How Information and Communications Technologies Will Change the Evaluation, Measurement, and Verification of Energy Efficiency Programs

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Acknowledgments

Executive Summary

In recent years ACEEE has examined the benefits of intelligent efficiency, our term for the gains in energy efficiency enabled by the new responsive, adaptive, and predictive capabilities of information and communications technologies (ICT). Our research has described the scope of intelligent efficiency (Elliott, Molina, and Trombley 2012), provided quantitative analysis of potential economic impacts (Rogers et al. 2013b), examined its application to freight logistics (Langer and Vaidyanathan 2014), and discussed how it will affect the manufacturing sector (Rogers 2014). These analyses have uncovered the potential of ICT to change the way energy efficiency program administrators conduct evaluation, measurement, and verification (EM&V) on their efficiency measures, projects, and programs.

Energy efficiency programs exist to compensate for the market's failure to give value to the benefits provided to all system stakeholders by individual investments in energy efficiency. Programs encourage utility customers to invest more in energy efficiency, and the system benefits from such investments can contribute to a state's resource planning efforts. In this adjusted market structure, efficiency programs function as an alternative to conventional utility investment in generation, transmission, and distribution assets and contribute to lower system and individual customer costs.

Efficiency programs expend considerable effort forecasting future savings from the energy measures customers install and later verifying that those savings have occurred. This can be a challenging, time-consuming, and expensive process. As a result, programs are continuously seeking ways to improve the accuracy and efficacy of their evaluation efforts.

Utility programs that try to affect customers' energy use fall into two categories: demand response and energy efficiency. Demand response programs focus on reducing system peak use, while the intent of energy efficiency programs is to reduce system load throughout the year. It is the latter that is the focus of most EM&V activities. Three types of programs are likely to benefit from ICT-enabled EM&V: prescriptive programs that set financial incentives per device installed, custom programs that target larger and more complicated projects with incentives tied to the volume of savings, and energy management programs that provide worker training and establish systems to manage energy consumption. Each type of program takes a different EM&V path to determine energy savings and program effectiveness. The EM&V employed in custom programs differentiates even further, depending on whether a given program targets the residential, commercial, or industrial sector. Custom programs will benefit most from the introduction of ICT-enabled EM&V.

All program types fit within a common programmatic structure, starting with individual energy measures and projects facilitated by programs that are part of larger program portfolios. EM&V is performed at each level and on most sector participants. The efficacy of program administrators and implementers is measured with the same thoroughness as efficiency measures and projects.

The overriding purpose of EM&V is to determine success in reaching energy savings goals. Secondary objectives include determining the cost effectiveness of efficiency programs, learning what works and what doesn't, and predicting future energy consumption trends.

This is accomplished through standard protocols that can involve any combination of utility bill analyses, field measurements, control groups, computer simulation, and end-user surveys and interviews. It is likely that ICT has the potential to improve each of these methodologies, either directly through new and improved capabilities or indirectly through changes to the energy sector.

Many energy-consuming devices such as lighting systems, chillers, fans, and pumps are now manufactured network-ready, with the ability to communicate with building management and process management systems. Devices and systems throughout a facility can communicate with one another via wireless networks and export their information to remote operators through the Internet. Cloud computing enables the manipulation of such field data remotely and inexpensively.

Smart meters are the most visible component of the smart grid, which enables bidirectional communication between utilities and customers. Interval energy data reported by these meters have become foundational to new analytic techniques such as remote building analysis and nonintrusive load monitoring. These new data analysis engines are enabling program administrators to identify customers with the greatest potential to save energy and simultaneously identify potential energy efficiency measures. As measures and projects are implemented, ICT-enabled EM&V techniques enable implementers to monitor energy savings as it happens (or does not) and make adjustments to maximize program success.

The availability of performance information through smart meters and smart devices reduces the need for onsite visits and measurement by implementers and evaluators. The same energy data streams that are used by customers to run their organizations can also be used by implementers to monitor project performance and by evaluators to measure program performance. These data streams can also be used to measure the persistence of energy savings, thereby improving program administrators' understanding of the efficacy of various energy measures.

Some types of evaluation are well suited for automated data collection and analysis, while others are not. Software as a service (SaaS) companies are having great success measuring the impact of residentially focused programs. By contrast, the determination of energy savings from custom projects in the industrial sector will continue to require onsite measurement and analysis by knowledgeable technicians.

The policy challenges of net versus gross savings will not go away with the addition of ICT. And issues related to data ownership, access, privacy, and security are likely to persist for a while. Other policy issues include the need for agreement on confidence levels, recovery of ICT infrastructure costs, and standardization of EM&V protocols across service territories and state lines.

Technical challenges will be related to the establishment of common measurement and communications protocols, the definition of terms, the sufficiency of skilled workers, and the overwhelming volume of information, which raises the classic challenge of distinguishing the signal from the noise. What information is needed for EM&V, and how much is enough?

The introduction of ICT to the management of the grid and the determination of energy savings opens up new methods for mitigating the market's failure to properly value energy efficiency. Efficiency programs may restructure to purchase energy efficiency as a commodity that can then be traded in regional capacity markets. More sophisticated customers may bypass programs and monetize that value themselves. Alternatively, utilities may bypass markets and send pricing signals directly to customers, who in turn will respond as their individual evaluation of energy dictates.

The complexity of the efficiency program sector means that a collective effort by all stakeholders is necessary to fully realize the potential of ICT to improve EM&V. Pilot programs and demonstration projects are good first steps to get the process started. Stakeholders should work together to determine if existing policies are still appropriate or if they are inhibiting innovation and market growth. Regulators should give administrators flexibility to experiment and invest in new technologies. Administrators should use this flexibility to learn where they can add value and improve the quality and efficacy of EM&V.

The energy efficiency sector has long sought the ability to measure energy savings as they happen. While this has not been fully realized, we are getting closer. ICT is simplifying the harvesting of savings data, improving the quality of analysis, and increasing the timeliness of reporting. All of these features improve energy efficiency programs and enable energy efficiency markets. By extension, they contribute to greater energy savings throughout the economy.

Introduction

More than $7 billion of utility customer funds is spent on energy efficiency programs each year (Gilleo et al. 2015). These investments result in 25.7 million megawatt-hours in energy savings and 374 million therms in reduced consumption of natural gas. Efficiency programs expend considerable effort forecasting future savings from the energy measures customers install and later verifying that those savings have occurred. This can be a challenging, time-consuming, and expensive process. As a result, programs are continually seeking ways to improve the accuracy and efficacy of their evaluation, measurement, and verification (EM&V) efforts and to reduce the cost of this necessary expense.

In recent years ACEEE has examined the benefits of intelligent efficiency, our term for the gains in energy efficiency enabled by the new responsive, adaptive, and predictive capabilities of information and communications technologies (ICT). Our research has described the scope of intelligent efficiency (Elliott, Molina, and Trombley 2012), provided quantitative analysis of potential economic impacts (Rogers et al. 2013b), examined its application to freight logistics (Langer and Vaidyanathan 2014), and discussed how it will affect the manufacturing sector (Rogers 2014). These analyses have also uncovered the potential of ICT to change the way energy efficiency program administrators conduct EM&V on their measures, projects, and programs.

Rapid advances in sensors, smart devices, energy management systems, and smart grid infrastructure have led to a massive increase in energy data production. Energy efficiency sector stakeholders are beginning to use data analytics and machine learning to turn the data from these devices into information, and information into knowledge that can be acted upon.[1] ICT has already improved their ability to identify opportunities to save energy. Now program administrators, implementers, and evaluators are testing ICT systems that calculate, track, and document energy savings and provide near-real-time feedback on program participation and effectiveness (Grueneich and Jacot 2014).

Our analysis begins with a summary of current EM&V practices and continues with an examination of how ICT will sustain and improve them. We also discuss several of the major challenges to the more widespread use of ICT for EM&V. Later in this report we explore the potential of ICT to transform the sector by creating dynamic energy-use baselines, opening up markets, and enabling customers to monetize the value of their energy efficiency investments. We conclude with an analysis of the implications for energy efficiency programs, practices, and policies and provide recommendations for actions that can facilitate the transition to ICT-based EM&V.

Energy Efficiency Programs in the Utility Sector

Before proceeding with an explanation of emerging technologies and how they are likely to change the energy efficiency sector, a review of the current structure of energy efficiency

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[1] Data analytics is the science of examining raw data with the goal of drawing conclusions about that information. Machine learning is a subfield of computer science that evolved from the study of pattern recognition and computational learning theory in artificial intelligence.

programs is in order. This will be a primer for those not already familiar with the sector, and for those already engaged in utility energy efficiency efforts, it will establish the definitions we intend to use going forward in this report.

Utilities often improve the capacity and efficiency of their generation, transmission, and distribution assets. Such efforts are called supply-side projects. Investments that improve the way energy is used by a utility's customers, the end users of the energy, are referred to as demand-side projects. A majority of states have determined that a cost-effective method to meet existing and future power needs is to invest utility customer funds in demand-side rather than supply-side resources. These states recognize that demand-side energy efficiency programs can mitigate the need to build conventional utility infrastructure such as a power plants and transmission lines.

Saving energy has a collective value in addition to the value realized by the individual customer. It benefits all utility customers and all stakeholders by bringing down overall system costs and improving system performance (Baatz 2015). The fact that this value is not normally recognized can be viewed as a market failure. Energy efficiency programs have been developed to compensate for this market failure.

Efficiency programs provide technical and financial assistance to customers and their supply chains to encourage them to make greater investments in energy-efficient products and practices. They work by overcoming the barriers customers face, including their limited knowledge of opportunities, ability to execute, and availability of funds, as well as competing priorities.

To put it another way, there are many investments in energy efficiency that end users might make if they were fully aware of their options. Or users might consider an investment and conclude that the energy cost savings are insufficient to justify it. These are the projects that program administrators hope to encourage, because they could yield savings that would otherwise not come to pass. Most programs do not pay for an entire energy measure but instead provide a financial incentive large enough to encourage customers to do something they had not planned to do (Rogers et al. 2013a).

PROGRAM TYPES

Demand Response versus Energy Efficiency Programs

Utility sector programs that attempt to affect the near-term energy use of utility customers can be separated into two categories: demand response and energy efficiency. Though there are synergies in the benefits of these two types of programs, they serve distinct purposes.

Demand response programs are intended to reduce peak consumption within a service territory. Each utility has a finite amount of generation (for electricity) and transmission (for electricity or natural gas) capacity to serve its customers. In order to ensure that the maximum demand for energy does not exceed its available supply, a utility implements programs that allow it to shed customer load during periods of peak demand.

One method utilities use to reduce peak demand is to call on certain large customers to reduce their usage during emergencies such as extreme weather events. Historically, these

programs function mostly through rate design. In certain customer class rates, there are clauses that exchange preferential commodity pricing for the ability to, with notice, curtail a customer's supply of energy. On a hot summer day, an electric utility will alert its larger customers that they must turn off equipment equal to a set amount of kilowatts (kW). If they do not, depending on the utility, they must either pay a fine or pay for the utility to purchase supplemental power on the wholesale market. In the case of a natural gas utility, it may limit the amount of gas a commercial customer can pull from its pipeline on a cold winter day when residential heating is a priority.

Since the 1970s, there have been programs that automatically reduce the loads of smaller customers. Often referred to as direct load control, these programs enable utilities to turn down or turn off customer devices such as air conditioners and electric water heaters in order to reduce system load during periods of peak demand.

By contrast, energy efficiency programs do not simply reduce usage during periods of peak demand; they also reduce the amount of electricity or natural gas a utility must supply throughout the year. The result is that more customers can be added without having to expand existing infrastructure.

Three Types of Energy Efficiency Programs

Three common types of efficiency programs that are likely to benefit from ICT are prescriptive, custom, and energy management programs.

Prescriptive programs provide financial incentives for qualifying equipment such as high-efficiency lighting or appliances. The two most usual incentives are rebates paid directly to the utility customer, and upstream incentives that provide funds to vendors who will in turn discount their prices.

In many prescriptive programs, the amount of energy savings derived from the equipment being installed is commonly "deemed" by program regulators—that is, set on the basis of field data collected from a sample of customers. Deemed savings values are prescribed in a database or technical reference manual (TRM) developed or adopted by a state utility regulator and periodically updated (York, Kushler, and Witte 2007).

Custom incentive programs offer financial incentives to customers for projects that are too complicated to take advantage of prescriptive rebates, or where the potential for larger savings justifies the additional cost of project engineering and measurement of actual energy use. These projects can include new construction, facility upgrades, and the retrofit or replacement of a building's equipment or a production process. The amount of financial assistance may be related to the amount of energy saved, or it may be a percentage of the overall project cost. When based on energy savings, the common method is to set a per-unit-of-energy-savings incentive amount ($/kWh of electricity or $/therm of natural gas) and calculate the total amount of the incentive by multiplying this value by either the estimated potential energy savings or the actual measured savings.[2] There is usually a cap on the

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[2] Estimated potential energy savings are referred to as *ex ante*; actual measured savings, as *ex post*.

amount of the payout based on available funds or a percentage of overall project cost (Rogers et al. 2013).

Energy management programs help medium and large customers to implement initiatives that establish a systematic process for continuously improving the use of energy.[3] They involve worker education and skills training, and they often include software that is used to collect energy consumption and savings data. Two examples of energy management standards are the standard for energy management ANSI/MSE 2000:2008 developed by the American National Standards Institute (ANSI), and the international version, ISO 50001, developed by the International Standards Organization (ISO). Both of these standards are built on the principles of promoting best practices and seeking continual improvement. Some energy management programs are based on one of these standards; others are based on independently developed protocols. Organizational standards such as ISO 50001 do not require software but can certainly benefit from the automation ICT makes possible.

Energy management programs in the Pacific Northwest have developed the Strategic Energy Management (SEM) program involving workforce education, training, and organizational culture change. Its structure is derived from continuous improvement programs such as Total Quality Management (TQM), Six Sigma, and Lean Manufacturing. It incorporates the "plan, do, check, act" approach that has been successfully applied to quality improvement in manufacturing systems, such as ISO 9001, and for environmental performance, such as ISO 14001 (Kolwey 2013). Some recent SEM programs have included energy management information systems (EMIS) as part of their engagements. These software tools enable customers to automate the collection, storage, analysis, transmission, and display of their energy consumption data.

Energy service companies (ESCOs) also run a type of energy management program whereby they work directly with customers on a contractual basis, guaranteeing a certain amount of savings over a certain period of time. Since the savings are guaranteed, the accuracy of savings estimates is very important. ESCO performance contracts often fall outside customer-funded energy efficiency programs and thus do not require utility or regulator involvement.

NOMENCLATURE

Energy efficiency *measures* (EEMs) are the nuts and bolts of efficiency efforts. A measure may be a device (e.g., high-efficiency lighting), a control technology (e.g., a smart thermostat), or a practice (e.g., precooling). *Projects* are collections of measures at a single facility or site (e.g., a home retrofit). *Programs* are prolonged efforts by an organization or collaborative of organizations that encompass a group of projects with similar characteristics and applications (e.g., an initiative to install advanced HVAC in commercial buildings). Finally, *portfolios* are collections of programs (SEE Action 2012). This hierarchy is depicted in figure 1.

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[3] For the purpose of this report, a small customer receives single phase power, a medium customer is covered by a rate for three-phase distribution-level power, and large customers are served at transmission grade.

Figure 1. Hierarchy of energy efficiency efforts.
Source: Slote, Sherman, and Crossley 2014.

Utilities may operate energy efficiency programs on their own or subcontract them to a third-party administrator. In this report, we will refer to the organization responsible for managing an efficiency program as a *program administrator*. Administrators often have a portfolio of different types of programs. They may implement some or all of them themselves, or they may contract out the day-to-day operation of a program to an *implementer*. Implementers seek out customers with the potential to save energy, encourage them with financial and technical assistance, and implement projects at the customers' facilities. *Regulators* oversee the activities of utilities and program administrators through the reports provided to them by program *evaluators*. Almost 80% of states outsource their program evaluation work to private consultants and contractors (Kushler, Nowak, and Witte 2012).

Conventional EM&V

This section gives a quick tour through the intricacies of energy efficiency program EM&V in order to see just what it is that ICT might eventually transform. The discussion is based on the *SEE Action Energy Efficiency Program Impact Evaluation Guide* (SEE Action 2012) and other sources as noted. For a more comprehensive analysis of EM&V practices and policies, see Kushler, Nowak, and Witte 2012. Readers already familiar with this subject may want to jump to the discussion of data collection on page 13.

Energy efficiency initiatives are designed to save energy. The overriding purpose of EM&V is to determine their success in reaching that goal. More particular objectives include the following:

- Help design, plan, and carry out effective energy efficiency initiatives
- Determine the energy savings and cost effectiveness of efficiency programs, in order to show in regulatory proceedings that public and ratepayer funds were properly spent
- Improve efficiency programs so that they grow in number and scope and save more energy

As shown in table 1, various stakeholders apply EM&V to measures, projects, programs, and portfolios at various stages of their planning and implementation. We discuss each type of EM&V later in this section.

Table 1. EM&V stages

Stage	Type of EM&V	Stakeholders	Purpose
Planning	Potential study Market assessment Feasibility study Setting deemed savings* Forecasting savings Determining baseline	Administrators and implementers	Determine opportunities and potential customers for energy savings. Establish deemed savings values. Set savings targets. Determine energy use baseline against which savings will be measured.
Implementation	Process evaluation	Implementers	Make midcourse corrections.
Evaluation	Verification of measures Impact evaluation Cost-effectiveness testing	Evaluators and regulators	Ensure effective use of public funds. Learn lessons to apply to future programs.

* Deemed savings are preestablished values for the energy savings of a particular measure. For example, on average, a CFL may be deemed to save a certain number of kWh over a certain number of years compared with an incandescent bulb.

In a certain sense, all EM&V is driven by the last stakeholders in table 1. Regulators are charged with ensuring that utilities are operated in a safe, reliable, and fair manner and that the costs they incur in fulfilling their obligation to serve are just and reasonable (RAP 2011). These costs include expenditures on ratepayer-funded energy efficiency programs. To have confidence that investments in end-user efficiency have the desired effect, public utility commissions (PUCs) require administrators to determine the level of savings from efficiency programs, usually through independent third-party evaluators.

NOMENCLATURE

Before going further, it may be useful to unpack the meanings of the acronym *EM&V* in terms of this framework. Strangely, it is most useful to start at the end of the acronym and work backward. Verification (the *V*) is the least ambiguous of the initials. Once the program is under way (and sometimes only at the end), program personnel and third parties verify that the energy efficiency measures have been installed and are operating properly. Measurement (the *M*) involves measuring the energy savings of particular projects. This is not a single, simple activity but a complex process that lies at the heart of EM&V and is the most fertile ground for ICT enhancements. *M* and *V* are often bundled into the term *M&V*, which sometimes signifies all the nuts-and-bolts work of determining energy savings. Alternatively, to make things more confusing, *M&V* also signifies one of three particular approaches to calculating energy savings, as distinct from deemed savings and control groups.

What remains is evaluation (the *E*), which is frequently distinguished from M&V in a couple of ways. First, the term often signifies the later stages of the EM&V process (for example, an impact evaluation and especially its last step, cost-effectiveness testing). Second, practitioners generally conduct M&V on projects (collections of measures in a single facility). Evaluators, on the other hand, evaluate programs (groups of similar projects) and portfolios (collections of programs). Unfortunately, these neat distinctions often break down in practice. The term *evaluation* sometimes expands to encompass M&V, as when we speak of a process or impact evaluation whose steps include measurement and verification. In short, the evaluation of a program sometimes signifies a later, discrete step in a process that begins with the M&V of its constituent projects, and it sometimes means the entire process, of which M&V is a part.

PLANNING STUDIES AND PROCESS EVALUATIONS

With that out of the way, we can return to the actual landscape of EM&V. Energy efficiency programs begin as possibilities for energy savings identified in *potential studies*. Utilities undertake the former to assess the potential energy savings and other benefits from future energy efficiency programs, often stretching out to a 10-year horizon. (See Neubauer 2014 for a detailed discussion of potential study methodology.) To begin designing particular programs, utilities undertake *market assessment* and *feasibility studies*. These assess the potential for energy savings among possible customers, based on their current energy usage and the measures that may be applied to it. Prior evaluations may already have determined the savings that can be expected from some of these measures and other benefits. These *deemed savings* can become the basis of *savings forecasts*, a key component of energy program planning.

In the absence of deemed savings values, administrators must collect and analyze facility-based data to determine what level of energy savings and other benefits can be expected from a proposed project. To simplify, they often estimate savings by subtracting forecasted energy use during the project period from a business as-usual-baseline. It is no trivial task, however, to calculate this baseline as well as the adjustments that may be necessary to account for changing conditions (e.g., weather) during the project period. This is one of the most fertile areas for ICT enhancements.

Once a program is under way, implementers frequently undertake process (sometimes called formative) evaluations to assess program operations and identify opportunities for improvement. This may involve M&V of measures, their savings, and other benefits, as well as an assessment of program administration and customer satisfaction. The aim is to make midcourse corrections so that the program can realize its full potential.

IMPACT EVALUATIONS

This brings us to the center of the EM&V process, a multistage impact evaluation of an energy efficiency program comprising the following steps:

1. Verify implementation
2. Determine first-year energy savings using one of these approaches:
   a. Deemed savings
   b. Comparison groups
   c. M&V
      Option A: Single-parameter measurement
      Option B: All-parameter measurement
      Option C: Whole-facility measurement
      Option D: Computer simulation
3. Calculate first-year net savings
4. Determine lifetime savings
5. Quantify multiple benefits
6. Determine cost effectiveness

Verification

As discussed above, verification involves confirming that each project's measures have been installed, are up to specification, and are working as designed. This confirms the project's potential to save energy and usually is done through field inspections and examination of program-tracking databases.

Determining First-Year Savings

Determining first-year energy savings is the key to successful EM&V. But since savings cannot literally be measured, the *SEE Action Energy Efficiency Program Impact Evaluation Guide* states:

> [S]avings are estimated to varying degrees of accuracy by comparing the situation (e.g., energy consumption) after a program is implemented (the reporting period) to what is assumed to have been the situation in the absence of the program (the "counterfactual" scenario, known as the baseline). For energy impacts, the baseline and reporting period energy use are compared, while controlling (making adjustments) for factors unrelated to energy efficiency actions, such as weather or building occupancy. (SEE Action 2012, xv)

DEEMED SAVINGS

We have already referred to deemed savings, the first and simplest approach to determining energy savings. Deemed savings values stipulate the amount of energy saved per single unit of an installed measure. In this approach, reporting-period energy use is not directly measured; practitioners simply verify the number of measures implemented and operational and then multiply that number by the deemed savings value.

Deemed savings are most often used in projects with well-documented measures, e.g., appliances. In many cases the savings values are stipulated in a database determined by a neutral third party; this source is usually codified in the regulatory order authorizing the creation of a program. For example, the California Energy Commission (CEC) and the California Public Utilities Commission (CPUC) sponsored the creation of the Database for Energy Efficient Resources (DEER), which provides well-documented estimates of energy

and peak-demand savings values (CEC 2015). The values in this and other databases ultimately derive from previous evaluations and studies involving actual measurement and analysis.

The deemed savings approach makes it relatively easy and inexpensive to determine program savings. However, since the savings are estimated, stakeholders cannot determine the actual program impact, which could be more than or less than the predicted results. Some programs address this issue by calibrating values as new information is collected. In these cases, they take "before" and "after" measurements from a sample of projects and use the actual values to establish future deemed values—or, in some cases, apply these values retrospectively (Kushler, Nowak, and Witte 2012).

COMPARISON GROUPS

Comparison groups are a more elaborate way of determining energy savings and can result in a more informed understanding of program-induced energy savings. The SEE Action guide distinguishes between two kinds of control groups. Randomized controlled trials (RCT) randomly assign customers to either the treatment group, whose members participate in the program, or a comparison group, whose members do not participate. Quasi-experimental methods (QEM) use a comparison group that has not been randomly selected. Both methodologies compare the energy use of a control group not involved in program activities with that of efficiency program participants. Evaluators collect energy consumption data for both groups and calculate the difference between the two sets of data. Both comparison-group approaches require a relatively large and homogeneous population of energy users. They are most often used in residential programs, since they involve so many customers, usually with a limited number of energy consumption profiles.

Of the two kinds of control groups, RCT tends to be more accurate in assessing savings, but it can be time consuming and expensive. In addition, it cannot be applied to full-scale programs since it requires random assignment to participant and control (nonparticipant) groups, whereas with full-scale programs everyone is eligible to participate.

The simplest QEM approach is the pre/post method, which compares the energy use of program participants before and after the program; in effect, participants become their own control group. Another methodology, matched control groups, constructs a nonrandom control group made up of customers who are as similar to the treatment group as possible. The matched group can be program nonparticipants who are similar to participants in many respects, or it can be later participants in the program. The latter approach takes advantage of customers' opting into or out of a program to create a comparison group.

M&V

M&V, the third approach to calculating first-year energy savings, can be the most expensive and elaborate, so it is usually applied only in the absence of deemed savings values or comparison groups. It is often used in connection with custom programs for large facilities whose energy use patterns are idiosyncratic and for which a comparison group is not possible. As discussed later, ICT may be particularly applicable in this area, as it has the potential for cost-effectively collecting and analyzing complex facility-level and measure-specific data.

The M&V-based determination of energy savings is based on the following formula:

Energy savings = (Baseline energy use) – (Reporting period energy use) ± (Baseline adjustments)

Baseline adjustments account for variables that might influence energy use during the reporting period but that are independent of program activities. These might include weather conditions, changes in building occupancy, and production levels. By applying these adjustments, evaluators can bring the same set of conditions to energy use in the pre- and post-implementation periods, so apples can be compared with apples.

Another important M&V consideration is the measurement boundary. Are energy use and savings being measured for a single piece of equipment, a system, or an entire facility? This boundary needs to be clearly defined from the outset, and pre and post energy use confined to it. A lighting retrofit, for example, can save energy not simply by drawing less power but by generating less heat and thus reducing HVAC load. Evaluation could be skewed if the lighting system is the measurement boundary used in the savings forecast but actual savings are subsequently calculated for the whole facility.

FOUR M&V OPTIONS

Four alternate options for conducting M&V are offered by the International Performance Measurement and Verification Protocol (IPMVP) (EVO 2014). Currently adopted by many states, this protocol was developed by a coalition of international organizations in the mid-1990s. It is commonly employed in ESCO performance contracts and is now also used by many third-party utility energy efficiency program evaluators (Slote, Sherman, and Crossley 2014). The options vary in terms of the measurement boundary and the method used to quantify the savings value.

IPMVP *Option A* and *Option B* use engineering models to (1) calculate energy consumption for a project end-use like a lighting system or a ventilation system, and (2) estimate savings by changing the model parameters that are affected by energy efficiency program. Parameters include (1) operating characteristics of the systems or facilities where the measures are installed (e.g., power draws of fan motors, efficiency of air conditioners), and (2) equipment operating hours and loads (e.g., how long the fan motor runs, air conditioners' load in tons). In Option A, only one of the key parameters need be measured directly during the baseline and reporting periods; the others are stipulated based on assumptions or analysis of historical facility data or on manufacturers' data on the affected baseline and/or equipment. In Option B, all the parameters affecting energy savings are actually measured rather than stipulated. Both options involve short-term or continuous measurement of both baseline and reporting-period energy use.

Option A suffices for projects in which a single parameter constitutes a substantial portion of the savings uncertainty, for example operating hours in a lighting retrofit. B is more suitable for system retrofits (e.g., a chiller) whose parameters are variable and complex in their interactions. As compared to A, Option B involves a trade-off. On the one hand, difficulty and cost increase with measurement complexity and savings variability; on the other hand, the more parameters that are measured directly, the greater the reliability of the savings determination. As we will discuss in later sections, this is fertile ground for the application of ICT.

Rather than focusing on energy efficiency measures, IPMVP *Option C* uses whole-building meters (usually the ones used for utility billing) to measure the energy use of an entire building or facility. Option C compares energy consumption during the reporting and baseline periods, usually using 9 to 12 months of monthly data for each. In addition, implementers monitor all independent variables that affect energy consumption during the performance period, including weather, occupancy, throughput, and operating schedules. Multivariate regression analysis factors these variables into the savings determination.

Since random or unexplained energy variations are normally found at the whole-facility level, Option C is most applicable to projects like whole-building retrofits with large energy savings. According to SEE Action:

> The larger the savings, or the smaller the unexplained variations in the baseline consumption, the easier it will be to identify savings. In addition, the longer the period of savings analysis after project installation, the less significant the impact of short-term unexplained variations. Typically, savings should be more than 10% of the baseline energy use so that they can be separated from the "noise" in baseline data. (SEE Action 2012, 4-6)

Finally, *Option D* forgoes direct measurement for computer simulation of system-level or whole-building energy consumption during the baseline and reporting periods. This energy-use simulation is calibrated with hourly or monthly utility billing data. Option D typically involves whole-building analysis tools that model lighting, heating, cooling, ventilation, and other energy flows. That is, it is heavily dependent on the ICT capabilities we describe later in this report.

Net versus Gross Savings

Variables external to a program that may affect energy use can lead to over- or underreporting of energy savings. Regulators often require programs to identify them and make appropriate adjustments. Thus, once the gross first-year energy savings have been determined, the next step in a complete impact evaluation often involves determining the net value of the savings.

Not all of the first-year savings can be attributed to the program's operation; for several reasons, some of the savings would have occurred even if the program were not operating. First, some customers would have implemented the same or similar measures without the program's being in place. These customers are often referred to as free riders. The energy saved by free riders must be subtracted from the gross savings to arrive at the savings actually attributable to the program. Similarly, the program may inspire both participants and nonparticipants to take other efficiency actions that lie outside the program's domain, neither subsidized nor required by it. These spillover savings must also be calculated and added to program-bounded values to arrive at the net program savings.

Market effects are a final factor. These are energy savings that come about as a result of changes in the market (e.g., a new tax policy) that affect the energy consumption of both participants and nonparticipants. See Kushler, Nowak, and Witte 2014 for a full discussion of free riders, spillover, and market effects.

In terms of the comparison group approaches discussed above, matched control groups can account for free riders and some market effects, but not as well as RCT methods. Yet not even RCT can address spillover and market effects that extend outside the control group, such as impacts on manufacturers and on other regions outside the test area.

Net-versus-gross calculations may involve complex algorithms and depend on extensive data, and they usually require surveys and interviews with end users (Mikhail Haramati, industrial engagement manager, Opinion Dynamics, pers. comm., April 14, 2015). They are certainly necessary to determine net savings for the M&V approach discussed above. Deemed savings values, on the other hand, may already include net-to-gross ratios, in which case the deemed savings will already be net and no further calculation is required. (Of course the studies on which deemed savings are based and updated must still do this work.) Finally, control group results may be either gross or net; if the former, this further discrete step is required to reach net values.

There is considerable disagreement in the energy efficiency sector on the need for and value of differentiating net from gross savings. Some regulators are concerned with the issue and are quite specific in the requirements they set for the determination of net savings. Others believe that the costs of free ridership are compensated by the benefits of spillover and that positive and negative market effects cancel each other out.

Measure-Lifetime Benefits

The next step is to determine the savings expected over the lifetime of the program measures. This is usually a simple calculation whereby the first-year savings are multiplied by the expected measure life. Again, however, the measure life does not come out of nowhere; it is based on prior studies that have collected and analyzed relevant data over long periods. As we will discuss, ICT can enhance such data gathering and analysis.

Multiple Benefits

The penultimate step is to identify and quantify the multiple benefits of the program beyond just energy savings. Accruing to program participants, utilities, and society as a whole, these benefits (sometimes called nonenergy benefits) may include occupant comfort, health, and safety; productivity enhancements for business; reduced system costs for utilities; and avoided emissions.[4] Since these benefits are an essential part of the value created by the program, they should be recognized and measured, and their value should be added to the value of energy savings. This quantification may depend on prior studies or may need to be performed by program evaluators.

Cost-Effectiveness Testing

Not taking multiple benefits into account skews the final step in an impact evaluation: cost-effectiveness testing. This activity usually involves third-party evaluators as it often figures

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[4] For a full discussion of multiple benefits, see four recent ACEEE papers: *Multiple Benefits of Multifamily Energy Efficiency for Cost-Effectiveness Screening* (Cluett and Amann 2015), *Multiple Benefits of Business-Sector Energy Efficiency: A Survey of Existing and Potential Measures* (Russell 2015), *Everyone Benefits: Practices and Recommendations for Utility System Benefits of Energy Efficiency* (Baatz 2015), and *Recognizing the Value of Energy Efficiency's Multiple Benefits* (Russell et al. 2015).

in regulatory proceedings. How do the quantified benefits of the program stack up against its costs? This is the ultimate measure of energy efficiency's value as compared with other energy resources, both demand and supply side. Evaluators may apply one or more of five standard cost-effectiveness test methodologies to arrive at a final result, one of which, the Total Resource Cost Test, is specifically designed to include multiple benefits.[5] Several recent ACEEE reports have stressed the importance of including all multiple benefits in cost-effectiveness calculations. A test is unfair if it weighs all of the costs of a program against only some of its benefits.

COST OF CONVENTIONAL EM&V

M&V for custom program projects has historically been a manual process. It has involved dispatching people to customer locations to verify installation, installing portable meters to take measurements, setting up spreadsheets to record and analyze energy data, and manually creating detailed reports to document all of the above.

Such a labor-intensive effort can be expensive. M&V for a single project can range from $5,000 to $50,000 (Nagappan 2012). The US Department of Energy's Federal Energy Management Program M&V Guidelines for performance contracting projects estimate the average, all-in cost of M&V ranges from 3% to 5% of total project costs (DOE 2008). A review of the evaluation costs for large demand-side management portfolios found that they range from 2% of portfolio costs in Indiana to 4% in California (Haeri 2014).

The cost of conventional EM&V varies with the frequency, complexity, and scope of data collection and analysis. Depending on the desired level of certainty in the results, measurements may be taken on an entire system or a single parameter, on every measure or a sampling of projects, more or less often, and for longer or shorter periods. As we discuss in later sections, ICT may be able to change this calculus and enable stakeholders to collect and analyze more savings data, achieve greater certainty, and incur lower costs.

ICT Tools for Gathering and Analyzing Energy Data

The past decade has seen the development of a number of technologies that utilities are trying to harness for efficiency program EM&V. Smart meters, smart thermostats, building management and process control systems, cloud computing, the Internet of Things (IoT), and remote analytics all offer new capabilities for gathering and analyzing energy data.

SMART METERS AND THE SMART GRID

The Energy Independence and Security Act of 2007 has encouraged the development of the smart grid, increasing the use of digital information and controls technology on the utility side of the meter to improve the electric grid's reliability, security, and efficiency (FERC 2014). Smart-grid infrastructure like smart utility meters can remotely collect detailed data on customer energy use. These meters are currently being installed on residential,

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[5] The five standard cost-effectiveness tests are: Total Resource Cost Test (TRC), Utility/Program Administrator Test (UCT/PACT), Participant Cost Test (PCT), Ratepayer Impact Measure (RIM), and Societal Cost Test (SCT). For a full discussion of evaluation methodologies, see Kushler, Nowak, and Witte 2012.

commercial, and industrial customers' buildings. As of 2014, more than 50 million smart meters had been installed nationally, a number that includes more than 43% of all US homes (IEI 2014).

Advanced metering infrastructure (AMI) uses various communication protocols to facilitate two-way communication between smart meters and the grid infrastructure. Smart meters are usually the first component of AMI deployed by an electric utility in a smart grid rollout (EPRI 2011). Unlike conventional meters, which must be manually read, smart meters can automatically provide very high-resolution interval data (with readings every quarter-hour, say, or even every few seconds), usually communicating through a utility's wireless network (Eckman and Silvia 2014). Meters with the ability to provide interval data have been around for some time but were previously restricted to research projects and to larger customers that had special time-of-use rates that justified their installation.

Utilities have a communications network overlaid on their distribution system, and meters are connected to it conventionally or via a wireless interface. AMI communications systems are usually highly secure (encrypted) and redundant and have the ability to automatically reconnect, or self-heal, when disrupted. AMI includes the software needed to enable communication among smart meters, utility distribution systems, and customers' energy management systems (Gellings 2011).

To facilitate the use of data analytics to improve the use of energy, the Department of Energy (DOE) created the Grid Modernization Laboratory Consortium, comprising representatives from several of the department's programs and national laboratories. One participant is the Pacific Northwest National Laboratory (PNNL), which has developed an open-source reference platform called Volttron.[6] This platform can be loaded onto a very small computer and yet is powerful enough to interact with utility distribution system sensors and controllers (PNNL 2015). It therefore has the potential to play an important role in energy efficiency, serving as a platform on which baseline determinations and energy savings reporting can be automated.

Volttron is an execution platform designed to facilitate the implementation of software agents that perform electric power system sensing and control tasks (Akyoul et al. 2012).[7] Volttron's true potential can be easily understood with a smartphone app analogy. Just as apps are developed to perform a particular task on a smartphone, software agents can be developed by third parties to control and sense various electric power system parameters (Srinivas Katipamula, staff scientist, PNNL, pers. comm., July 13, 2015). AMI infrastructure, execution platforms such as Volttron, and applications that can perform M&V can work together to create an electric grid that is as interactive and dynamic as our telecommunications network is today.

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[6] An open-source reference platform is a software program developed in a public and collaborative fashion and the use of which is not restricted by proprietary code or licensing requirements.

[7] A software agent is a computer program coded to perform certain tasks with autonomy.

SMART THERMOSTATS

Smart thermostats enable the intelligent control of residential heating, ventilating, and air-conditioning (HVAC) systems. They incorporate sensors and programming algorithms that can sense and respond to complex inputs in real time, including household occupancy, behavior, and comfort preferences. They can be part of home area networks composed of various smart devices, appliances, and in-home displays of energy use and associated data. By communicating with homeowners through smartphones and tablets, smart thermostats enable consumers to remotely monitor and adjust operations of HVAC equipment and systems.

In addition, smart thermostats can connect to the cloud to access services associated with home hardware. For instance, they can be programmed to react to price signals or other inputs sent by utilities to change temperature set points, and they can cycle HVAC equipment off to reduce peak demand and energy use when electricity prices are high.

Smart thermostats enable customers to match home HVAC operation to their individual preferences and behaviors to increase performance and energy savings. The EPA Connected Thermostats initiative is developing performance specifications for ENERGY STAR© labeling of these devices (York et al. 2015).

BUILDING MANAGEMENT AND PROCESS CONTROL SYSTEMS

Many new appliances and systems have built-in sensors that can communicate with facility networks. Older devices can be retrofitted with inexpensive sensors and controllers so that they can also be network enabled. These networked devices provide performance information to centralized controllers on a continuous basis so that operators can monitor performance and make informed and timely decisions.

It is likely that the market will seek plug-and-play capabilities (GridWise 2005) such as we have with office equipment. With such capability, a new device such as a chiller or air conditioner, upon installation, will connect to a building's network wirelessly, announcing itself to a building management system. Information will be exchanged, and going forward the facility operator will be able to see the new device and have real-time access to its performance data. For example, the ENERGY STAR program has been working with manufacturers to develop appliances that are able to communicate energy data to users and respond to signals from utilities (Lundin 2013).

The control systems for commercial buildings and manufacturing processes are also benefiting from low-cost sensors and ICT. More and more systems can be controlled automatically and/or remotely. Communication between devices and building or facility systems is now handled through common communication protocols such as BACNet or Modbus.[8]

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[8] A communication protocol is a set of rules that facilitate interoperability among different communication devices over a network

A few advanced building management systems (BMS) are now including data historians that retain information on device settings, energy consumption, building occupancy, and weather data.[9] This historical information enables a BMS to compare current and past variables and, through computer simulation and machine learning, determine optimal operating conditions (Rogers 2014).

Manufacturing process control systems are also using data historians, remote data analytics, and inputs from vendors to improve throughput and reduce costs. Mesh networks made up of WiFi-enabled sensors on each device within a production facility eliminate the need for costly wiring and enable the collection of operating data in real time.[10] Control systems harvest this information and present it to operators in the context needed to make quick and effective decisions—within the plant or anywhere around the globe.

An energy management information system (EMIS) is essentially a set of software tools that can provide a common platform to analyze, transmit, and ultimately display energy consumption data. It provides greater situational awareness of a facility and simplifies performing a comprehensive, bottom-up energy analysis. Recording and saving a facility's data is another very important function of an EMIS (Henwood and Bassett 2015). An EMIS can be a standalone software program with its own data feeds or an application on existing building or process control system software that leverages access to data inputs from a facility.

Information from building and manufacturing processes is different from information collected from utility meters. It resides with the end user, and it is up to the user whether to share it with another organization such as a program implementer. There are many methods in development to enable facilities to share their information with programs and other stakeholders such as ESCOs.

Figure 2 shows the difference between utility meter information, which is used to track overall energy consumption, and intra-facility tracking information from lighting control, building management, and other systems. Natural gas and electricity meters give a macro view, whereas control systems present a micro view.

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[9] A data historian is a device that stores performance information in a contextualized manner so it can be retrieved and compared with current performance information.

[10] A mesh network has multiple pathways by which information can travel. Unlike a conventional linear communications system in which disruption of a single segment disrupts the entire chain, a mesh network will self-heal by routing information through one of many alternate routes.
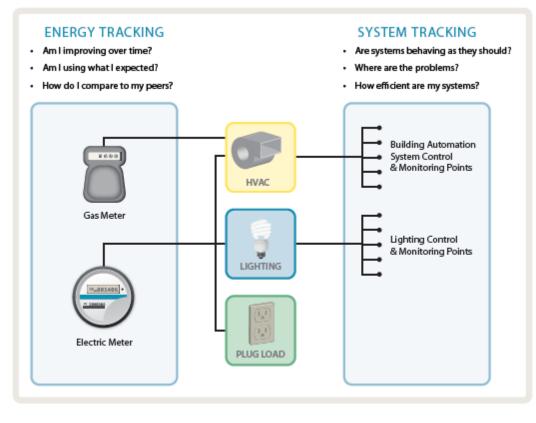
ENERGY TRACKING
- Am I improving over time?
- Am I using what I expected?
- How do I compare to my peers?

SYSTEM TRACKING
- Are systems behaving as they should?
- Where are the problems?
- How efficient are my systems?

Figure 2. Energy tracking and system tracking. *Source:* Friedman et al. 2011.

CLOUD COMPUTING

Much of the data storage and data analysis that has been described so far does not reside within a single server but is spread across multiple servers. This is often referred to as cloud computing. The cloud may be located within an organization's building, at a central location within an organization, or among distributed servers furnished by a data service provider. The cloud may be controlled from within the data owner's systems whether the servers are onsite or offsite. Many organizations choose to use a public cloud, an arrangement in which another organization is responsible for providing a fully managed application service and controlling data storage, security, service levels, and access.

Common characteristics of cloud computing include on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service (Sisley et al. 2014). Cloud computing reduces the cost of data analytics, and the ability to access data remotely makes them available to just about every organization that can benefit from them.

One method by which cloud computing reduces costs and increases effectiveness is by enabling an organization to centralize the location of software programs. Instead of loading the same software onto each computer within a company, it can store one copy of the program in the cloud where all authorized users within the organization can access it. Software as a service (SaaS) is a software distribution model in which applications are hosted by a service provider and made available to customers over a network such as a company's intranet or more broadly through the Internet (Sisley et al. 2014). A software

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application to determine energy savings is an example of a SaaS product that can be utilized by a building management or process control system.

INTERNET OF THINGS (IoT)

More than half the devices currently connected to the Internet communicate without human instruction or intervention (Ericsson 2011). These devices can be as simple as a sensor measuring the power flowing through a lighting system or as complex as a building management system monitoring multiple aspects of a large commercial building. Devices can exchange information with other devices, with people, or a combination of the two. The machine-to-machine communication (M2M) that exists on the Internet is referred to as the Internet of Things, or IoT. The term is also used to refer to the connected devices within an organization's intranet.

REMOTE BUILDING ANALYSIS (RBA)

Wireless networks, sensors, and smart grid meters open up the opportunity to access energy data remotely. With proper permissions and security in place, building owners can get information from wherever they are and, if they like, share it with their vendors, utilities, efficiency program administrators, and program evaluators.

Remote building analysis (RBA) is the term we will use in this report for the process of using analytical software programs and interval data from utility meters, weather data, and other publicly available data to rapidly analyze large portfolios of buildings and screen potential candidates for energy efficiency measures.

As opposed to a conventional audit that uses monthly billing data, RBA typically uses one year of a building's interval energy consumption data to derive a baseline of overall energy use. Given a stable operating history and a robust analytical engine, this baseline can include an end-use disaggregation of energy systems like cooling, heating, lighting, ventilation, and plug loads. To arrive at a distillation of energy uses in a single building, as shown in figure 3, multiple buildings must first be analyzed in detail and their energy-use profiles compiled. It is the large volume of compiled information that enables an analytical engine such as an RBA software program to disaggregate the energy uses of a single building. Many of these analytic engines also use other information available in the public domain, such as local hourly weather data, satellite imaging, and web searches (Summers et al. 2013; Grueneich and Jacot 2014).
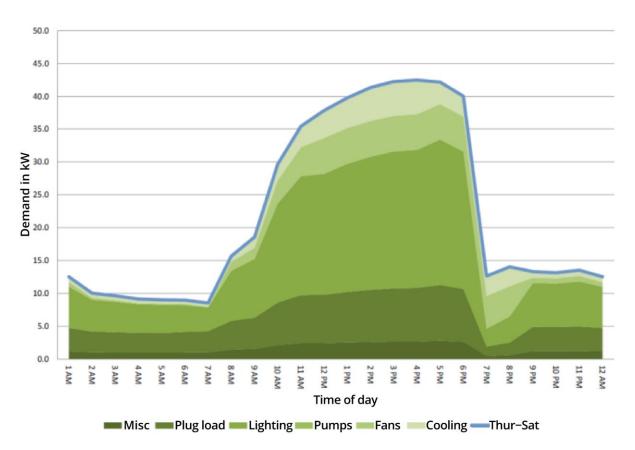
Figure 3. End-use disaggregation. *Source:* Summers et al. 2013.

Another top-down, no-touch method for determining energy use by various building systems is an approach called non-intrusive load monitoring (NILM). Originally developed at MIT in the 1980s, it involves analyzing meter-level current, voltage, active power, and reactive power data to disaggregate a facility's energy uses (Hart 1992). This technique requires much greater granularity of data than does RBA. It employs machine learning principles and requires accurate knowledge about the number of appliances in the facility and their submetered data during the learning period (Alles and Zenger 2014, Parson et al. 2012). The recent penetration of smart thermostats and smart meters has renewed interest in NILM; although the complexity of the process and the need for robust computing power are likely to limit its use in the near term.

Application of ICT to Efficiency Program EM&V

Having examined current EM&V practices and new information and control technologies, we are now in a position to bring them together. As we have seen, many projects require considerable pre-implementation data gathering and analysis to set baselines and forecast potential savings. Post-implementation EM&V often requires equipment metering, computer modeling, and interviews with end users. ICT can automate much of this data collection and analysis. New analytical techniques are giving evaluators the ability to monitor and meter what is relevant and then extract what is needed to gain intelligence about energy consumption.

Programs across the country are currently testing ICT-enabled analytical tools to determine what works and what does not. The previous section discussed some of them; we will look into others here. One or two technologies may ultimately emerge as the most powerful, but at this point it is too early to tell which ones they may be. There may well end up to be multiple effective methods for harvesting and analyzing customer energy data. It is likely that each technique will have its market, as each will have competitive advantages specific to a customer segment.

In the short term, ICT is likely to affect the EM&V activities of program implementers, administrators, and evaluators. In the long term, it may change energy efficiency markets and the responsibilities of evaluators and regulators. The next two sections will focus on EM&V. We will discuss longer-term changes toward the end of this report.

RESIDENTIAL PROGRAMS

An increased level of automation in energy efficiency programs is already apparent in the residential sector. Utilities have hired companies like Bidgely, Opower, and EnergySavvy to run behavior programs that attempt to influence customers' use of energy through routine communications that nudge them toward more efficient energy practices. Prompts include comparisons of current energy use to past use, and information on technical and financial assistance.

Case Study: Residential Energy Efficiency Program Use of ICT

Bidgely is an SaaS developer providing utilities with tools to segment and target residential customers most appropriate for homeowner-focused energy efficiency and demand response programs.

The company also has a software product that can disaggregate advanced utility meter data and provide appliance-level energy consumption information. This allows a utility to send customers a bill identifying the factors that contribute to their total charges at the appliance level. The Bidgely software uses additional information such as weather, geography, and efficiency standards to identify inefficiencies and provide recommendations. Positive changes in a customer's energy consumption can be identified and communicated back to the customer, most frequently via a mobile device.

A third product sends consumers timely nudges to encourage energy-saving behavior or participation in other energy efficiency programs. The communications are specific, actionable, and personalized. Bidgely claims that 41% of participants in a recent program changed their behavior and averaged a 6% reduction in household energy consumption. Many of the performance values, such as participation rates and energy savings, are calculated as the program progresses. The M&V is essentially baked into the implementation of the program (Bidgely 2014).

Some current residential programs are even more robust. One type uses smart thermostats to recognize patterns, learn customers' habits, and make adjustments to reduce overall energy consumption. Another type uses cloud-based, third-party data analysis to study the energy consumption histories of thousands of customers. These latter residential programs identify common energy-use profiles within a group of customers, set up treatment and control groups using RCT or QEM, and monitor their energy consumption (Oster, Guiterman, and Rigney 2015).

Residential behavior programs save energy by changing customer habits. They send consumers information on how they are doing compared with past performance and relative to peer groups. Automated program analysis provides timely key performance information to implementers and administrators on an ongoing basis. Metrics include energy savings per dollar spent, energy savings to date versus projected energy savings, and monthly participation rates.

ICT can also help with other aspects of residential program evaluation, as well as with cost effectiveness. Conventional EM&V often uses surveys to get a handle on factors like free riders and spillover—a very time-consuming and expensive process. ICT can capture some of these variables automatically. The use of ICT to track customer energy use can help make residential programs scalable, as the effort and cost involved in expanding a program can be quite small. As more customers are added to the program, the administrative cost per customer goes down, which in turn improves the program's cost effectiveness.

COMMERCIAL AND INDUSTRIAL (C&I) PROGRAMS

Commercial Energy Efficiency Programs

Commercial facilities have heterogeneous energy use profiles, and the heterogeneity of the industrial sector is even greater. However, because the energy use of larger commercial and industrial facilities is so great, facility-specific energy efficiency M&V may be a cost-effective option. As demonstrated in the case study below, new SaaS analytical models can cost-effectively identify opportunities for commercial sector energy efficiency projects and then determine the resulting savings. Automated commercial programs can be scaled more easily than existing labor-intensive approaches. This means that more customers can be reached, and more energy saved.

Case Study: PG&E Commercial Whole Building Demonstration

Pacific Gas and Electric (PG&E) is running a commercial whole-building (CWB) demonstration to establish proof of concept for an analytics-enabled whole-building performance approach to unlock deep (15%+) energy savings in existing commercial buildings. If proven, and if accepted by the California Public Utilities Commission (CPUC), this approach could play a formative role in helping California achieve its ambitious zero-net-energy targets for existing commercial buildings.

PG&E is the program administrator for the demonstration, and the data analysis is being handled by third-party software vendors and a technical evaluator. Engineering analysis is handled and reviewed by consulting engineers. As part of the demonstration, the energy consumption of qualified buildings is being analyzed using conventional onsite assessment and energy modeling techniques in parallel with methods using data analytics and interval meter, weather, and other data. These techniques are applied to identify energy efficiency measures and verify the savings of participating buildings, of which there are 12 to date.

The energy efficiency measures are a mix of retrofitting, retro-commissioning, operational, and behavioral measures. Once these measures are identified and implemented, data analytics are used to help establish an energy-use baseline from which to determine customer savings. In addition, as a source of comparison, calibrated simulation is used in the conventional method to determine above-code savings, as has historically been required by the CPUC.

The CPUC is expected to appoint an external program evaluator for the demonstration. Project implementation for the current 12 participating buildings will be largely completed by the end of 2015, with monitoring and analysis continuing through at least 2016.

The Lawrence Berkeley National Laboratory recently evaluated the ability of several off-the-shelf analytical tools to determine the savings from commercial buildings and found the results to be promising (Granderson et al. 2015). Using actual field data sourced from hundreds of interval meters, the research team found that for a quarter of the population of buildings in the data set, the energy savings resulting from program activities could be determined within a 6.5% margin of error, and that was without close inspection of the facilities or adjustments for nonroutine variations in energy use (Granderson et al. 2015). The other three-fourths of the buildings did not operate in a sufficiently steady state for the analytics to work without higher levels of inspection and the identification of critical events. Analytical techniques such as RBA can be used to identify buildings that operate in a steady state and categorize the level of variability in those that do not.

Industrial Energy Efficiency Programs

Determining a baseline at most industrial facilities has traditionally required experts with an understanding of the facility as well as experimentation with multiple variables (Crowe et al. 2014). Some new intelligent control systems can perform these functions at the same time as they reduce energy consumption and determine and report savings.

Case Study: ComEd, Silver Beauty, and Digital Lumens Intelligent Lighting System

Through a custom incentive program called Smart Ideas for Your Business, ComEd, the Illinois operating unit of Exelon Corporation, provides businesses $0.05 per kWh saved, up to 50% of costs, for projects that reduce energy consumption.

Silver Beauty, a warehouse management company in the Chicago area, took advantage of this program to retrofit the lighting in its 177,000-square-foot warehouse. The new system included LED lights controlled by a reactive and predictive intelligent control system provided by Digital Lumens. The system has self-metering and historical data collection capabilities that enable it to determine a dynamic baseline and report energy savings in near real time.

After a custom incentive was approved and a project installed, the energy savings would have to be validated before the customer could receive a payout. That required tracking billing charges and comparing them with the baseline estimate, and it usually took 60 to 90 days. The Digital Lumens system streamlined the measurement and validation of energy savings by providing the information automatically.

In the end, the system reduced energy use by about 1.2 million kWh per year, which was 92% of previous consumption. (This reduction may seem extreme, but it is not uncommon to see significant energy savings from lighting projects that replace old, very inefficient systems that were left on all day with new LED systems that operate only when people are present.) The accuracy of the automatically reported savings was confirmed by ComEd's third-party M&V contractor, who conducted a traditional post-project analysis (Digital Lumens 2013).

Many facilities have their own internal networks to which multiple devices are connected. Information flows from the devices to a local network, and from the local network through the Internet to corporate headquarters or a contracted energy management vendor. More advanced building management systems (BMSs) come with smart technologies that use historical information in a computer simulation of current conditions to determine optimal operating parameters. These control systems harvest data from devices throughout a facility

and provide operators with contextualized energy consumption information so they can use it for decision making.

The energy consumption of industrial facilities is more heterogeneous than that of residential and commercial buildings, because it involves variables that go beyond weather and operation schedules. For example, production metrics—like the number of units produced—greatly influence energy consumption. An EMIS that collects historical information can be used to assess the energy intensity of an operation relative to current conditions. For example, an EMIS can help answer the question "Is this facility using more or less energy today than it would have on an identical day two years ago before the recent upgrades?" (Friedman et al. 2011) An EMIS can make this information available to the process operator and can export some or all of it to other stakeholders. Connection of a smart device to the Internet directly or through an EMIS can give multiple parties access to energy savings data.

BMS and EMIS technologies are increasingly being used to improve data analytics models and data availability for industrial energy efficiency programs. Program administrators can employ an EMIS to determine an energy-use baseline and identify potential energy efficiency measures. Some EMISs are able to take advantage of a facility's existing supervisory control and data acquisition (SCADA) systems along with a diverse metering infrastructure to acquire the facility-level data sets required. Implementers can determine savings values in near real time and transfer them to program administrators.

Case Study: Efficiency Nova Scotia's EMIS Program

Since 2012, Efficiency Nova Scotia, a Canadian electricity efficiency utility, has been running an EMIS-based program that targets industrial and institutional facilities. Five organizations, four of them industrial, are currently at various stages of program execution. To date two industrial participants are actively using EMIS in their organizations; the other two are finishing their installations.

The program is aimed at maximizing sustained energy savings by creating a management infrastructure and by training facility staff in the use of EMIS software. A management protocol facilitates the entry of relevant data into the EMIS, which in turn proves operators and management the information they need to optimize facility energy use. Efficiency Nova Scotia offers financial incentives to cover up to 50% of the cost to develop, design, and implement an EMIS.

Early in the program, an implementer, Energy Performances Services, carries out a comprehensive EMIS audit of a facility. This audit identifies energy and other requirements and formulates strategies to identify, collect, and transmit the data required by the EMIS. The facility receives an incentive if it decides to go ahead with the EMIS implementation.

Once completed, the EMIS translates various data streams into actionable information that operators and management can use to develop and carry out operational energy efficiency measures. These measures are identified and their performance measured using the data collected from the facility.

Program savings are evaluated by a third-party evaluator following M&V protocols for the Superior Energy Performance® (SEP™) program, a system for managing energy use. The evaluator has accepted the savings reported by the EMIS program, which, after three years, total more than 4.5 million kWh (Henwood and Bassett 2015).

Demand Response Programs

In the past, users of demand response programs would not be able to know until a day later how these programs performed during a curtailment event. With ICT, fast polling of customer meters allows program administrators to see their usage every 15 minutes (or even more frequently) and thereby determine the total peak reduction as it happens (ConEdison 2014).

By applying load disaggregation algorithms, administrators can identify the best candidates for engagement. They can also use insights gained from RBA to design programs that empower customers to adjust energy usage to fit their cost and comfort goals. This, in turn, increases the attractiveness of the programs and boosts customer participation rates (Silver Spring 2014).

In the residential sector, ICT has enabled a new generation of demand response programs that allow customers to shed a range of loads, such as pool pumps or appliances, and to do so in a more interactive way that minimizes disruption and dissatisfaction. In the commercial and industrial sectors, ICT enables detailed, two-way communication between utility and customer. Demand response signals can be issued and responded to in an automated fashion. We discuss a particular example of this capability, OpenADR, in a later section.

As we have seen, demand response programs aim to reduce peak demand, whereas energy efficiency programs aim to reduce consumption. New technologies are beginning to blur the line between these program types. ICT allows loads to respond dynamically to both utility system and customer needs. In the future, it is likely that more programs will be designed to satisfy both goals.

ESCO Performance Contracts

Energy service companies (ESCOs) have for decades been helping public-sector and institutional facilities reduce energy consumption through performance contracts. In these arrangements, the ESCO makes the capital investment in upgrading the energy-consuming equipment of a facility: lighting, heating, air-conditioning, hot water systems, and so forth. As a result of these investments, the facility's energy costs go down, thereby freeing up cash for the facility to repay the ESCO. The energy cost savings are essentially split between the facility and the ESCO, so the more energy saved, the more the ESCO can potentially earn.[11]

The cost-intensive and time-consuming nature of onsite energy analysis is one of the reasons ESCOs have traditionally avoided customers without stable energy-use baselines. Applied to baseline analyses and savings forecasting, ICT may enable ESCOs to expand the scope of their services and the markets they serve. Many ESCOs already use the IPMVP protocol and pull information from building management systems (Clay Nesler, vice president, global energy and sustainability, Johnson Controls, pers. comm., June 18, 2015). Smart meters

[11] There are many types of performance contracts, each with different features and benefits. The example used here was chosen for its simplicity and relevance to the pay-for-performance concept.

could become another gateway for ESCOs to help customers manage their energy use and participate in demand response events and even energy resource capacity markets.

THE FUTURE OF C&I EM&V

Single-Streaming Data

Utilities initiate most energy efficiency program data collection since they already collect customer data for billing purposes. Their infrastructure can be one of the channels for data exchanges between business sector EM&V stakeholders. As we have seen, smart thermostats and facility-level BMS and EMIS are another key channel for EM&V data. These two data streams—one controlled by the utility and the other by the facility—operate in isolation. What if they could be combined into a single conduit?

The capabilities of utility-system smart meters are only going to increase. Meters can communicate with specific smart devices or networks that control multiple devices. They certainly have the capability of talking to a facility's energy management system, as well as to external systems such as gas and water networks (Marc Collins, senior principal energy consultant, and Luke Scheidler, energy consultant, Itron, pers. comm., May 15, 2015).

Combining utility meter interval data with facility-system data streams will create a more detailed understanding of the energy use within a facility and improve the tracking of energy savings from efficiency measures and projects. On the utility side, energy consumption data can be combined with other, publicly available data on local parameters such as outdoor air temperature. If agreed to by the customer, data streams from within the facility could be added to the mix to produce a richer understanding of energy use. For example, production and occupancy levels could be correlated with energy consumption to facilitate more robust data modeling and analysis. Another use of parallel data streams is to compare them with each other and seek matching patterns that can be applied to a broader population of customers for which only one data stream, most likely utility meter data, is available.

ICT also enables these rich data streams to flow to multiple EM&V stakeholders. Information can move from the utility meter at the customer's facility through the utility's communication system to program implementers, administrators, and evaluators. These personnel can use interval data supplied by smart meters to track the energy use and savings of customers. Combine this with BMS data, and EM&V practitioners have immediate access to the information they need for determining energy savings using any of the four IPMVP options. The type of data to be collected can be negotiated among the customer, program implementer, and evaluator. Figure 4 shows this data system.
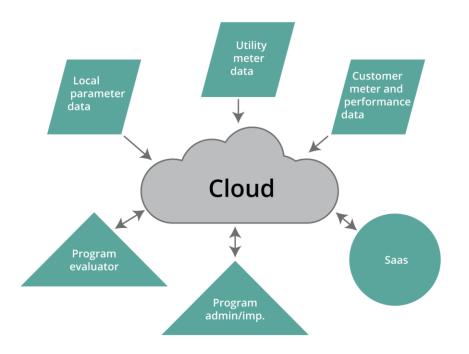
Figure 4. Enhanced data sharing

ICT-enabled access to richer data may ultimately shift the focus of ratepayer-funded programs from component-based measures with less complex EM&V requirements to systems-based programs. It will also help utilities identify more potential participants (Raghavan 2015). In current practice, buildings with predictable behavior (e.g., stable start-up and shutdown times) will reveal energy efficiency opportunities more accurately than those with more complex characteristics, mainly because their baselines are more stable (Granderson et al. 2015). Combining utility smart meter data with the information streams from a customer's management system will enable much more sophisticated modeling of heterogeneous building baselines. This will widen the field of prospects for business sector energy efficiency programs.

Real-Time Energy Savings Information

Advanced ICT can enable facility-level energy managers to observe an energy efficiency measure's performance in near real time with the help of user-friendly and easy-to-understand visualizations. In the long term, managers may be able to choose among various third-party software packages that perform different monitoring activities, according to their needs. *Real time* is the key term for program EM&V. Rather than evaluating projects by comparing "before" and "after" snapshots, programs will eventually be able to track energy savings at the same time as consumption, as they happen (Raghavan 2015). That is, once the technology is fully developed, energy measure, project, and program performance evaluation will proceed as savings take place. All stakeholders—implementers, administrators, and evaluators—will have access to the same stream of rich data. From the outset, evaluators will be able to partner with implementers to design a data collection plan and start receiving data feeds. Later they can run the information through their own

analytical tools to verify the implementers' claims (Tim Guiterman, director of EM&V solutions, EnergySavvy, pers. comm., November 13, 2015).

In the near term, it is likely that programs will operate with both conventional and ICT-enabled EM&V practices in place. Once the newer techniques have proved effective, conventional onsite metering and data gathering for some programs will give way to less burdensome methods, reducing or possibly even eliminating the need to enter many customers' premises to conduct ex post EM&V (Eckman and Silvia 2014). The amount of onsite work eliminated will depend on the number of submetered systems and the budget allocated for M&V. For small-scale residential investments, combining short-duration whole-premises interval meter data with historical energy consumption information should suffice. At the opposite end of the spectrum, in a large industrial facility with unique processes and operating patterns, these technologies are not likely to eliminate the need for onsite measurement and analysis (Marc Collins, senior principal energy consultant, Itron, pers. comm., September 11, 2015). Ultimately it is likely that analytical tools will become sufficiently robust to deal with a significant portion of the building stock at a high confidence level.

USING ICT AT EACH STAGE OF EM&V

In general, ICT can give EM&V practitioners a single, near-real-time stream of data from which they can determine energy savings and identify projects that work best. This capability can enhance each stage of the EM&V process.

Market assessment. Program administrators can use ICT to identify energy efficiency opportunities and plan marketing drives. Remote analysis can expedite the identification of customers and measures with the greatest potential to save energy. Program administrators are finding value in SaaS companies, like FirstFuel and Retroficiency, that can help determine the consumption and demand savings potential of numerous commercial buildings. Program administrators can then focus their limited resources on buildings with the highest savings potential and on those that can help reduce grid congestion in capacity-constrained areas (Craft and Fisher 2014). In response to this opportunity, many administrators have launched pilot programs to test the data analysis engines of various SaaS providers.

Setting baselines and forecasting savings. Accurately determining a sizable facility's pre and post energy use requires complex models involving a large number of variables. Lutz and Pagadala (2014) identify eight factors that can render pre-implementation forecasts inaccurate: calculation method, inappropriate baseline, equipment specification, unquantified fuel impacts, changes in operating conditions, tracking database discrepancy, ineligible measures, and program rule compliance. ICT-enhanced tracking and analytics can help mitigate many of these challenges.

Process evaluation. ICT-based M&V approaches offer the opportunity to track actual savings versus expected savings in near real time. If savings are not hitting the expected mark, implementers can try to identify why measures are not performing as expected. Then they can attempt to fix them on the fly or come up with further measures to meet the target.

Planning programs. Current program performance data bear on the planning of future programs, whose start dates are often dictated by regulation or by a utility's fiscal calendar. ICT-enabled data streams and analytics can replace some retrospective lessons learned with ongoing learning that administrators can use for program design (Ellis 2015; Oster, Guiterman, and Rigney 2015).

Deemed savings. It is relatively straightforward to automate the calculation of project savings from a database of deemed values. In addition to savings values, the database or technical reference manual (TRM) may include factors that adjust for application, location, and other variables. As we discussed, evaluators may also analyze information gathered from more robust field sampling to update the energy measure savings values and factors in TRMs. Conceivably, the TRMs could be digitized and tied to program tracking. Evaluation could then focus less on verifying deemed savings and more on conducting research to develop deemed parameters for future use.

Net versus gross savings. Evaluators can devise analytical models that use energy data in conjunction with customer information to help determine net energy savings. Statistical models that compare the energy use of participants and a control group of nonparticipants can capture savings that are net of free riders and spillover.

Cost-effectiveness testing. ICT clearly makes it possible to arrive at a more accurate determination of energy savings. It can also automate the calculation of multiple (nonenergy) benefits and the application of any of the five most commonly used cost-effectiveness tests. Evaluators may eventually be able to compare cost-effectiveness results arising from multiple sets of alternative tests and assumptions.

Measuring savings persistence. The same systems and models that measure energy consumption during the reporting period can be left in place to track longer-term results. Monitoring periods can be extended to see how savings change over time.

Policymaking. Armed with faster, more accurate forecasting and determination of savings, regulators and policymakers will be able to assess the impact of programs in a timelier manner. Information on the effectiveness of particular programs will help them shape future program goals and offerings. This in turn will lead to more agile and informed policymaking that treats energy efficiency as an investment-worthy resource and ultimately increases the amount of energy saved nationally.

Enhanced EM&V for energy efficiency may also factor into state compliance with the Clean Power Plan. The same tools being used to determine energy savings can be modified to determine emissions reductions. Though beyond the scope of this report, this is certainly an area worthy of research.

SUMMARY OF BENEFITS

ICT can help uncover customers with potential energy savings opportunities and identify the measures they will value. It can also increase the effectiveness of programs and enhance confidence in the quality of savings data. Program implementers can track performance in near real time, and evaluators can be more certain of project savings. The more data

available for analysis, the more accurate the analysis is likely to be. Conventional efforts look at monthly utility bills. Emerging techniques use hourly or 15-minute-interval data supplied by smart meters. Adding system energy data from customer facilities can provide additional granularity, enabling even more effective identification of opportunities and tracking of savings.

As always, program administrators, implementers, and evaluators are being asked to keep their expenses down. ICT enables them to perform more accurate and timely EM&V at a lower cost. For one thing, remote automated data gathering is likely to be less expensive than traditional onsite inspection. This means that either the overall cost of EM&V can be reduced or higher-quality EM&V can be accomplished within a given budget. For example, information can be collected over longer periods of time to track the persistence as well as the volume of savings (York et al. 2013). And since ICT-enhanced EM&V can be scaled quickly, it can evaluate more projects and more programs with marginal incremental costs.

Of course, ICT also promotes the scalability of the programs themselves. The use of cloud computing to conduct remote analysis of large numbers of customers' data reduces the marginal cost of adding additional customers. The administrative cost of running a program is untethered from the number of customers engaged.

Challenges and Ways Forward

The opportunity of ICT to improve EM&V for energy measures and efficiency programs is quite compelling. However there are technical, financial, and political challenges to overcome before widespread deployment of automated baseline prediction methods will be possible. Sensors, equipment, control systems, and networks must be able to communicate with one another, and when they do, the definitions of terms and units must be standardized. The costs and benefits associated with these innovations need to be understood so they can be equitably assigned and shared. Policies need to focus on the large picture of economic growth and the maximizing of long-term benefits.

More specifically, we anticipate the following challenges to realizing the full value of ICT to efficiency program EM&V.

- Determination of baseline
- Determination of net energy savings
- Agreement on confidence levels
- Dealing with masses of data
- Performance standards and interoperability
- Technical expertise
- Data ownership, access, privacy, and security
- Cost recovery of ICT infrastructure

We will now look at each of these challenges individually.

DETERMINATION OF BASELINE

Before the savings from an energy measure can be determined, an evaluator must know what energy consumption would have taken place absent the energy measure.

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Determination of an energy consumption baseline can often be a challenging endeavor. A study by Pacific Gas & Electric's Whole Building Energy Efficiency program found that "roughly 40% of buildings experience year-to-year changes in electricity consumption in excess of 10% (based on random sample). These changes in consumption are typically unrelated to weather and thus are not captured by analyzing the relationship between weather and electricity use during the period prior to the installation of energy efficiency improvements" (Bode, Carrillo, and Basarkar 2014).

While M&V can control for the effects of weather on energy consumption, the largest sources of the year-to-year change in energy use for most buildings are operations and occupant behavior. Even with quantitative screens that reduce baseline errors by half, many facilities still see baseline errors at least as large as realistic whole-building energy savings from energy conservation measures (Bode, Carrillo, and Basarkar 2014). Techniques as rigorous as regression analysis allowing for various key indicators of energy use may not be sufficient to establish a proper baseline.

Proper EM&V will always be more than a pattern-matching problem. There will still be a need to have an engineer examine the changes in a building or in its use (J. Granderson, deputy for research, LBNL, pers. comm., June 29, 2015). Nonroutine adjustments will always come up and will have to be accommodated. Without detailed information on these changes, implementers and evaluators cannot establish a proper baseline from which to determine energy savings. This additional information can be collected through questionnaires, interviews, and onsite inspection.

Although it is unlikely that these new techniques will enable the automated analysis of all buildings, there are many buildings that are quite stable and therefore lend themselves to accurate baseline prediction. In many service territories, that number may be more than are currently being touched by existing programmatic efforts (J. Granderson, deputy for research, LBNL, pers. comm., Sept. 17, 2015). The new analytical techniques we have discussed can help programs screen and target buildings that behave in predictable manners and that will give the best M&V results after implementation. The number of buildings can be increased substantially with modest inspection to take note of changes to operations and occupancy. Including an onsite visit in a program does not preclude using regression analysis or the tools that streamline the process with automation.

DETERMINATION OF NET ENERGY SAVINGS

Another challenge to automating EM&V functions under the traditional efficiency regulatory policy framework is the determination of net energy savings. Since determination of a customer's motivations for implementing an energy measure likely cannot be automated, the programs will need to either continue interviewing each customer or develop a multiplier that discounts gross savings. The multiplier can be determined through a sampling process in which a cross section of customers is interviewed periodically to recalibrate the multiplier. The more heterogeneous the customer set and the more complex the efficiency projects, the more difficult it will be to automate the determination of net savings and the more person-to-person interaction will continue to be required.

ICT can help in this regard through improved communications, such as online questionnaires and video conferencing. It also simplifies the identification and use of comparison groups, and its robust analytical models produce higher levels of confidence in both gross and net savings values. Analytical models can draw from multiple databases—such as those that contain customer service interactions, customer payment histories, and marketing interactions—and thereby enable a utility to make connections between marketing efforts and program participation, or between energy savings from program participation and improvements in the timeliness of bill payment. The ability to cross-link and inspect multiple databases could aid in identifying free riders, spillover, and market effects. So even if the volume of person-to-person interaction is unchanged, the quality of the output will improve.

CONFIDENCE LEVELS

How good is good enough? That question was raised by several of the people interviewed for this report. There is no commonly accepted level of confidence or error rate in assessing and reporting efficiency savings (SEE Action 2012). This has always been a fundamental challenge for the EM&V of energy efficiency programs, the result of the counterfactual nature of efficiency (Schiller, Goldman, and Galawish 2011).[12] What level of certainty is required for long-term resource planning? What level is required for demand response events? It is likely the values are not the same. If greater uncertainty is acceptable, what compensating (or risk mitigating) actions must be taken? And who should be responsible for their costs?

Lack of an agreed-upon threshold means software developers are chasing a moving target and program evaluators are delaying deployment of new analytical tools. Resolution of this issue cannot be accomplished by a single entity but will require the input of many stakeholders. The goal of these collaborative efforts should be to present common recommendations to regulators on performance levels that ensure not only that energy efficiency investments are cost effective, but that EM&V investments are also cost effective.

It would be logical to apply cost-benefit and risk management principles to help balance the costs and value of information derived from EM&V (Schiller, Goldman, and Galawish 2011). The amount of benefits the program evaluator stands to gain from the accuracy of an EM&V procedure should be used to decide its exhaustiveness. Underestimation or overestimation of savings from a program involving large investments can lead to an inaccurate assessment of cost effectiveness. In this case a program evaluator may prefer an EM&V procedure that is more accurate and exhaustive. However a regulator may find it too expensive. Agreement on a confidence-level standard that can be used to differentiate baseline prediction models by the amount of error they induce in energy savings calculations will aid both the evaluator and the regulator (Granderson et al. 2015). A confidence level need not be universal. It may vary depending upon the nature of a project or type of efficiency program. Program administrators and stakeholders may wish to weigh the costs of achieving various

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[12] See Determining First-Year Savings on p. 8.

confidence levels for their particular program and recommend one or more options to regulators.

MASSES OF DATA

The more data one collects, the more one must deal with and store. Even with all of the improvements in data analytics, this still adds cost. Each data stream must be contextualized—that is, it must be identified and labeled in a way that makes it useful for analytical systems and operators. Contextualizing data usually requires technicians with considerable energy, efficiency, and IT expertise. Technicians are also needed to parse the enormous volume of data and determine what is needed to make informed decisions.

The more information streams, the more relationships that must be established. For example, if the only data stream is billing information, an analyst can easily identify a change in monthly energy consumption with a dozen data points. However, if there are data streams from a dozen systems within an office building, each reporting information in 15-minute intervals, the analyst may need to understand how each system influences the others and then track performance over months to identify the cause of a change in energy consumption. Is this additional information useful? It depends on whom you ask. The building manager may find the more detailed information of value, but the program evaluator may not.

PERFORMANCE STANDARDS AND INTEROPERABILITY

The interoperability barrier can be broken into two subcategories, one pertaining to M&V issues and the other to issues surrounding ICT adoption. The first set is largely policy related and the second is technology related. Many policy issues predate the emergence of ICT; others are either new or just different versions of old ones.

Policy Challenges

The effort to resolve EM&V issues in the energy efficiency sector has been long and arduous. The fragmented legal authority and administrative responsibility in the utility sector and the structural and policy diversity among states have prevented the adoption of a national EM&V standard (Kushler, Nowak, and Witte 2012). Historically, there has not been a single protocol for determining energy savings (Slote, Sherman, and Crossley 2014). This issue has been a challenge for both private and public sector energy efficiency stakeholders.

A single national protocol would allow the sharing of data and analytical models across service territories and state lines. It is certainly possible that states leading on efficiency could support a common effort to develop a consistent EM&V methodology, working with efficiency and ICT experts as well as with EM&V consultants. The development of such a national EM&V protocol is likely to be a lengthy process requiring the long-term commitment of organizations. Development cannot rely on specific individuals because they will come and go over the years. Regulatory bodies, government agencies, advocates, program administrators, and program evaluators will all need to commit for the long term.

The Department of Energy has recognized this barrier and is leading the Uniform Methods Project, a collaborative effort to develop national measurement and verification protocols for determining energy savings for commonly implemented program measures (Haeri 2015).

The collaborative comprises energy efficiency program administrators, evaluators, EM&V consultants, and energy efficiency advocacy groups such as ACEEE. The goal of this initiative is to strengthen the credibility of energy efficiency programs by improving the consistency and transparency of how energy savings are determined (DOE 2015a).

Through the Uniform Methods Project, DOE aims to establish easy-to-follow protocols based on commonly accepted engineering and statistical methods for determining savings for a core set of commonly deployed energy efficiency measures. The protocols also include

- A description of measure and application conditions
- An algorithm for estimating savings
- An example of a typical program offering and alternative delivery strategies
- Considerations for the M&V process, including an IPMVP option
- Data requirements for verification and recommended data collection methods
- Recommended program evaluation elements
- Alternatives for lower-cost EM&V approaches (DOE 2015f)

It is unlikely that all the state utilities and utility regulatory commissions will adopt the same M&V protocols for programs within their states. However this should not discourage efforts to standardize EM&V policies as much as possible. Doing so will bring economies of scale to administrators, implementers, and evaluators that operate in multiple states and, by extension, lower the marginal costs of analysis services. In any case, regardless of the methods they use, evaluators should disclose their methodologies and assumptions. Transparency is key to public trust in the evaluation process.

Technological Challenges

Much of the energy savings that will result from the application of ICT will be through improving the efficiency of complex systems. A single device such as a pump can be made more efficient through design improvements; however, a pumping system can save energy through optimized operation. This is often referred to as system efficiency.

When the computer controls of multiple systems are connected to one another, they form a network, each system communicating with the rest of the network. Each system can benefit from this network relationship, and so can the entire network. This is what is known as the network effect.[13] For any new technology to succeed and reap the benefits of a network effect, multiple devices and systems must be connected to the network, and that necessitates the development of standards. In the case of ICT-enabled data analysis, we will need standards for data sources to be used, how and in what form data is communicated, context, and data management.

One of the major challenges has been the misinterpretation of energy data due to a lack of context in the streams of information from devices. For example, there may be incompatibility of time series of information: Device A may take measurements every hour,

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[13] A network effect occurs when the value of a good or service increases with the number of people who use it. Examples are telephones, the Internet, and online social networks.

while device B takes measurements only once a day. If device A sends the value *100 kWh saved*, device B might understand it as 100 kW-days saved, unless the time information is also communicated and there is programming to interpolate the value. This problem, in turn, brings to light broader challenges that deal with database management, lack of common terms and definitions in the EM&V industry, and lack of industry-specific standard communication protocols that can be used to transfer data.

PROPOSED SOLUTIONS

Several collaborative efforts are under way to address these ICT-specific interoperability issues. Below we discuss four such efforts, each in a different stage of development. Should these efforts prove successful, they will facilitate the communication of information between utilities and their customers using different communication technologies.

- Building Energy Data Exchange Specification, a dictionary of common building terms
- Grid Wise Architecture Council, developing guidelines for interaction among participants on the smart grid
- Project Haystack, working on naming conventions for database management
- Open Automated Demand Response, developing common protocols for automated demand response

Building Energy Data Exchange Specification (BEDES). Just as with people, communication between devices is facilitated by a common set of definitions such as those contained in a dictionary. Computers also benefit from standardized terms of communication and database fields and formatting. The Department of Energy created BEDES to help facilitate the exchange of information on building characteristics and energy use (DOE 2015c). It was developed to be used in software tools and management practices that help stakeholders make energy investment decisions, track building performance, and implement energy-efficient policies and programs. As the number of public and private tools that utilize BEDES grows, a network effect will come into being as they contribute to an interoperable ecosystem of software that lowers the cost in time and money currently involved in sharing and aggregating data. This will also increase the availability of products and services that utilize energy data, allowing them to achieve greater market penetration and deliver better information to decision makers (DOE 2015b). BEDES is not a software tool, database, or schema but rather a dictionary that provides common terms and definitions that different tools, databases, and data formats can share (DOE 2015b).

Grid Wise Architecture Council (GWAC). This collaborative group is working on interoperability and guiding principles for the smart grid. It comprises industry leaders who see a set of guiding principles, or architecture, as necessary to facilitate the development and growth of the smart grid as a platform for new markets (GWAC 2005). Customers' ICT-enabled devices and smart grid components must be able to talk to one another in a common language with recognized standards for terms, units of measurement for data, and security standards if the full potential of the smart grid is to be realized. The architecture will provide guidelines for interaction among participants and interoperability among technologies and systems.

GWAC has identified the following features of interoperability.

- Exchange of meaningful, actionable information between two or more systems across organizational boundaries
- Agreement on the meaning of the exchanged information
- Agreement on the expected response to the information exchange,
- Quality of service in information exchange: reliability, fidelity, and security

Project Haystack. Predicting a correct baseline is essential for accurate M&V of energy measures. The development of communication-enabled low-power sensors has made it possible in building retrofit projects to connect to a network of as many systems as exist in a new building. The data generated by these networks of sensors and meters are very diverse in nature, and in many cases the same data can be stored in different ways. Therefore, it will be valuable to have a standard naming convention and taxonomy for mapping these data in a database that can be accessed and analyzed by machines to find patterns and relations (Project Haystack 2015).

Project Haystack is an effort to introduce this much-needed standardization in semantic data models and web services. The project uses a system of tags and creates standard data structures of predefined data formats. It provides standardization provisions for a wide variety of data from different sources like networks, electric panels, energy meters, air handler units, chillers, boilers, and lighting.

Open Automated Demand Response (OpenADR). The utility sector worked with Lawrence Berkeley National Laboratory (LBNL) to create automated demand response (ADR) so utilities could communicate with advanced building energy management systems (Piette et al. 2009). OpenADR basically defines application programming interfaces (APIs) that establish the routines, protocols, and tools enabling third parties like the utilities, energy and facility managers, aggregators, and hardware and software manufacturers to create software and infrastructure that facilitate automatic demand response.

Customer facilities with the proper equipment can be programmed to respond to a demand response request. The request may be to curtail some of their load during periods of peak demand, or it may be a pricing signal that customers may accept or decline.

OpenADR also has built-in compatibility with other popular open-source protocols like SOAP, OASIS Energy Market Information Exchange (EMIX), OASIS Web Services Calendar (WS-Calendar), and BACnet (Piette et al. 2009). The Volttron platform mentioned earlier will be OpenADR compatible.

OpenADR systems are capable of transferring additional information over the established infrastructure. The interoperability problems associated with the ICT aspect of M&V automation can be alleviated in part with the help of an API-based approach to standardization. It will enable applications to readily exchange energy and energy savings data. This type of system can serve as the backbone of an efficiency program that involves routine two-way communication between customer and utility.

TECHNICAL EXPERTISE

Organizing and labeling energy-use data streams are not functions that can be automated. They require technicians with an understanding of energy and the systems that use energy. If an efficiency program is involved, add to the mix knowledge of how energy savings are achieved and expertise in efficiency EM&V. Knowledge of all of these areas seldom resides within a single person, and people with the necessary expertise are likely to be hard to find. The same shortage of workers with appropriate skills that affects the IT and telecom industries will probably also affect the energy efficiency community. This is a soft barrier compared with other challenges, but one that nevertheless will inhibit greater deployment of ICT-enabled EM&V.

DATA OWNERSHIP, ACCESS, PRIVACY, AND SECURITY

The question of who has access to customers' energy consumption data has emerged as a legal issue. What rights do utilities have to the data? Do third-party vendors have the same rights? Depending on the answers, customer approval may be required before the utility or nonutility vendor can access the information. According to one position, the data are owned by the customer, and therefore program administrators and implementers will have to negotiate an agreement with them. This can be addressed through an online release form that customers sign when registering for an efficiency program. This is a simple step, but it does make the administration of a program a bit more complex.

The issue of energy data sharing can also extend to commercial property owners. Many buildings have individual meters for each tenant. Property owners' participation in efficiency programs may be contingent on their receiving building energy data. They will not be allowed access to individual tenant data but could receive aggregated data. The challenge, though, is that they must either get permission from each tenant or request historical aggregated building data from the utility. Neither of these approaches addresses the need for continued data access for ongoing tracking of energy savings progress. To address this need, the EPA created Portfolio Manager web services that connect to its Portfolio Manager database. Among its many features, this offering enables the collection and aggregation of whole-building data for building owners without compromising tenant privacy (SEE Action 2013).

Depending on the rules that regulators have established for access to customer data, a utility may be able to give third-party vendors access to data if they are subcontractors to the utility (which many ICT vendors are), subject to nondisclosure agreements (Dian Grueneich, senior research scholar, Stanford University, pers. comm., September 8, 2015). When a utility subcontracts with a third party to administer an efficiency program, it should outline in the contract who owns which data sets and how data should be handled. If a non-subcontractor needs access to customer data, it must negotiate directly with the customer. Some companies like Nest Labs have a policy that the data belong to their customers and that service providers may use that information only with explicit customer permission (Nest 2015).

Sisley et al. (2014) discuss risk mitigation strategies for customer data. It is the responsibility of the utility to protect the energy customer data under its control. Utilities will often conduct a privacy impact assessment (PIA) to determine the privacy, confidentiality, and

data-breach risks associated with the collection, use, and disclosure of personal information. They also use PIAs to define the measures that may be used to mitigate identified risks. It is unlikely that they will have practices in place to eliminate all risks, but they should have plans to reduce those that cannot be eliminated.

Risk mitigation activities include risk acceptance, avoidance, sharing, and transference as well as risk mitigation proper. *Risk acceptance* requires giving customers the authority to determine how broadly their information can be shared. The success of many software apps on mobile phones has shown that users are willing to sacrifice some level of privacy (data) in exchange for valuable services. If all the benefits of ICT-enhanced programs accrue to parties other than energy users, they will be less inclined to share their data. Conversely, if they see value in exchange for the data, it is more likely this market barrier will be surmountable.

As for *risk sharing* and *transference*, the complexity of utility sector networks and relationships with vendors makes it highly likely that customer data will reside in systems not under utility control. The risk associated with handling customer data is often shared by utilities but seldom transferred to other parties. *Risk mitigation* can be accomplished by anonymizing customer data and establishing standard operating procedures for data handling. Most of the data collected by utilities and third-party vendors are anonymized and protected by standard cybersecurity measures.

The risks to be addressed in the energy sector are not unique, and the protocols for anonymizing and sharing data are well established. For example, all the telecommunications companies use such protocols to anonymize the mobile usage data of their customers. The financial industry routinely exchanges very personal information, including bank account and Social Security numbers between institutions. Faced with security breakdowns in recent years, the financial sector is developing more secure technologies and processes that will make breaches less likely to occur in the future and mitigate consumer losses when they do. All these technologies, practices, and policies are transferrable to the energy sector.

Finally, in addition to PIAs, all organizations connected to the smart grid should plan and design cybersecurity risk assessments when they develop new systems and networks and should conduct them on an ongoing basis. It is important that all customers have confidence that in being connected to the smart grid or participating in an efficiency program, they are not opening themselves up to an exploitation of their energy consumption information.

COST RECOVERY OF ICT INFRASTRUCTURE

ICT is evolving into essential infrastructure that is little different from the power lines and poles and substations that are needed to maintain a distribution or transmission system. However that does not necessarily mean that utilities' investments in ICT will be approved by regulators, who are legally bound to approve only those expenditures that they determine are just and reasonable—that is, of value to utility customers. They may not allow utilities to recover the full costs of ICT investments without a reasonable showing that the costs will provide benefit to customers—and not just any benefits, but benefits the utility has been authorized to provide.

Regulators have little history of approving SaaS expenditures. The tendency may be to treat it incrementally: ICT that is incorporated into modernized hardware or required to optimize its usage will be allowed as a recoverable expense, but ICT that brings a wider range of systemic benefits to the utility and its customers may be rejected as a recoverable expense if the relationship to traditional hardware and systems is not linear or direct. For example, regulators might allow a utility to replace an internal, proprietary email server with an outsourced, Internet-based one on the basis of operating cost savings, broader availability of support, and improved reliability. However they might deny cost recovery of the incremental costs associated with extending the usage of the outsourced service to deal directly with customer communications. They might rule that such services are new or enhanced and therefore nonessential (Marc Collins, senior principal energy consultant, Itron, pers. comm., September 11, 2015).

A second challenge arises from the fact that a single ICT investment can support multiple smart grid functions. Calculating its value requires knowledge of all likely benefits and the ability to attribute them. According to Miller (2014), "In some cases, the communication upgrade may end up supporting functions that are implemented only later. Perhaps these functions would not even be considered until after the new communications are in place—the available bandwidth inspires system planners to consider functions that previously were unfeasible. "

Determining value and assigning benefits are barriers to increased investment in intelligent efficiency and smart grid technologies. Just as the value of distribution lines is not dissected at the individual pole level, investments in ICT should be examined holistically, recognizing that each part is a piece of a larger whole.

Utilities are motivated to make investments for which they can get cost recovery and a rate of return, for example in generating stations, transmission and distribution (T&D), and so on. So, whether it is intended or not, many utilities are biased toward investing in large capital assets (Hayes et al. 2011). Not only do investments in technology upgrades have to compete with such capital investments, but they also decrease the need for such capital investments in the future. Unless the issue of cost recovery is addressed by regulators, utilities may not perceive investments in intelligent efficiency as being in their best interests (Hayes et al. 2011).

The last issue is cost recovery for smart meters and other AMI assets not already installed. Some of the existing AMI infrastructure was subsidized by funds from the American Recovery and Reinvestment Act of 2009 (ARRA). The utilities in some states, such as New York, have installed few if any smart meters. These are expensive outlays, and not all state regulators have approved associated cost recovery. In the absence of AMI data, programs seeking to capitalize on ICT may need to tap into the data feeds from remote sensors or building management systems. This additional hurdle will be a barrier to ICT-enabled M&V in those states, since AMI infrastructure is generally seen as a necessary foundation for ICT-enabled energy services (Dian Grueneich, senior research scholar, Stanford University, pers. comm., September 8, 2015).

Farther into the Future

The introduction of ICT and M2M to the energy efficiency sector could potentially reduce the need for some, but not all, existing energy efficiency programs. This will be possible because it might enable customers to recover through competitive markets the value their energy efficiency has to the larger energy system. The ability to accurately quantify and verify their energy savings creates a potentially tradable commodity. Efficiency programs could restructure to purchase this commodity, and markets could emerge to facilitate the trading of such commodities.

We can anticipate that these changes will happen along a timeline like the one in figure 5, with programs initially tying financial incentives to actual energy savings.

Dynamic savings
programs

Energy efficiency
markets

Time-of-use pricing

Figure 5. Penetration of ICT into the energy efficiency sector

The next step might be the availability of time-of-use pricing and customers' ability to respond to that information. Ultimately, customers will have access to markets where they can trade their energy savings, or "negawatts," just as a generator might sell its megawatts. Large customers with sufficient sophistication will enter the markets on their own, while smaller customers or those with less interest in the details may participate through third parties and utility-sector programs.

The changes in program design and the development of new markets will change the policies of regulators. We can also anticipate it will have some effect on the roles and responsibilities of administrators, implementers, and evaluators. It may also bring in new market entrants, such as financial companies, or ESCOs may expand their offerings.

FUTURE PROGRAM DESIGN

The use of ICT and M2M enables the establishment of a dynamic baseline—a baseline of energy use that varies with current operating conditions. With a dynamic baseline, the pre- and post-implementation energy use for a specific measure or group of measures can be determined with a considerable degree of confidence.

This development provides an opportunity to move from energy efficiency programs that are device-based to programs that are system , whole building, or performance based. Older programs that may be reaching the limits of what can be achieved with fixed rebates for purchasing specific items may be updated to use the concept of dynamic savings, especially if such programs can appeal to their larger industrial and commercial customers or allow third parties to aggregate savings across customers (Rogers et al. 2013b).

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With the ability to determine current usage and future savings relatively easily, inexpensively, and accurately, a building operator or factory manager and the efficiency program administrator (or a third party) can begin a conversation on paying for performance. Once in place, a smart meter, smart thermostat, advanced BMS, or EMIS will be able to compare post-implementation usage with a previous baseline under similar operating conditions and then determine associated energy savings. The intelligent device might also have the ability to forecast future energy demands (Rogers et al. 2013b).

Performance information could be reported to the program administrator and an incentive paid on the basis of energy saved. Programs might provide a bulk of the incentive up front, based on forecast energy savings, and later release the balance as actual performance is reported. That balance could increase or decrease depending on whether more or less energy has been saved than forecast, and it could be released over a period of one or more years. This approach could lower energy consumption in existing buildings by providing regular reporting on energy usage so that, even if conditions change, building owners and occupants could maintain lower energy levels. Such an approach would be particularly effective in states that rely on efficiency to meet carbon reduction goals (Grueneich 2015). Both parties would have to agree to the baseline and the protocols for determining the energy savings at the beginning of the project.

Program administrators could experiment with dynamic savings approaches, refining the approach as they learn what does and does not work, then gradually expanding to a larger pool of appropriate customers (Grueneich 2015). They would do well to participate in collaborative efforts to establish common energy management practices and energy savings determination protocols. Existing efforts to develop common protocols for demand response, such as the OpenADR Alliance, can be leveraged and expanded to communicate energy data between utilities and their customers. It opens up programs to third-party vendors and aggregators that can sign up dozens or even hundreds of customers to participate in efficiency programs that make payments based on metered savings.

As utilities install smart grids, they can work with their more sophisticated commercial and manufacturing customers to supply a facility's advanced BMS or EMIS with smart-grid data on the value of energy for any given time of day and customer location. Each customer can then respond with changes in energy usage that reflect internal priorities, one of which may be reducing energy expenses.

PROJECT FINANCING

Analytical tools can provide the type of data that allow true financial risk-management approaches by expressing energy savings values in terms of uncertainty and confidence. ICT-enabled data collection and analysis are already facilitating third-party financing of energy efficiency programs. Energy service companies like Joule Assets, kWantera, and Icetec can quickly and accurately perform cost benefit and risk analyses of efficiency projects. These analyses can be used by lending companies to determine the terms of their lending. Some of the financial companies, like Joule Assets and SparkFund, go one step further and create new financial instruments based on loans for energy efficiency investments. They then bundle and securitize the loans in secondary financial markets (Joule Assets 2015, SparkFund 2015). These financial companies are setting up energy

efficiency funds just as is done for solar power systems. By taking on a portfolio approach in which hundreds or thousands of projects are financed, they can dilute the risk associated with an individual project, thereby improving the terms of the financing instrument. Better financial terms for investments in energy efficiency will translate into a greater volume of investments.

WHOLESALE ELECTRIC POWER MARKETS

Sensors, intelligent efficiency, communication networks, and data analytics are all coming together to simplify the determination of a baseline, current energy consumption, and the savings from projects. This in turn opens up the possibility of treating energy efficiency as a resource on equal terms with conventional resources.

Over the past four decades we have seen the development of wholesale energy markets that have facilitated competition in the supply of both electricity and natural gas. The wholesale natural gas supply market that emerged in the 1970s has been well developed for decades, with many sources of natural gas, a robust network of transmission pipelines, and commodity and futures trading exchanges. Competition exists for the wholesale supply and transmission of natural gas purchases. Organizations that need to purchase large quantities of natural gas, such as local distribution utility companies (LDCs), large commercial firms and institutions, and industrial customers, can purchase supplies of natural gas in just about any quantity and on any schedule they need. They can also hedge their pricing in futures markets. Residential and small-business customers can rarely take advantage of such commodity competition. They are served by LDCs that are subject to conventional utility regulation.

Competitive wholesale markets for electricity are still developing, with those in the Northeast the most advanced. Among the most robust are the Independent System Operator for New England (ISO-NE) Forward Capacity Market and the markets run by the PJM Interconnection regional transmission organization (ISO NE 2015; PJM 2015a). The first has responsibility to ensure the availability of competitively priced wholesale electricity for Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and most of Maine, and the second manages the flows of electricity in the mid-Atlantic grid, which covers all or parts of 13 states and the District of Columbia (ISO NE 2015; PJM 2015b). They both operate energy markets for buying and selling day-to-day wholesale electric power, capacity markets for ensuring long-term system reliability, and ancillary service for ensuring short-term system reliability.

Energy markets provide a platform for trading electricity on a real-time and day-ahead basis. Generators of electricity bid in capacity to supply electricity to one or more electrical service territories (PJM 2015b). Theoretically, any generator can supply any service territory with power. However built into a generator's bid are tolling charges by the transmission system to transfer power from source to load, so the movement of power is usually limited in distance.

More recently, energy efficiency and demand response have become eligible energy resources that can be bid into the various markets within both ISO-NE and PJM (ISO NE 2015; PJM 2015c). For example, each year PJM organizes a base residual auction (BRA) in

which participants can bid in their resources, to be provided three years in the future. A given load can be met by a combination of generation and energy savings.

In one emerging market structure, suppliers bid their energy resources into near-term or long-term capacity markets that are designed to meet expected future loads. The operators of these markets select bids, starting with lowest cost and moving toward higher cost until they have secured sufficient capacity to meet system demand for the prescribed period. The price of the last bid accepted is called the clearing price, and all accepted bids receive that rate regardless of bid price.

This system rewards low-cost resource providers and benefits from greater market participation. The more market participants, the more competitive the auction, and the greater the pressure to submit a lower bid. If all resources that are available are bid into a market, the market should meet the demands of the system at the lowest cost. Because the cost of energy efficiency resources are generally lower than conventional generation resources, they can compete quite well in these markets (Molina 2014).

Energy efficiency resources can be bid into these markets by utilities, program administrators, or private third parties who fund energy efficiency investments and then realize revenues by aggregating savings from multiple projects and bidding them into forward capacity markets. For example, Vermont Energy Investment Corporation (VEIC), the State of Vermont's appointee operating Efficiency Vermont, a statewide energy efficiency utility, represents the interests of the state's ratepayers through participation in the ISO-NE Forward Capacity Market (FCM). Gross revenue from the FCM in 2013 was expected to be approximately $3,535,000 (VEIC 2013).

The EnerNOC case study below is an example of how an independent third party can aggregate the demand reductions from multiple facilities and bid them into a forward capacity market.

Case Study: Resource Capacity Markets and Demand Response

EnerNOC, a Boston-based energy services company, is participating in PJM capacity markets by bidding demand-side generation and/or the load-shedding resources of their customers into capacity markets (Lacey 2013; EnerNOC 2009). Many of its customers are not sufficiently large or sophisticated enough to participate in the market themselves, so EnerNOC aggregates their energy resources and uses its expertise to monetize the value of customers' investments in energy efficiency.

To be successful in this endeavor EnerNOC must be able to verify to the PJM the demand reduction promised. To accomplish this, it tracks customers' energy consumption at a granular level. This includes reading meters and controlling equipment in five-minute increments. That information is then normalized to external factors such as weather, occupancy, and production so EnerNOC can understand what drives energy consumption (Lacey 2013). Data analytics are used to predict customers' future energy consumption and match it to the needs of the energy market.

The business model highlighted in the EnerNOC case study is built around load shedding (demand response), but it could just as easily be built around aggregating the energy savings from multiple projects at multiple facilities, as is done by Efficiency Vermont. When implementers have a detailed understanding of customers' energy consumption profiles

and how customers respond to specific energy efficiency measures, they can aggregate savings from projects with the same profile to create a particular type of energy efficiency resource. Alternatively, they can aggregate multiple profiles to create a more uniform energy efficiency resource to bid into the market. Figure 6 shows how complementary these energy efficiency and demand response products are in meeting the needs of an electric system. Energy efficiency lowers the overall demand curve throughout the day, while demand response lowers the peak. Both activities reduce the volume and size of generation and transmission needed to meet customer demand, thereby lowering overall system costs.
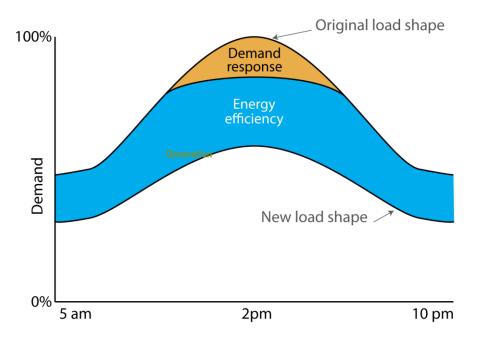

Figure 6. Effect of energy efficiency and demand response on daily demand curves

In order for energy efficiency to be treated with the same confidence as conventional generation—which can document quite easily the volume of electricity generated—the markets must have confidence that the volume of savings will materialize when and where promised. To meet this need, the ISO-NE Forward Capacity Market requires participants to have an M&V plan that describes how they will ensure that ISO-NE can rely on the capacity reduction promised and how they will measure and verify capacity savings during specific peak hours. Emerging EM&V technologies and practices could have a great effect on both requirements. Since they can aid in the establishment of an energy consumption baseline, and since they can collect energy performance data on a continuous basis, they can also report on demand reduction and energy savings during periods of market participation.

ICT is currently enabling companies like EnerNOC and VEIC to sell demand reductions into capacity markets where they can monetize the savings of their customers. As these technologies and methodologies improve, barriers to greater market participation will fall, and the electric system will operate more efficiently and in a way that is less costly to end users.

CHANGING UTILITY PARADIGM

In a possible future, the utility will no longer be at the center of the energy sector. Customers will be. The term *prosumer* has emerged to describe energy customers who are active participants in the generation and consumption of energy services. Many large customers have some type of onsite generation, and more than 100,000 small solar PV systems are being installed each year (Motyka and Clinton 2015; SEIA 2014). These and many more customers with an ability to dynamically control their loads will be targeted by third-party aggregators with services that take advantage of demand response programs and forward capacity markets who will offer them services that can monetize their investments in efficiency. Many customers will likely want to be able to buy and sell energy resources among themselves, independent of the utility and regulatory communities (Zichella 2015). All of this will be enabled by new information and communications technologies, data analytics, and automated M&V methodologies.

As figure 7 illustrates, the customer will replace the utility at the center of the energy market. The many components of the energy delivery sector might be deconstructed into contestable markets in which there are many service providers.
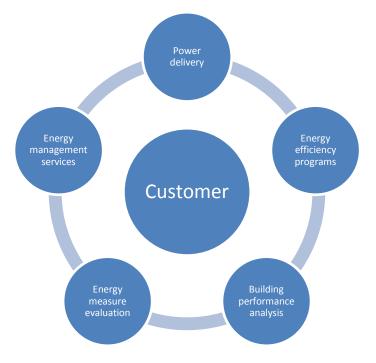

Figure 7. Customer-centric future

Insights into what this might look like have started to emerge. The recent New York Reforming the Energy Vision (REV) Order states that distributed system platform providers will provide or sell a set of products and services to customers and service providers (Zichella 2015). In February 2015, the State of New York Public Service Commission (PSC) issued an order that lays out a new regulatory policy framework and implementation plan. REV will reorient both the electric industry and the ratemaking paradigm toward a consumer-centered approach that harnesses technology and markets (Zichella 2015). Much

of this change will be facilitated by recent ICT advances and will require improvements in communications and EM&V protocols.

One major hurdle, however, is that the majority of New York residences and small/medium commercial buildings do not have smart meters (IEI 2014). Such meters are generally seen as a necessary foundation to the use of ICT in energy services. Installation of the meters will cost billions of dollars, and to date the PSC has been silent on a plan to pay for the meters in both the short and the long term, especially in the light of the NY REV's goal of lowering bills.

California, too, is reviewing the role of its utilities at the distribution level and seeking to enhance the part that distribution-level resources, especially on the demand side, can play (CPUC 2015; Grueneich 2015). One area of focus is the integration of distributed energy resources (DERs) into utility distribution system planning, operations, and investments.[14] Another focus area is developing a new regulatory framework enabling utility customers to most effectively and efficiently choose from an array of demand-side resources and DERs, focusing on both customer and system benefits, and within a regime of significantly reducing carbon emissions (CPUC 2015).

Policymakers and utilities outside of New York and California are also recognizing that the market is changing and starting to analyze what changes are best for their states, utilities, and consumers. Much as the advent of cellular technologies transformed the telecom industry, ICT will help to transform the energy sector. Customers are asking for more control and more choices but also seeking to avoid significant bill increases. However, unlike the telecom industry, which has rapidly abandoned landlines, energy experts generally expect that most consumers and businesses will remain physically connected to the larger utility distribution system and grid. Therefore, we can anticipate that regulated utilities will continue to play a significant role for the foreseeable future.

Recommendations and Conclusions

The complexity of the efficiency program sector means a thoughtful and measured approach is necessary if we are to fully realize the potential of ICT to improve EM&V. The common feature of many of the solutions we have identified so far is the requirement for collaborative effort. The problems are too complex and too broad in scope to be solved by a single government agency, utility, or trade organization. Regulators, utilities, program administrators, technology providers, and evaluators will all need to be involved. Each has an important perspective and set of resources to bring to the challenge.

Pilot programs and demonstration projects are good methods for proving the efficacy of advanced analytical techniques. However many techniques require large data sets; this necessitates working with a utility and may require working with a significant segment of a

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[14] The California investor-owned utilities issue local capacity requirements request for offers (LCR RFO) for gas-fired generation, combined heat and power, demand response, energy efficiency, energy storage, renewables, resource adequacy, and distributed generation (SCE 2015).

customer population. In some instances, analytic engines can be tested on historical data, but this may not always be possible.

Policies that were established in the past to balance the interests of stakeholders should be reevaluated in light of new capabilities made possible by new technologies. Program administrators should work with their regulators to determine if existing policies are still appropriate or if they are preventing innovation and market growth. Where they find existing policies wanting, stakeholders should work together to develop new policies that facilitate innovation and balance stakeholder interests.

Regulators should give program administrators the flexibility to experiment and invest in new technologies; in turn, program administrators should use this flexibility to test the capabilities of ICT-enabled evaluation practices and determine where and when they can add value. Technology providers should work with both to identify and understand new risks, and all three groups should work together to ensure customer protection.

Evaluators and regulators should work together to ensure the transparency of evaluation methods and assumptions, as both are important to the proper interpretation and acceptance of evaluation results. Stakeholder understanding of the EM&V methods used by a program is key to their trust in program results.

Table 2 summarizes how each group of stakeholders will be affected by the incorporation of ICT into EM&V practices. The stakeholders are grouped according to their roles in the energy efficiency industry (Granderson and Cody 2015).

Table 2. Impact of ICT-enhanced EM&V on energy efficiency sector stakeholders

Role	Stakeholders	Impact
Policymaking	Federal, state, and local governments	Greater mandate for energy efficiency as a resource
Regulatory oversight	Public utility commissions	Development of energy efficiency markets
Program evaluation	Program evaluators	More insight into project and program performance
Project financing	Investment firms, program administrators, government agencies	More sophisticated financial models
Program implementation	Program administrators and implementers, energy service companies, facility-level energy managers	More timely and accurate performance tracking

As described throughout this report, the influence of ICT will be comprehensive across the efficiency sector and influence the design and execution of programs from customer engagement to portfolio evaluation. All stakeholders will be affected, and each will realize new benefits and face new challenges.

CONCLUDING THOUGHTS

The energy efficiency sector has had a long-standing goal of being able to measure energy savings with the same accuracy and fluidity that utilities achieve in measuring electricity consumption. The industry-standard Westinghouse meter has provided very accurate measurement (+/– 0.3%) for well over a century. It is unlikely that such precision will ever be achieved for a single energy-saving measure (DOI 2000; Watthourmeter.com 2015). It is possible, though, to know with a high degree of certainty the gross reduction in energy consumption from a portfolio of energy measures and projects. So while the promise of ICT is not yet fully realized, we are getting closer.

The energy efficiency sector will be transformed by the ubiquity of ICT. It will simplify the harvesting of savings data, improve the accuracy and timeliness of reporting, and assist in providing context to energy data. In addition to influencing utility-sector energy efficiency programs, this capability will also increase the volume of efficiency bid into capacity markets and financed by private-sector financial markets.

We have seen how ICT can be used to identify opportunities to save energy. We have also seen how analytical tools can be used to determine the gross savings of an energy measure and relay that information to the end user and program administrator. The information can come from a smart meter, intelligent efficiency measures, or facility energy management systems. The anchoring service of these advanced technologies will continue to be measuring and reporting the supply of energy, just as the anchor of the smartphone is making telephone calls. But the motivation for networking energy-consuming systems will be the information and knowledge they provide, just as the motivation to have a smartphone is no longer merely about telephoning (St. John 2014). The information on consumption will be harmonized with the information on savings, and the overall energy performance of a facility will be documented in near real time. The energy savings information will then be aggregated at the program level and reported out to stakeholders.

This capability will have a profound impact on energy efficiency programs. It is already changing how programs interact with customers, especially regarding the identification of opportunities. It will change how post-implementation data are collected and reported. By incorporating ICT into the design and management of their services, program administrators and evaluators will be able to improve the effectiveness of their actions and reduce their operating costs.

ICT can provide greater transparency and confidence in the accuracy of efficiency efforts, thus providing important assurances (with possibly reduced oversight) to regulators and program administrators. In the short term, it is an innovation that sustains the existing paradigm by reducing costs and improving the effectiveness of existing business models. In the long term, this technology also has the ability to radically change the market by reducing previously intractable market barriers. When barriers are removed, markets open up to greater participation and competition, which in turn can reduce the need for mandatory programs to compensate for market failures.

There will still be a need for transparency, and this will require regulatory oversight. And ICT technologies will not completely eliminate the need for programs. Many market barriers

will remain. But when markets can put a value on where and when consumption is reduced, energy efficiency moves closer to realizing its full value in the marketplace and closer to the ability to compete on equal terms with supply to meet resource demands.

It has often been said that for markets to function properly, a certain level of trust is required. New products and services will have to prove their worth at each step of the way. As they do, the use of ICT to automate EM&V will increase, and so will the level of trust in the energy efficiency sector. And with this increase in confidence, the sector is sure to grow.

Efforts to develop new policies and design new programs will be all the more challenging given the speed of technological advancement. But such efforts will be worth the investment. The penetration of ICT into the energy efficiency program sector is inevitable, and effective EM&V practices are needed if we are to ensure that everyone benefits. Success in this task will be good for the energy efficiency sector by bringing down costs and increasing energy savings, and both of these will be good for energy consumers and the US economy. The determination of savings will be more accurate and less costly. This will translate to greater confidence in the benefits of all energy measures, and that will result in greater investment in energy efficiency and ultimately a more energy-efficient economy.

References

Akyol, B., J. Haack, S. Ciraci, B. Carpenter, M. Vlachopoulou, and C. Tews. 2012. "VOLTTRON: An Agent Execution Platform for the Electric Power System." In *Proceedings of the Third Annual Workshop on Agent Technologies for Energy Systems*. Southampton: University of Southampton. www.ates2012.org/papers/paper6.pdf.

Alles, H., B. Zenger. 2014. "A Commercial Disaggregation System for Residential and Light Commercial Buildings." In *Proceedings of the Second International Workshop on Non-Intrusive Load Monitoring (NILM)*. Austin: University of Texas. nilmworkshop14.files.wordpress.com/2014/05/alles_commercial.pdf.

Baatz, B. 2015. *Everyone Benefits: Practices and Recommendations for Utility System Benefits of Energy Efficiency*. Washington, DC: ACEEE. aceee.org/everyone-benefits-practices-and-recommendations.

Bode, J., L. Carrillo, and M. Basarkar. 2014. "Whole Building Energy Efficiency and Energy Savings Estimation: Does Smart Meter Data with Pre-Screening Open up Design and Evaluation Opportunities?" In *Proceedings of the ACEEE 2014 Summer Study on Energy Efficiency in Buildings,* 4:36–49. Washington, DC: ACEEE (American Council for an Energy-Efficient Economy). aceee.org/files/proceedings/2014/data/papers/4-442.pdf.

CEC (California Energy Commission). 2015. "DEER: Database for Energy Efficiency Resources." Accessed September 17. www.energy.ca.gov/deer.

Cluett, R., and J. Amann. 2015. *Multiple Benefits of Multifamily Energy Efficiency for Cost-Effectiveness Screening*. Washington, DC: ACEEE. aceee.org/multiple-benefits-multifamily-energy-efficiency.

CPUC (California Public Utilities Commission). 2015. "Procurement Process." Accessed October 18. cpuc.ca.gov/PUC/energy/CHP/processes.htm.

Craft, R., and B. Fisher. 2014 "Energy-Efficient Buildings, Analytics and Con Edison." *Electric Light & Power*. August 21. www.elp.com/articles/print/volume-92/issue-4/sections/energy-efficiency-demand-response/energy-efficient-buildings-analytics-and-con-edison.html.

Crowe, E., H. Kramer, and J. Effinger. 2014. *Inventory of Industrial Energy Management Information Systems (EMIS) for M&V Applications*. Portland: Northwest Energy Efficiency Alliance. neea.org/docs/default-source/reports/e14-295-neea-industrial-emis-inventory-report-final-2014-08-25_kw-edited_5.pdf?sfvrsn=8.

DOE (US Department of Energy). 2008. *Federal Energy Management Program (FEMP) M&V Guidelines: Measurement and Verification for Federal Energy Projects Version 3.0.* Washington, DC: DOE.

DOE. 2015a. "About the Uniform Methods Project." Accessed May 4. energy.gov/eere/about-us/about-ump.

———. 2015b. "Building Energy Data Exchange Specification (BEDES)." Accessed May 6. energy.gov/eere/buildings/building-energy-data-exchange-specification-bedes.

———. 2015c. "Building Energy Data Exchange Specification (BEDES) FAQs." Accessed May 6. energy.gov/eere/buildings/bedes-faqs.

———. 2015d. "Building Energy Data Exchange Specification (BEDES) Related Projects." Accessed May 6. energy.gov/eere/buildings/bedes-related-projects.

———. 2015e. "Uniform Methods Project for Determining Energy Efficiency Program Savings." Accessed October 15. energy.gov/eere/about-us/ump-home.

———. 2015f. "Uniform Methods Project: Determining Energy Efficiency Savings for Specific Measures." Accessed May 4. energy.gov/eere/about-us/ump-protocols.

Digital Lumens. 2013. "Case Study: Flexible Energy Efficiency Program Reaps Massive Energy Savings." Boston: Digital Lumens. digitallumens.com/wp-content/uploads/2015/07/Case-Study-ComEd.pdf.

DOI (Department of the Interior). 2000. *Facilities Instructions, Standards, and Techniques Volume 3-10: Watt-Hour Meter Maintenance and Testing.* Denver: DOI. www.usbr.gov/power/data/fist/fist3_10/vol3-10.pdf.

Eckman, T., and M. Sylvia. 2014. "EM&V 2.0—New Tools for Measuring Energy Efficiency Program Savings." *Electric Light and Power*. February 12. www.elp.com/Electric-Light-Power-Newsletter/articles/2014/02/em-v-2-0-new-tools-for-measuring-energy-efficiency-program-savings.html.

EEC (Energy Efficiency Coalition). 2015. "Comments of the Energy Efficiency Coalition Regarding PJM's Capacity Performance Proposal." Accessed August 13. www.pjm.com/~/media/committees-groups/committees/elc/coalition-briefing-papers/coalition-paper-energy-efficiency-coalition.ashx.

Elliott, N., M. Molina, and D. Trombley. 2012. *A Defining Framework for Intelligent Efficiency*. Washington, DC: ACEEE. aceee.org/research-report/e125.

Ellis, C. 2015. "21st Century DSM Measurement: Quantification for Market Transformation." Presentation to ACEEE Market Transformation Conference. April. aceee.org/sites/default/files/pdf/conferences/mt/2015/D3-Ellis.pdf.

EnerNOC. 2009. *Demand Response: A Multi-Purpose Resource for Utilities and Grid Operators*. 2015. Boston: EnerNOC. www.enernoc.com/themes/bluemasters/images/brochures/pdfs/2-Whitepaper-DR-A_Multi-Purpose_Resource.pdf.

EPRI (Electric Power Research Institute). 2011. *Estimating Costs and Benefits of a Smart Grid*. Palo Alto: EPRI. epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001022519.

EVO (Efficiency Valuation Organization). 2014. *International Performance Measurement and Verification Protocol: Core Concepts*. Washington, DC: EVO. www.evo-world.org/index.php?option=com_rsform&formId=124&lang=en.

FERC (Federal Energy Regulatory Commission). 2014. "Smart Grid." October 24. www.ferc.gov/industries/electric/indus-act/smart-grid.asp.

Fetter, J., S. Thomas, A. Potes, and G. Rahl. 2012. "Energy Efficiency in the Forward Capacity Market: Evaluating the Business Case for Building Energy Efficiency as a Resource for the Electric Grid." In *Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings,* 5:126–138. Washington, DC: ACEEE. aceee.org/files/proceedings/2012/data/papers/0193-000167.pdf.

Friedman, H., E. Crowe, E. Sibley, and M. Effinger. 2011. *The Building Performance Tracking Handbook*. Prepared for the California Energy Commission (CEC). Portland: Portland Energy Conservation, Inc. www.cacx.org/PIER/documents/bpt-handbook.pdf.

Gellings, C. 2011. *Estimating Costs and Benefits of a Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid*. Palo Alto, CA: Electric Power Research Institute (EPRI). www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001022519.

Gilleo, A., S. Nowak, M. Kelly, S. Vaidyanathan, M. Shoemaker, A. Chittum, and T. Bailey. 2015. *The 2015 State Energy Efficiency Scorecard*. Washington, DC: ACEEE. http://aceee.org/research-report/u1509.

Granderson, J., and T. Cody. 2015. "M&V 2.0 Deployment Plan." Unpublished manuscript, last modified July 25.

Granderson, J., P. Price, D. Jump, N. Addy, and M. Sohn. 2015. "Automated Measurement and Verification: Performance of Public Domain Whole-Building Electric Baseline Models." *Applied Energy* 144: 106-113. eetd.lbl.gov/sites/all/files/lbnl-187596_0.pdf.

Grueneich, D. 2015. "The Next Level of Energy Efficiency: The Five Challenges Ahead." *Electricity Journal* 28 (7): 44-56. www.sciencedirect.com/science/article/pii/S104061901500144X.

Grueneich, D., and D. Jacot. 2014. "Scale, Speed, and Persistence in an Analytics Age of Efficiency: How Deep Data Meets Big Savings to Deliver Comprehensive Efficiency." *Electricity Journal* 27 (3): 77-86. dx.doi.org/10.1016/j.tej.2014.03.001.

GWAC (GridWise Architecture Council). 2005. "GridWise Architecture Council Interoperability Path Forward Whitepaper." Richland, WA: GWAC. www.gridwiseac.org/pdfs/interoperability_path_whitepaper_v1_0.pdf.

Haeri, H. 2015. *The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures*. Golden, CO: National Renewable Energy Laboratory (NREL). energy.gov/sites/prod/files/2015/02/f19/UMPIntro1.pdf.

Hart, G. 1992. "Nonintrusive Appliance Load Monitoring." In *Proceedings of the IEEE*, 80 (12): 1870–1891.

Hayes, S., S. Nadel, M. Kushler, and D. York. 2011. *Balancing Interests: A Review of Lost Revenue Adjustment Mechanisms for Utility Energy Efficiency Programs*. Washington, DC: ACEEE. aceee.org/research-report/u114.

Henwood, A., and P. Bassett. 2015. "EMIS Program Design, Delivery and Results with Efficiency Nova Scotia." In *Proceedings of the ACEEE 2015 Summer Study on Energy Efficiency in Industry*, 1:1–13. Washington, DC: ACEEE. aceee.org/files/proceedings/2015/data/papers/1-88.pdf.

IEI (Institute for Energy Innovation). 2014. *Utility-Scale Smart Meter Deployments: Building Block of the Evolving Power Grid*. Washington, DC: IEI. www.edisonfoundation.net/iei/Documents/IEI_SmartMeterUpdate_0914.pdf.

ISO-NE (Independent System Operator for New England). 2015. "Energy-Efficiency Forecast." Accessed October 15. iso-ne.com/system-planning/system-forecasting/energy-efficiency-forecast.

Kolwey, N. 2013. *Utility Strategic Energy Management Programs.* Boulder, CO: Southwest Energy Efficiency Project. www.swenergy.org/data/sites/1/media/documents/publications/documents/Utility _SEM_programs_03-2013.pdf.

Kushler, M., S. Nowak, and P. Witte. 2012. *A National Survey of State Policies and Practices for the Evaluation of Ratepayer-Funded Energy Efficiency Programs*. Washington, DC: ACEEE. aceee.org/research-report/u122.

———. 2014. *Examining the Net Savings Issue: A National Survey of State Policies and Practices in the Evaluation of Ratepayer-Funded Energy Efficiency Programs*. Washington, DC: ACEEE. aceee.org/research-report/u1401.

Lacey, S. 2013. "Intelligent Efficiency: Innovations Reshaping the Energy Efficiency Market." *Greentech Media.* June 4. www.greentechmedia.com/articles/read/intelligent-efficiency-innovations-reshaping-the-energy-efficiency-market.

Langer, T., and S. Vaidyanathan. 2014. "Smart Freight: Application of Information and Communications Technologies to Freight System Efficiency." Washington, DC: ACEEE. aceee.org/white-paper/smart-freight-ict.

Lanzisera, S., K. Pister, and M. Lorek. 2014. "Electricity Submetering on the Cheap: Stick-On Electricity Meters." In *Proceedings of the ACEEE 2014 Summer Study on Energy Efficiency in Buildings*, 1:146–155. Washington, DC: ACEEE. aceee.org/files/proceedings/2014/data/papers/1-226.pdf.

Lundin, B. 2013. "EPA/Energy Star Appliances Encourage Smart-Grid Functionality." *SmartGrid News*. July 2. www.smartgridnews.com/story/epaenergy-star-appliances-encourage-smart-grid-functionality/2013-07-02.

Lutz, A., and P. Pagadala. 2014. "Discrepancy, What Discrepancy? Reasons for the Difference between Claimed and Evaluated Savings." In *Proceedings of the ACEEE 2014 Summer Study on Energy Efficiency in Buildings*, 4:251–262. Washington, DC: ACEEE. aceee.org/files/proceedings/2014/data/papers/4-924.pdf.

Miller, C., T. Lovas, M. Martin, and R. Schmidt. 2014. *Communications: The Smart Grid's Enabling Technology*. Arlington, VA: NRECA (National Rural Electric Cooperative Association). www.smartgrid.gov/files/NRECA_TPR2_Communications.pdf.

Molina, M., and M. Neubauer. 2014. "Still the First Fuel: National Review of the Cost of Utility Energy Efficiency Programs." In *Proceedings of the ACEEE 2014 Summer Study on Energy Efficiency in Buildings*, 8:248–260. Washington, DC: ACEEE. aceee.org/files/proceedings/2014/data/papers/8-1233.pdf.

Motyka, M., and A. Clinton. 2015. *Energy Management Passes the Point of No Return*. Washington, DC: Deloitte. www2.deloitte.com/content/dam/Deloitte/us/Documents/energy-resources/us-er-deloitte-resources-study-series.pdf.

Nagappan, P. 2012. "Retroficiency Offers a Quick Solution for Building Energy Audits." *GreenBiz*. April 4. www.greenbiz.com/blog/2012/04/04/retroficiency-offers-quick-solution-buildings-energy-audits.

Nest. 2015. "Privacy Statement for Nest Products and Services." Accessed July 15. nest.com/legal/privacy-statement-for-nest-products-and-services/

Neubauer, M. 2014. *Cracking the TEAPOT: Technical, Economic, and Achievable Potential Studies*. Washington, DC: ACEEE. aceee.org/research-report/u1407.

Oster, J., T. Guiterman, and M. Rigney. 2015. *Transforming Energy Efficiency through Modern Measurement*. Seattle: EnergySavvy. land.energysavvy.com/modern-measurement-white-paper/.

Parson, O., S. Gosch, M. Weal, and A. Rogers. 2012. "Non-Intrusive Load Monitoring Using Prior Models of General Appliance Types." In *Proceedings of the Twenty-Sixth AAAI Conference on Artificial Intelligence*, 356–362. Palo Alto, CA: Association for the Advancement of Artificial Intelligence. www.aaai.org/ocs/index.php/AAAI/AAAI12/paper/view/4809.

Piette, M., G. Ghatikar, S. Kiliccote, E. Koch, D. Hennage, P. Palensky, and C. McParland. 2009. *Open Automated Demand Response Communications Specification (Version 1.0)*. California Energy Commission. openadr.lbl.gov/pdf/cec-500-2009-063.pdf.

PJM (PJM Interconnection). 2015a. "PJM Manual 18: PJM Capacity Market." Accessed August 3. www.pjm.com/~/media/documents/manuals/m18.ashx.

———. 2015b. "PJM Markets Factsheet." Accessed August 10. www.pjm.com/~/media/about-pjm/newsroom/fact-sheets/pjms-markets-fact-sheet.ashx.

———. 2015c. "Reliability Pricing Model Demand Response and Energy Efficiency." Accessed August 10. www.pjm.com/~/media/markets-ops/rpm/20090406-dr-ee-in-rpm-collateral.ashx.

PNNL (Pacific Northwest National Laboratory). 2015. "What Is the VOLTTRON™ Platform?" Accessed October 12. transactionalnetwork.pnnl.gov/volttron.stm.

Project Haystack. 2015. "Docs." Accessed August 5. project-haystack.org/doc.

Raghavan, B. 2015. "Exploring Real-Time Measurement & Verification." Presentation to ACEEE Market Transformation Conference. April. aceee.org/sites/default/files/pdf/conferences/mt/2015/D3-Raghavan.pdf.

RAP (Regulatory Assistance Project). 2011. *Electricity Regulation in the US: A Guide.* Montpelier, VT: RAP. www.raponline.org/search/recommended-reading.

Rogers, E. 2014. *The Energy Savings of Smart Manufacturing.* Washington, DC: ACEEE. aceee.org/sites/default/files/publications/researchreports/ie1403.pdf.

Rogers E., R. Elliott, A. Chittum, C. Bell, and T. Sullivan. 2013a. *An Introduction to U.S. Policies to Improve Industrial Energy Efficiency.* Washington, DC: ACEEE. aceee.org/research-report/ie133.

Rogers, E., R. Elliott, S. Kwatra, D. Trombley, and V. Nadadur. 2013b. *Intelligent Efficiency: Opportunities, Barriers, and Solutions.* Washington, DC: ACEEE. aceee.org/research-report/e13j.

Russell, C. 2015. *Multiple Benefits of Business-Sector Energy Efficiency: A Survey of Existing and Potential Measures.* Washington, DC: ACEEE. aceee.org/research-report/ie1501.

Russell, C., B. Baatz, R. Cluett, and J. Amann. 2015. *Recognizing the Value of Energy Efficiency's Multiple Benefits.* Washington, DC: ACEEE. aceee.org/research-report/ie1502.

SCE (Southern California Edison) 2015. "Energy Procurement: Local Capacity Requirements (LCR). " Accessed October 18. www.sce.com/wps/portal/home/procurement/solicitations/lcr/.

Schiller, S., C. Goldman, and E. Galawish. 2011. *National Energy Efficiency Evaluation, Measurement & Verification (EM&V) Standard: Scoping Study of Issues and Implementation Requirements.* Berkeley: Lawrence Berkeley National Laboratory. emp.lbl.gov/sites/all/files/lbnl-4265e.pdf.

SEE Action (State and Local Energy Efficiency Action Network). 2012. *Energy Efficiency Program Impact Evaluation Guide*. Prepared by S. Schiller, Schiller Consulting, Inc. Washington, DC: SEE Action. www4.eere.energy.gov/seeaction/sites/default/files/pdfs/emv_ee_program_impact_g uide_1.pdf.

———. 2013. *A Utility Regulator's Guide to Data Access for Commercial Building Energy Performance Benchmarking*. Prepared by A. Schulte, ICF International. https://www4.eere.energy.gov/seeaction/system/files/documents/commercialbuildi ngs_data_access_guide_0.pdf.

SEIA (Solar Energy Industries Association). 2015. *Solar Market Insight Report 2014 Q4.* Washington, DC: GTM Research. http://www.seia.org/research-resources/solar-market-insight-report-2014-q4.

Silver Spring Networks. 2014. *The SilverLink Sensor Network: A New Way to Create Breakthrough Insights, Efficiencies and Customer Relationships*. Redwood City, CA: Silver Spring Networks.

Sisley, E. 2014. *Cloud Computing Considerations in the Smart Grid*. Wakefield, MA: SGIP. sgip.org/SGIP/files/ccLibraryFiles/Filename/000000001638/SGIP_Cloud_Computing_ Whitepaper.pdf.

Slote, S., M. Sherman, and D. Crossley. 2014. *Energy Efficiency Evaluation Measurement, and Verification: A Regional Review of Practices in China, the European Union, India, and the United States*. Montpelier, VT: Regulatory Assistance Project. www.raponline.org/document/download/id/7064.

St. John, J. 2014. "Itron Launches Its Grid Edge Intelligence Platform to Merge Meters, Comms, Apps and IOT." *Greentech Media*. October 14. www.greentechmedia.com/articles/read/Itron-Launches-its-Grid-Edge-Intelligence-Platform-to-Merge-Meters-Comms.

Summers, H., D. Chan, and C. Hilger. 2013. *FirstFuel Scaled Field Placement.* Prepared for Pacific Gas and Electric Company. San Francisco: Enovity, Inc. www.etcc-ca.com/sites/default/files/reports/ET%2012PGE3341_First%20Fuel_Final.pdf.

VEIC (Vermont Energy Investment Corporation). 2013. *Efficiency Vermont Annual Plan 2013.* Burlington: VEIC. https://www.efficiencyvermont.com/docs/about_efficiency_vermont/annual_plans/E VT-AnnualPlan2013.pdf.

Watthourmeters.com. 2015 "A Brief History of Meter Companies and Meter Evolution." Accessed November 14. www.watthourmeters.com/history.html.

York, D., M. Molina, M. Neubauer, S. Nowak, S. Nadel, A. Chittum, N. Elliott, K. Farley, B. Foster, H. Sachs, and P. Witte. 2013. *Frontiers of Energy Efficiency: Next Generation*

Programs Reach for High Energy Savings. Washington, DC: ACEEE. aceee.org/research-report/u131.

York, D., S. Nadel, E. Rogers, R. Cluett, S. Kwatra, H. Sachs, J. Amann, and M. Kelly. 2015. *New Horizons for Energy Efficiency: Major Opportunities to Reach Higher Electricity Savings by 2030.* Washington, DC: ACEEE. aceee.org/research-report/u1507.

Zichella, C. 2015. "Tipping Point for Transactive Energy?" *Switchboard.* Natural Resources Defense Council staff blog. May 6. switchboard.nrdc.org/blogs/czichella/tipping_point_for_transactive_.html.