an asset; using their own capital resources could artificially raise the cost of AMI deployment.[24] More-advanced analysis strategies and software platforms will allow utilities to effectively utilize AMI data for multiple use cases such as creating more time-varying rates, customer targeting, meter-based P4P tracking, and planning.

Another technology gap stems from utility reluctance to adhere to consistent data formats and transmission protocols, such as Green Button Connect My Data, and to adopt comprehensive interoperability standards to support connections among smart meters, customer devices, and communications and information systems (DOE 2016). This creates a barrier for third-party data sharing. Continued advancements in mobile apps are also needed to share real-time data and energy usage insights with customers (DOE 2016). There are limited examples of utilities using such applications.

Customer

Families and businesses themselves are key actors in leveraging AMI to save energy on their bills; most energy savings require some action by customers, such as responding to a rate, purchasing energy efficiency equipment or services, or setting up automated devices. Barriers for customers include lack of engagement, interest, or motivation. Customers need access to educational materials and support services to understand program structure and elements and how to save energy and earn rewards. Customers also need personal energy usage insights delivered to them in an accessible and timely manner. Personalized insights and tips for energy usage reduction, delivered within 24 hours of an energy savings event through the customer’s preferred mode of communication (e.g., phone call, text, e-mail, or mobile application), can motivate customers to save energy more than impersonal, delayed information.

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[24] Exceptions are found in New York, which allows a rate of return for prepaid software services, and Illinois, which is considering extending the potential opportunity to earn a partial rate of return to pay-as-you go services.

Practices to Leverage AMI to Save Energy

Leveraging AMI to save energy requires action from utilities in their roles as energy efficiency program administrators, grid planners, and grid operators. They are also the primary entities identifying AMI technologies, selecting vendors, and investing in these resources on behalf of the system and their shareholders. State utility regulators review the prudence of AMI investments, provide oversight to determine whether to allow expenses or incentives associated with these investment, and in limited instances set performance standards for AMI investments. The ecosystem of third parties can provide critical services that leverage AMI in data science, customer segmentation, customer marketing and program implementation, and resource aggregation to meet planning needs. Of course, customers too have a key role to play, as many of the use cases for AMI to save energy require their initial investment or continued participation.

Below, we outline the practices our research found among utilities and regulators that can ensure successful deployments that leverage AMI for customer energy savings, including some practices that address the barriers outlined above.

UTILITIES AND PROGRAM ADMINISTRATORS

Implementation of AMI by a utility is much more complicated than simply changing out meters. Effective deployment and use of AMI require coordination across multiple departments or units within the typical utility structure, including:

- *Information technology and accounting*. Data management, recordkeeping, and customer billing
- *Planning*. Customer and load data for forecasting
- *System operations*. Monitoring and managing system resources to meet loads
- *Marketing/communications*. Educating and informing customers about AMI
- *Customer service* (including programs for energy efficiency, demand response, and DER). Using AMI capabilities to help customers change behavior and take other actions to reduce or shift energy use to lower their energy costs
- *Regulatory affairs*. Gaining approval needed by regulators to adopt AMI
- *Rate design*. Exploiting new opportunities to create time-varying rates

Utilities and program administrators need to break down traditional silos that contain these various functions in order to manage and use AMI to its fullest capabilities to benefit customers and system operations. That includes investing time to coordinate internal and external communication systems and processes, as PECO did for its initial communications rollout for AMI, and as PGE continues to do in its efforts to leverage multiple use cases of AMI.

The highly granular data that AMI provides are beneficial only if they can be effectively managed, analyzed, and used to inform and motivate customers to take actions to achieve desired outcomes. Utilities and program administrators need to invest in data scientist capacity accordingly, bolstering capabilities such as big data management, analytics, security, and communications. AEE (2017) stresses the need for utilities to invest in back office and data management systems to allow customers full access to their data in a form that is easy to understand and identifies opportunities for beneficial changes. AMI data also need to be readily available not just to customer billing and records departments, but also to demand-side management program staff, system planners, and system operators. Utilities should engage the range of actors within and outside the utility who might identify use cases for the data, create systems for those who will be handling and entering it, and establish guidelines for accessing and interpreting it (e.g., definitions for each entity in the data warehouse).

Some early experiences with utility rollout of AMI demonstrate the need for effective communications. Moving from traditional, manually read meters to billing based on AMI is a large change for customers. Without effective communications, customers may resist the changes out of concerns about data privacy, security, or increased costs. Utilities need to build strong business cases for AMI that clearly show how customers will benefit. They also need to provide the tools and services necessary to enable customers to take advantage of AMI and realize its benefits. Utilities should tell the story of what steps are needed to save money from the capabilities of AMI and associated pricing or incentives.

An effective approach for rollout of AMI with time-varying pricing is to make participation opt-out as opposed to opt-in. Investor-owned utilities in California are taking this approach for time-of-use rates, as are leading municipal utilities such as SMUD (DOE 2016) and Fort Collins Utilities (DOE 2013).[25] BGE has successfully combined opt-out peak-time rebates with behavioral demand response in its Smart Energy Rewards program. The program has more than 1.1 million customers enrolled—a result that BGE achieved by registering customers automatically when AMI meters were installed. Customers can opt out, but the large majority have not done so; 70% have participated since 2015 (BGE 2019). This program is not focused on energy efficiency but has delivered 1,280 MW in peak demand savings across five summers between 2013 and 2017 (AEE Institute 2018). The 2018 forecasted annualized energy savings for the Smart Energy Rewards program is 4,719 MWh. Additionally, $16,064,171 in total bill credits were paid to customers (BGE 2019).[26]

A more typical approach to rollouts of TOU pricing with AMI is to have customers opt in. Such an approach generally yields much lower participation, although participants are often more engaged. SMUD conducted pilot programs to test different approaches to introducing TOU rates, using both opt-in and opt-out designs. SMUD's evaluation of these pilots found higher enrollment rates for opt-out approaches without significant differences in dropout

[25] Fort Collins Utilities technically did not offer opt-out; rather it offered options to customers with a standard AMI rollout that would address their privacy or other concerns. One option was to reprogram the AMI to not collect interval data (a single electric data point/day); the other option was to record interval data but not transmit it via radio broadcast, thus necessitating manual meter reading at an additional cost of $11/month.

[26] Customers earn $1.25 per kWh saved during an Energy Savings Day between 1 p.m. and 7 p.m. during the control season. Energy reductions are measured against a baseline determined by a customer's average energy usage for nonevent days with similar temperature and humidity conditions (AEE Institute 2018).

rates or peak demand reductions.[27] Benefit–cost analysis of these pilots revealed greater net benefits and more favorable business cases for opt-out than for opt-in (DOE 2016).

REGULATORS

Regulators can align the behavior of monopoly firms (their investment in AMI) with the public interest (the potential benefits of AMI, including saving energy) by setting performance standards for utilities and then enforcing them with positive and negative consequences (Hempling 2013). In the case of smart grid deployment, regulators must first assess the costs and benefits of smart grid investments relative to their affordability, safety, and reliability and to environmental and other performance standards. This includes quantifying and incorporating the benefits from saving energy into regulatory proposals. Some utility applications fail to include a cost–benefit analysis in their business case; regulators can require such an analysis to support their decision making.[28] They must then monitor performance to ensure that those benefits are delivered, using the tools available to them, including mandates for specific actions and adjustments to compensation. Finally, regulators can set standards and oversee investments in a way that encourages utilities to innovate on behalf of ratepayers.

Quantifying and Incorporating Benefits from Saving Energy in Business Cases

As early as 2009, the National Association of Regulatory Utility Commissioners (NARUC) issued a resolution on smart grids calling on member commissions to ensure that any smart grid technology deployment plans continue to be subject to record-based reviews. These reviews should "ensure proposals—and in particular the utility's proposal for recovery of its capital outlays—are both cost-effective and actually result in benefits to ratepayers" (NARUC 2010).

Regulators, coop boards, and municipal oversight bodies have reviewed such plans since 2009, choosing to approve tens of millions of meters in dozens of AMI proposals but also rejecting some notable ones. As these oversight bodies review AMI proposals, they should use a robust cost-effectiveness framework that considers the role of customer benefits, including customer energy efficiency, in justifying the utility investment. The Electric Power Research Institute (EPRI) offers one such framework, which evaluates a range of benefits including customer and environmental ones, and which was used by PG&E and San Diego Gas & Electric in California in their proposals (EPRI 2010). The EPRI framework includes key benefits from energy savings, including avoided energy costs, energy procurement, and price mitigation. Including these can help properly value investments in AMI and can help motivate regulators to put in place metrics or requirements that these savings materialize.

Where those customer benefits are core to the business case, utility proposals should clearly outline how they will achieve those benefits, and approval of investments should be contingent on inclusion of an adequate plan for how new capabilities will be used to advance energy efficiency. Proposals should include any complementary investments on the

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[27] See Cappers et al. 2016 for more information and analysis of default designs for rate structures.

[28] For example, Indiana Michigan Power in Michigan filed their rate case in May 2019, including a request for cost recovery of their AMI investment. They did not include a cost–benefit analysis in that filing (Case U-20359).

utility back end or in customer communications, which would be necessary to realize those customer benefits. For example, the communications capabilities of AMI should be able to send pricing or load control signals through the meter to devices in the home if demand response programs are envisioned as a use case for AMI. Similarly, billing systems must be capable of integrating the rates into customers' bills.

Adjusting Shareholder Compensation for AMI Investment Based on Performance

In addition to approval of new technology needs, regulators and other oversight bodies determine whether and to what extent ratepayer funding can be spent in support of those investments. As they review AMI proposals, states apply different levels of scrutiny, which may or may not include a societal perspective depending on which cost-effectiveness test is used (NEEP 2017). State regulators have a range of financial options for encouraging utilities to deliver on expected benefits from AMI, including energy savings and customer benefits. These include performance-based regulation to align investments with desired outcomes, making additional earnings from AMI conditioned on realization of claimed benefits. Regulators can also consider delay or denial of some compensation to shareholders when benefits are not delivered, such as when a program fails to produce a reduction in the authorized revenue requirement that was expected due to projected operational savings from AMI.[29] However there is a risk that this will chill investment, as local distribution companies will be less likely to invest where cost recovery is uncertain or not timely or where regulators place conditions on recovery.

Maryland regulators successfully tied shareholder compensation to delivery of expected benefits in an early AMI deployment. BGE's initial petition to deploy AMI (Case 9208) was rejected in 2009 due to concerns about the cost–benefit analysis. The utility resubmitted the application with an updated business case, including a consumer education and communication plan to better support energy conservation (NEEP 2017). Although BGE was granted approval for the deployment, cost recovery in base rates was deferred until the investments proved cost beneficial. In response, BGE deployed one of the most successful behavioral demand response and peak-time rebate programs in the country, Smart Energy Rewards, described in the Practices to Leverage AMI section below.

Regulators can also use performance-based regulation (PBR), especially performance incentive mechanisms (PIMs), to tie compensation to desired policy outcomes rather than spending. PIMs are commonly used for energy efficiency programs, but an increasing number of states are looking to these mechanisms to encourage outcomes such as reliability, peak demand reduction, greenhouse gas reduction, beneficial electrification, and targeted DER deployment.

The Regulatory Assistance Project (RAP) recommends consideration of PBR methods to advance two desired outcomes: delivering investments on budget and completing their deployment on time. For example, French regulators used PBR in the smart-grid rollout of Électricité Réseau Distribution France (ERDF), a distribution system operator. They used

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[29] There are numerous cases, such as in Washington, Massachusetts, and Pennsylvania, where regulators have disallowed full recovery of undepreciated assets to protect ratepayer interests (Peskoe 2016).

metrics around cost controls, deployment timing, and system performance when installed, as well as metrics to measure whether operational improvements, such as reduced line losses and meter reading, were actually occurring (Littell et al. 2019). RAP notes the potential for gaming risk with PBR, and suggests using benchmarking, rules around including costs in rate base only when "used and useful," and careful review of timelines and budgets to mitigate that risk.[30]

We are not aware of any PIMs associated with *leveraging* AMI, where PIMs are specifically focused on measuring service results, such as energy or demand savings outcomes from these investments. Littell, Shipley, and O'Reilly (2019) offer multiple examples of potential goals and outcomes for AMI. We reproduce in table 4 their examples that are potentially relevant to the energy savings use cases described in this work. Regulators could also consider metrics to encourage outcomes from use cases like targeting and technical assistance or from grid-interactive efficient buildings, measured in program adoption or the value of grid services procured through GEBs.

Goal	Outcome	Performance criterion/functionality	Metrics to track
Feedback. Customer understanding of energy use	Higher customer satisfaction or understanding of energy use	Operation of customer energy usage portal	Customer usage of energy portal; one-time or regular access
Pricing. Vibrant real-time or TOU energy market for residential users	Customer costs more reflective of system costs; efficient pricing	Customer on a real-time or time-varying rate plan	# and % of customers opting out of or taking price offering
Data access. Authorized access to customer data by third-party energy providers	Utility supports system for customers to share data with third parties	Third-party energy service company ability to access Green Button data	Number of third parties that successfully access customer data through Green Button Connect or other utility data-sharing method; % of customers able to authorize third-party service company requests on first attempt (target: 95%); % of time third-party service provider receives access when authorized by customers (target: 95%)

Table 4. Goals, outcomes, and performance criteria and metrics associated with AMI deployment. ***Source:*** **Littell, Shipley, and O'Reilly 2019.**

Although we have yet to see the emergence of PIMs for leveraging AMI to advance energy efficiency, some of the customer engagement metrics proposed as earning adjustment mechanisms in New York's Reforming the Energy Vision proceeding could be relevant. These included metrics that measure increased customer engagement

[30] "Used and useful" is a standard for assets that are required and that operate in an effective and efficient manner (CPUC 2017).

through online portals, use of utility-provided data feeds, and use of download options, and metrics that measure the prevalence of customer-oriented products that use AMI data (New York PSC 2016).

Setting Performance Standards for Data Access and Energy Savings

Although there are operational benefits that accrue immediately upon deployment of AMI, most customer-focused benefits require further actions by utility regulators. In such areas as energy savings and data access, regulators can directly set standards for expected utility performance associated with AMI rollouts.

Despite the potential for energy savings and the limited application of AMI as a tool to support energy savings across US utilities, we saw few examples of state regulators requiring utilities to verify that they delivered peak kW or seasonal or annual kWh savings from AMI investments. Southern California Gas (SoCalGas) is a notable exception. In its 2010 approval of the utility's AMI proposal, the California Public Utilities Commission required that SoCalGas set a goal to save 1% of residential gas usage and that it track and attribute the conservation impacts of the AMI rollout, reporting every six months from August 2013 to February 2018 (CPUC 2010). The utility met this requirement through a combination of seasonal home energy reports targeted at winter heating and particularly cold-weather-sensitive customers, weekly "bill tracker alerts," and standard home energy reports (Schellenberg 2017). As shown in figure 6, the utility tested a wide variety of combinations, with successful results (greater than 1.0% savings) in some of the tests in the first two years of the program and savings greater than 1.4% in the last two program years (SoCalGas 2018). While the highest savings rates were beyond typical gas savings from home energy report programs, the average savings were close to typical. This suggests strong impacts for some individuals from the season-specific and end-use-specific messaging that required AMI data, but average savings overall, consistent with the discussion of feedback above.

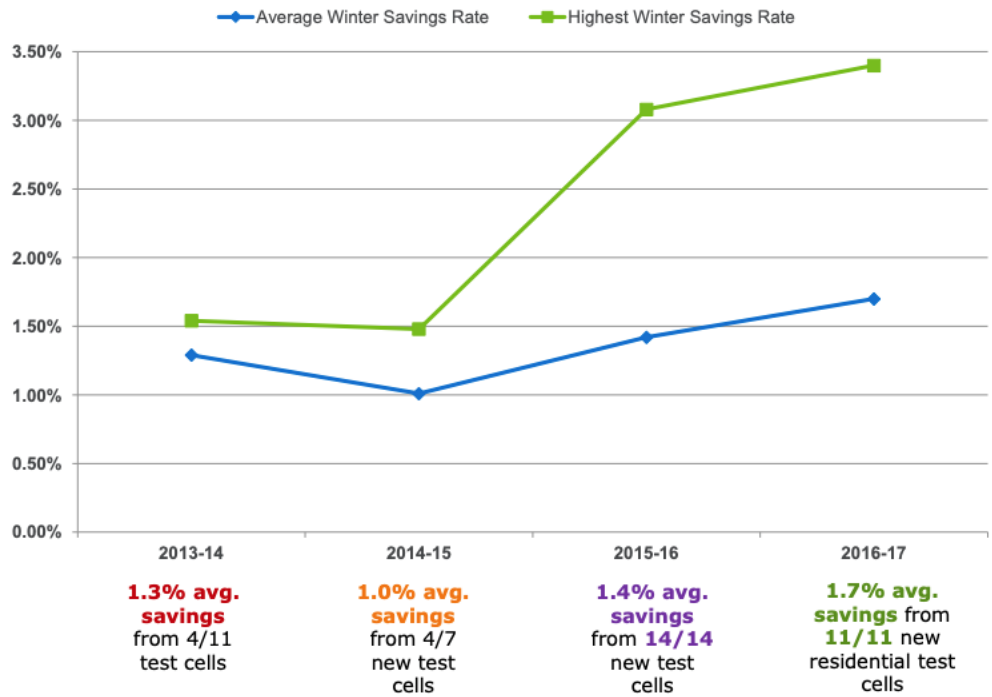

Figure 6. Average household savings from test cells in SoCalGas heating season–focused behavioral programs from 2013–2014 to 2016–2017 program years. *Source:* Schellenberg 2017.

Another form of performance standards are data access and customer privacy protections, which are critical to ensure that customers realize energy savings benefits from AMI. Customers and their third parties must be able to gain access to data in a timely fashion.

ACEEE's *State Scorecard* offers a road map for regulators to follow to enable interval data access, building on a framework created by Mission:data (Murray, Kier, and King 2017). First, regulators can require utilities to provide energy usage data to customers in a standardized electronic format, like Green Button Connect. Only six states have done so as of 2019 (Berg et al. 2019). Second, regulators can ensure that third parties have access to data by providing guidelines for how customers can share access. Sixteen states have such guidelines, and ten states require provision of individual energy usage data to third parties upon customer authorization (Berg et al. 2019). Finally, regulators can require that utilities provide aggregated data to owners of separately metered commercial or multifamily properties and public agencies, enabling benchmarking and identification of opportunities for energy efficiency improvements. Four states have such a requirement for multi-tenant building owners, and eight require utilities to provide this data to public agencies (Berg et al. 2019).

Encouraging Innovation to Leverage AMI

Much of the potential value from AMI derives from differences in the time and locational value of energy savings on the grid. Regulators will need to ensure that valuation and transaction mechanisms are available to unlock that value while protecting vulnerable customers.

Time-varying pricing can enhance the value of energy efficiency and peak demand reductions (Baatz 2017), enabling demand-side resources to lower system costs and customer bills. States without time-varying rates can leverage lessons learned from other states, focusing on designs that limit peak period duration and critical peak pricing period frequency, and coupling rates with communications that support responsive decisions and with technologies that automate customer response, such as programmable thermostats (Sherwood et al. 2016). Such rates primarily deliver peak demand reductions and system efficiency but also support some energy savings. Where utilities lack experience with such pricing, regulators can encourage or require pilots with defined plans for scaling based on lessons learned.

Similarly, regulators can use pilots and innovation plans to encourage utilities to test other use cases that leverage AMI, including targeting and segmentation, new ways of providing feedback, P4P, and grid-interactive efficient buildings. They can also pilot new M&V approaches alongside existing methods to understand their impact before rolling them out as the default method. These pilots can help address utilities' risk aversion and reluctance to innovate without preapproval (Fairbrother et al. 2017).

Conclusions and Recommendations

Technological advancements and market developments have fueled the rapid growth of AMI since the early 2000s. It is the foundation of the grid modernization needed to replace aging infrastructure and integrate DERs. The business case for AMI has relied primarily on operational benefits for utilities, which include:

- Reduced metering and billing costs
- Enhanced ability to detect, isolate, and respond quickly to outages
- Improved safety

The granular interval data provided by AMI also offer many potential advantages to energy efficiency, demand response, and bill management benefits for customers. AMI data can help utilities and third parties create better, more compelling, more cost-effective energy efficiency offerings by:

- Enhancing the quality of and insights from near-real-time feedback on energy consumption and using AMI data for behavioral feedback
- Providing time-varying pricing that reflects varying energy costs at different times of day and year. Near-real-time feedback, combined with communications and possible automation, can better inform and motivate customers to respond to pricing signals and change their energy use accordingly.
- Targeting energy efficiency and other demand-side programs, incentives, and services to those customers most likely to benefit from them
- Improved M&V, to support greater accuracy in impact estimates and more continuous learning through near-real-time feedback to program managers
- Promoting grid-interactive, efficient buildings that extract more grid value from customer programs by providing more flexible demand

- Supporting energy procurement and meter-based pay-for-performance programs that better align outcomes, address siloing between resources, and support acquisition of energy efficiency and other demand-side options as a resource
- Enabling conservation voltage reduction on electricity distribution networks to reduce demand and energy use

We find that many utilities are underexploiting AMI capabilities and its attendant benefits, thus missing out on a key tool to deliver value to their customers and systems. In particular, they underutilize AMI's ability to support customer energy efficiency through information, pricing, and technical assistance insights, and its ability to improve program design through targeting, P4P, and more robust evaluation. When they neglect to use AMI data, they also largely undervalue the potential grid benefits from efficiency programs in grid-interactive efficient buildings.

Some of AMI's benefits can be provided by other technologies like building energy management systems, home energy managements systems, smart thermostats, and other ownership models besides utility deployment. However only AMI appears to be capable of delivering all the use cases outlined for energy efficiency.

Utilities can learn from the experiences of other utilities in rolling out AMI and associated pricing and customer programs. One key to successful rollouts is customer engagement, beginning with market research, stakeholder and community outreach, and customer targeting. Continued engagement efforts include providing customers with education, accessible support, and personalized energy usage insights. Utilities need to clearly demonstrate and articulate AMI's benefits for their customers' energy use. They need to build a strong business case for both customers and regulators that tells a clear story about how AMI will be used to deliver customer benefits, including energy savings.

Another key to gaining the greatest benefits from AMI is to couple it with well-designed, customer-friendly time-varying pricing, including meaningful marketing and education for those rates. This structure gives customers the best opportunity to reduce costs by modifying their energy use. Time-varying pricing is also critical for grid flexibility; it sends appropriate price signals to customers about system costs at different times. These signals enable them to shape and shift load to optimize grid performance and reduce system costs.

AMI also can enable conservation voltage reduction as a means to reduce distribution power losses. The few successful examples of CVR demonstrate its effectiveness. We encourage greater use of this capability of AMI.

As utilities develop and implement AMI, they also need to include complementary investments to realize the full spectrum of customer and grid benefits. This may involve acquiring new areas of expertise, whether by internal staffing or contracting with qualified, experienced vendors. Key functions include data management and system integration.

Successfully leveraging AMI to advance energy efficiency also requires supportive regulation. Regulators should:

- Ensure that proposals by utilities for implementing AMI include and accurately quantify a full set of customer benefits, including saving energy and reducing costs
- Require utilities to demonstrate how they use AMI technology to help achieve customer energy efficiency
- Require that AMI cost recovery be contingent on delivery of benefits claimed in proposals.
- Create performance incentives or other mechanisms to align spending with desired outcomes, including energy savings, or processes, such as data access or use of AMI data for program design
- Support and approve time-varying pricing, such as TOU rates, in concert with AMI rollouts.
- Set standards or requirements to deliver the expected savings or other benefits from AMI
- Establish clear data access rules that ensure data security and provide options for customers, third parties, and residents in buildings served by multiple meters, such as many multifamily buildings
- Allow for pilots and innovation activities designed to test and scale applications that leverage AMI data for customers, the market, or the utility
- Encourage utilities to implement CVR as part of their AMI rollouts.

Rollouts are premised on the ability of this technology and associated systems to deliver benefits to customers and utilities, not the least of which is saving energy. To achieve this result, however, takes more than simply giving customers more detailed energy use data. Utilities must actively engage with their customers and offer them a range of services to support their energy savings investments and actions, such as behavioral feedback.

AMI is considered by many to be a foundation of grid modernization and all its many benefits to customers, grid operators, and resource providers. One such benefit that is currently underutilized is reducing energy use through increased energy efficiency of customer end uses and the distribution network. To realize this benefit, utilities need to fully leverage AMI as a powerful tool toward the many uses and applications for energy efficiency that can be advanced by AMI's data and communications capabilities.

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Appendix A. Interviewees

We interviewed each of the individuals below to gain background knowledge and confirmation of our primary desktop research. We gratefully acknowledge their contributions and note that these interviews do not imply affiliation or endorsement.

General Expertise

Advanced Energy Economy, Ryan Katofsky

US Department of Energy, Buildings Technology Office, Monica Neukomm, Johanna Zetterberg, Steve Dunn, Amy Jiron

Edison Electric Institute, Adam Cooper

Lawrence Berkeley National Laboratory, Peter Cappers, Annika Todd

Mission:data, Michael Murray

Plugged In Strategies, Chris Villarreal

Smart Energy Consumer Collaborative, Patty Durand, Nathan Shannon

Service Providers

Copper Labs, Dan Forman

Opower, Oracle, Marisa Uchin and JD Toppin

Recurve, Carmen Best

Uplight, Monty Prekeris and Bryan Dreller

Utilities and Program Administrators

Baltimore Gas and Electric, Leigh Jarosinski

Detroit Edison, Joel Miller

NYSERDA, Megan Fisher and Kyle Monsees

PECO, Mike O'Leary and Jeff Myers

PGE, Erik Cederberg and Kirk Page

VEIC, Dan Fredman

Appendix B. Use Case Definitions

Table B1 details use case definitions from the survey of electric utilities we used in this report and from the *2020 Utility Energy Efficiency Scorecard*. These descriptions represent publicly available data and program information from 2018, largely based on 2018 regulatory filings, 2018–2020 planning documents, and additional filings on utility and public utility commission websites. For utilities that do not operate on the calendar year, we used data from the 2017–2018 program year.

Table B1. Use case definitions

Program measure	Description
Energy use feedback to consumers in real time	Allowing consumers to better understand their behavior and adjust their energy usage to increase savings. Includes programs that provide feedback in near real time. Typically requires advanced metering infrastructure (AMI) installation.
Behavior-based feedback	Reducing energy consumption through social science theories of behavior change by providing information to customers, by leveraging interpersonal interactions, or by providing consumer education. Excludes programs that rely on traditional program strategies such as incentives, rebates, or regulations.
CVR or VVO	Improving the efficiency of a utility's transmission and distribution system through voltage reduction systems, whether explicitly included in the utility's energy efficiency portfolio or not.
TOU rates	Charging different prices for electricity during different times of the day and year.
GEBs	Incentivizing buildings that reduce energy waste and carbon emissions while offering flexible building loads to the grid. This may include integrating energy efficiency and demand response to better value the many benefits of grid-interactive efficient buildings.
Data disaggregation	Extracting end-use-level and/or appliance-level data from an aggregate or whole building energy signal to engage consumers and to target relevant programs to specific customers.

Source: ACEEE survey of top 52 electric utilities' energy efficiency offerings and performance in 2018