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Business Case for Nonintrusive Load Monitoring

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May 2016

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Summary

This report explores how utilities, researchers, and consumers could benefit from a lower cost approach to submetering using non-intrusive load monitoring (NILM). NILM is a process of using data from a single point of monitoring, such as a utility smart meter, to provide an itemized accounting of end use energy consumption in residential and small commercial buildings.

Pacific Northwest National Laboratory (PNNL) prepared this report for the Bonneville Power Administration (BPA). PNNL participated in an advisory group as part of a research project sponsored by the U.S. Department of Energy (DOE), the Bonneville Power Administration, and the State of Washington. The Electric Power Research Institute (EPRI) convened the advisory committee for two workshops held to identify ways in which NILM may be used. PNNL, on behalf of DOE, helped to cosponsor the first of these workshops held at the EPRI offices in Palo Alto, CA, in 2013. The second was sponsored by EPRI and held in Orlando, FL, in 2015.

To identify a set of priority use cases, PNNL summarized the findings of the workshops, and developed descriptions and value propositions for each use case in coordination with an advisory group, which included about 20 representatives of industry, utilities, researchers, and government agencies. The highest priority use cases are to

1. Inform residential customers and utilities -about energy use and load shapes of individual electrical appliances.
2. Enable M&V for utility demand response (verify individual electrical appliances have modified consumption accordingly in response to DR command) and efficiency programs (verify savings from efficiency measures via more efficient end-use technologies).
3. Enable diagnostics and preventative maintenance of electrical appliances/systems for improved building operations.

The business case for uses of NILM for informing energy end use analysis and savings efforts is presented here. Results of an end-use monitoring study of a bank branch conducted by PNNL are also presented for purposes of illustrating the need for better data in energy savings modeling (DOE 2013a).

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1.0 Introduction

Non-intrusive load monitoring (NILM) is a process of using data from a single point of monitoring, such as a utility smart meter, to provide an itemized accounting of a buildings' end use energy consumption. These systems are most applicable to residential and small commercial buildings. This process takes bulk energy consumption data from advanced utility meters and disaggregates individual loads. Low-cost interval metering and communication technology improvements over the past ten years have enabled the maturity of load disaggregation (or non-intrusive load monitoring) technologies to better estimate and report energy consumption of individual end-use loads.

NILM technologies are just emerging in the market. Some approaches use central data collection devices while others analyze end uses based on utility smart meter data. Business models for NILM vendors are still being worked out to provide continuous, real-time load monitoring and analysis. However, vendors are also facing challenges recognizing loads and identifying signature events (on, off, and phases of operation for complex equipment). Despite these challenges, approximately 60 vendors are developing and launching NILM products and services.

A key enabling technology for NILM is the smart utility meter. Smart utility meters communicate real-time bulk electricity consumption data. Approximately 43 percent of U.S. households, equating to about 50 million total meters, were equipped with smart meters as of September 2014 (IEI 2014). In California, over 90 percent of households have smart meters. In the Northwest, about 30 percent of homes are equipped with smart meters capable of providing the interval data that will be needed for NILM.

Smart meters allow utilities to offer services such as home energy reports, downloadable energy use data, budget setting, high usage alerts, and online portals with easy-to-understand graphics (IEI 2014). All of these services are based on whole-house aggregate billing data. NILM offers the opportunity to expand on these services by extending the digital utility-to-customer relationship to specific appliances and other end uses.

By providing an itemized accounting of end uses, NILM can serve as a replacement technology for traditional submetering. NILM's potential low cost could allow it to replace the traditional technologies used in energy measurement and validation (M&V). At the same time, NILM could facilitate a host of new customer services that could bring value to consumers and utilities. NILM could potentially make end-use monitoring cheap enough that small businesses and residential consumers could harness itemized load data to enhance end-use control, and save energy and money. Utilities could more accurately target demand side management programs, including both demand response and energy efficiency, to better manage end use loads.

Utilities, organizations promoting energy efficiency, researchers, and engaged customers have long been interested in measuring disaggregated energy use. This information is useful for evaluating the performance of energy efficiency measures, identifying the shapes of utility loads, and conducting experiments in home operations. To date, the process of collecting disaggregated data has involved installing multiple meters, data loggers, and communication devices to measure energy consumption. Purchasing, installing, and tracking this type of equipment is expensive and inflexible. The high cost limits the number and scope of studies that develop and analyze disaggregated data. It also forces the use of models and calculations to estimate energy performance rather than actual measurement.

NILM technologies have a tremendous upside. However, the technology has not yet been demonstrated as consistently reliable. In this report, Pacific Northwest National Laboratory presents the potential benefits of more mature and reliable NILM products and services to provide granular data that meets utility and consumer needs. Results of an end-use monitoring study of a bank branch conducted by PNNL are also presented for purposes of illustrating the need for better data in energy savings modeling (DOE 2013a).

The Electric Power Research Institute (EPRI) held two workshops and convened an advisory committee to identify specific use cases for how NILMs may be used. Pacific Northwest National Laboratory (PNNL) helped to cosponsor the first of these workshops on behalf of the U.S. Department of Energy (DOE). To identify a set of priority use cases, PNNL summarized the findings of the workshops, and developed descriptions and value propositions for each use case in coordination with an advisory group, which included about 20 representatives of industry, utilities, researchers, and government agencies.

The first workshop was sponsored by the Electric Power Research Institute (EPRI) and the U.S. Department of Energy (DOE), and held at the EPRI offices in Palo Alto, CA in 2013. The second was sponsored by EPRI and held in Orlando, FL in 2015. The advisory group is part of a PNNL research project sponsored by DOE, the Bonneville Power Administration, and the State of Washington.

2.0 Use Cases

The Advisory Group identified the highest priority use cases as follows:

1. Inform residential customers and utilities about energy use and load shapes of individual electrical appliances;

2. Enable M&V for utility demand response (verify individual electrical appliances have modified consumption accordingly in response to DR command) and efficiency programs (verify savings from efficiency measures via more efficient end-use technologies);

3. Enable diagnostics and preventative maintenance of electrical appliances/systems for improved building operations.

Table 1 describes how NILM technology could be applied to the use cases and the value proposition for doing so for a total of five use cases. Vendors focused the use cases on the residential market, but they are also applicable to small commercial buildings.

Table 1. NILM Use Cases for Utilities

NILM Applications that Meet Use Cases Most Important to Utilities		
Use Case	**NILM Application**	**Value Proposition**
Quantify energy use and load shapes of individual electrical appliances	Replace expensive submetering and expert installation to achieve end use data – automated analysis	Reduce study cost for utilities – increase sample size. Reduce building operational costs for consumers and building managers. Enable demand response.
Low cost verification to enable M&V for utility demand response and efficiency programs	Replace expensive submetering and expert installation to achieve end use data – automated analysis	Reduce utility cost to evaluate efficiency and demand response technologies and programs – increase sample size – increase confidence in evaluation
Diagnostics and preventative maintenance of electrical appliances	Replace expensive submetering and expert installation to achieve end use data – automated analysis	Reduce building operational cost for small building consumers – Better predict and plan for appliance maintenance and replacement
Disaggregated energy use for building management systems	Replace expensive submetering and expert installation – automated analysis	Cost effective energy saving measure
Automated auditing process	End use data and automated analysis	Reduce utility program cost - better target auditing program participants – replace inaccurate models with data

With NILM the five use cases can be met using less expensive technology to access end-use data and provide automated analysis. Both of these functions are currently available in the market, but are expensive, especially when all loads are measured.

3.0 The Value of End-Use Load Data

The value of submetered data is as an indicator of the potential value of NILM since NILM provides end-use metering at a fraction of the cost. Submetering conducted in commercial buildings is a good example of how NILM can provide value.

PNNL completed an end-use monitoring study conducted in a bank branch and found that end use loads were quite different than what the company had been using for modeling purposes in both new construction and renovations (DOE 2013a). Two discoveries were made when measured values were incorporated into building simulation models. First, old models deviated about 20 percent from actual energy consumption. Second, the strategies that had been chosen were not delivering expected results, because they simply were not targeting the most critical loads. A third finding was that heating and cooling equipment was consistently oversized throughout the bank's branches. Analyzing load data resulted in an immediate capital savings of millions of dollars for this equipment across the bank's portfolio of branches, in addition to energy savings. The monitoring study was completed to support modeling for the design and construction of a new bank branch that is net zero, i.e., the building produces as much energy as it consumes over the course of a year. This example helps to demonstrate the value of disaggregated end use data.

The second example also involves a bank branch (DOE 2013b). Bank of America uses a sophisticated energy management system to track and control most loads in its portfolio of branches. When Bank of America worked with PNNL to design and construct a branch designed to be 50 percent more efficient than code, the building was not performing to anticipated efficiency levels. Although the lighting system was state-of-the-art, a monitoring study using end use meters found that lighting in the building was somehow coming on during off hours. Fixing that problem resulted in the building performing within 2 percent of modeling expectations and brought energy consumption to the 48 percent savings that the building was designed to achieve. A monitoring and validation study that was included in commissioning activities provided the data to solve this problem. Savings were in comparison to Standard 90.1-2004 of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), the American National Standards Institute (ANSI), and the Illuminating Engineering Society of North America (IESNA). This example arises from a building commissioning application. Navigant Research has estimated that building commissioning in North America has resulted in annual revenues of $3 billion (Navigant 2015). Building commissioning is a significant business area that both demonstrates the value of using end-use load data for quality assurance purposes and that could benefit from NILM technologies.

Due to expense, monitoring studies are seldom completed in residential single-family homes. Most comprehensive end-use studies are part of research projects. Good examples are included in the recent Residential Building Stock Assessments (RBSA) (Larson 2014, NEEA 2012). These studies were managed by the Northwest Energy Efficiency Alliance with funding from regional utilities in the Pacific Northwest. The RBSA are conducted periodically to better understand end use loads and load shapes to assist in utility planning. A description of the 2011 RBSA points out that "despite the long-term existence of the U.S. Census and the Multiple Listing Service, there is no national database of the physical characteristics of homes. When utilities devise rebate programs to incentivize energy efficiency upgrades, they need to know the size of the potential market for those rebates so they can prioritize and fund them" (Du Bois 2012).

Residential homes also could potentially benefit from commissioning services, which could be brought into the affordable range for households with application of NILM technology. Approximately 60 percent of HVAC systems have installation, commissioning, and performance problems, leading to as much as a 30 percent increase in annual energy consumption (Lstiburek and Pettit 2010 and Domanski et al. 2014). Accurate end-use load monitoring identifies malfunctioning equipment both for commissioning and retro-commissioning. One application for NILM could include remote diagnosis of residential and small commercial buildings to identify strong candidates for energy upgrades. This approach could replace, or at least enhance, audits and the non-calibrated modeling that accompanies them (Berges et al. 2010).

4.0 NILM as a Bridging Technology

One can make the argument that new communication capabilities and the "internet of things" could make NILM obsolete before it becomes commercially available. In comparison to NILM, an advantage of these new technologies is that they potentially could come as standard features in new appliances and equipment. If they are standard issue, then consumers need not worry about making an independent decision to acquire them. With the right communication infrastructure and analytical capabilities, end use studies could be relatively straightforward.

However, this infrastructure is not yet in place. Further, it will take many years for internet-capable appliances to penetrate the market to a large enough extent to provide value for broad studies of load shapes and measure evaluations, especially in lower-income households that may tend to use older appliances. ASHRAE provides a list of life expectancies for heating, ventilation, cooling, and refrigeration equipment. The list is tilted toward commercial equipment, but does include a 10-year life expectation for window air conditioners, 15 years for residential single or split air conditioning packages, and 15 years for residential heat pumps. Commercial equipment life expectancy runs roughly from 15 years to 30 years (ASHRAE, 2016). It will take many years for the stock of existing equipment to be replaced with new equipment that includes the sensors, memory, and communication technology needed to join the internet of things.

Refrigerators offer a good example of how market penetration for new products with on-board sensor and communication technology may proceed. There are about 170 million existing refrigerators (EPA 2015). About 10 million new units are purchased each year. There are between a half-million and one million housing starts per year (Census 2015). Assuming that a half million new refrigerators go to new homes, it would take about 18 years for the stock of existing refrigerators to be replaced. However, about 44 percent of replaced units go to secondary use (DOE 2010). It is unclear how long it takes for these secondary units to clear the market.

Water heaters are another example. Using data from a 2010 DOE report, between 8 and 9.5 million water heaters were shipped each year between 2000 and 2009 (DOE 2009). At the time of the report, existing homes contained just over 100 million water heaters. Assuming that a half million are installed in new homes on an annual basis, it would take about 11 years for the stock of water heaters to turn over.

It may take as long as 20 years before the internet of things can fully capture significant end use loads. Effective NILM could serve as a bridging technology to include existing and older stock during the transition to the internet of things.

Other technologies are also available to help bridge these technologies to the internet of things. Energy management systems have long been available and in use in large commercial buildings and industrial facilities. Companies with large portfolios of buildings may centralize all HVAC controls in a single, central location for an entire continent. Examples include Bank of America and The Home Depot (DOE 2013b and DOE 2013c). However, these systems are complex and expensive, and are not used in most small commercial buildings or in residential settings. More affordable approaches using NILM could help to reach these smaller building types.

These estimates are based on average appliance and commercial equipment lifespans. Actual lifespans can vary tremendously, especially for water heaters. Consumers are unlikely to replace equipment until their particular unit stops working or some event, such as a kitchen remodel, prompts consumers to seek a new appliance.

5.0 Cost Considerations

Researchers have suggested that NILM will cost about $200 per household (Berges et al. 2010). Based on conversations with vendors and building scientists, a price point of greater than $500 would make it difficult for NILM to penetrate the residential and small commercial market. For purposes of the calculations in this paper, we will assume a cost of $500 per household for a mature, commercially-available NILM product. A price of less than $500 would likely result in a more rapid penetration rate, but the more conservative number is used here. In addition to installation costs, some vendors will include service fees for ongoing analysis and even notification if equipment energy consumption is outside of norms.

For comparison, the cost of a Nest Thermostat, developed by Nest Labs, is currently about $250. These devices do not track energy consumption. However, they do offer enhanced mobile control of the thermostat and the device can learn consumers' schedules and preferred temperatures and adjust operations to accommodate changes in the weather. The thermostats can also collect and communicate data for storage and analysis by Nest Labs. This communication can send data to Nest Labs, and Nest Labs can send operating signals back to the thermostat. This two-way communication has given Nest Labs the ability to launch demand response programs in partnership with utilities. (An example of a news article on this topic is in Olson and Tilley 2014.) One utility pursuing this type of program is Portland General Electric (Clearing Up, 2015).

Although the technology differs from NILM, the Nest thermostat has a similar price point and offers similar, although more focused, services as to what NILM aspires to offer in the future. The Nest also demonstrates a commercially flourishing disruptive technology that provides consumers with a more sophisticated version of a set-back thermostat in the same vein that smart phones provide a more sophisticated version of a cell phone. The Nest demonstrates that consumers are willing to purchase sensing and control equipment that provides enhanced services, although the services are different than those offered by NILM, which involve real-time, end-use data on utility costs and energy usage. Nest also demonstrates that there is value to the manufacturer (and to the utilities that are entering into partnerships) in collecting data from Nest users and the interactive control the Nest provides. This interactive aspect was captured in a *Wall Street Journal* article from June 2015, which described Nest Labs as a "connected home business" rather than a "smart thermostat" manufacturer or similar label (Barr 2015). Nest Labs now reports working with utilities all over the world on load-shaving programs. Nest Labs has also demonstrated how a connected product can provide enhanced services to consumers without charging a service fee.

6.0 Benefits

6.1 Benefits of Reducing the Cost of Submetering

For utilities and others researching building energy efficiency, one of the benefits of working with NILM will be reducing the cost of traditional building monitoring. Based on the experience of the author and an informal survey of four organizations that provide or use monitoring services, the cost of whole-house submetering using traditional end use sensors, data loggers, and communication equipment, is about $20,000 per home. Because of the expertise required to install this equipment, costs can vary tremendously depending on the granularity of the end uses under investigation, travel requirements, and the number of subject houses in near proximity to one another. Another variable is the number of fuel types involved and the number of appliances for each fuel type. (Note that NILM only monitors electric loads.) The cost of analysis is in addition to the monitoring costs and varies depending on the consistency of the data and the number of homes in the sample. Installations typically require hiring an electrician to install sensors inside the electrical panel. It is conceivable that as competition from NILM arises, traditional providers will find ways to innovate or cut their margins to maintain their market.

Table 1 compares traditional submetering approaches with the general objectives that NILM could achieve.

Table 2. Traditional Submetering versus NILM

Traditional Submetering	NILM Objectives
Multiple sensors and data loggers accurately monitor end-use loads (ground truth).	Accurate monitoring of disaggregated major end-use loads with simplified (or no) sensors and central data analysis.
Trained expert (and often an electrician) needed to install, maintain, and analyze.	No trained expert needed to Install. Automated analysis.
Typically used by electricity service providers or researchers with 5-15 minute interval rate.	Easy to use by consumers, electricity service providers and other applications with 5 minute or less interval rate.
Expensive to meter for research-quality monitoring studies – total cost averages $20K per building, plus analysis. One time event.	Low cost – literature suggests $200 per home – we assume $500. Fee may be up front, subscription, or both. Ongoing service.
Information owned by utility or researcher – often inaccessible.	Information available to consumers, utilities, and researchers.

The RBSA involved 100 homes. At the cost of traditional monitoring approaches, the estimated cost of monitoring this number of homes would be in the range of $1 million to $2 million. Assuming a cost of $500 per home using NILM, the cost would be $50,000. Even if an additional $500,000 were needed for a full year of an analyst’s time, the cost would be about half of the traditional approach, assuming the utility paid the full cost of the NILM. NILM accuracy would need to improve for this approach to be viable (Mayhorn, et al., 2015).

Many utility or scientific research studies rely on smaller populations of houses. In some cases these studies involve side-by-side comparisons of similar homes with one house containing one or more enhancements and one left as a control. Other studies involve full or partial monitoring of a small population of houses to investigate a building practice or efficiency measure with or without a control. And some verification of efficiency measures is based solely on utility bills with no break out of specific measures or other end uses at all. The reduced cost of NILM, in comparison to traditional monitoring, could allow for larger populations and more robust study designs. At $500 per home and lesser total costs, utilities would have the option of increasing sample sizes to improve statistical confidence in their studies.

6.2 Benefits of Better Informed Consumers

Earlier sections of this paper provided examples of how information resulting from studies of end use loads can impact building performance, energy savings, and decision making. As noted, data on operations and energy consumption can have an oversized impact on how well buildings are designed, modeled, commissioned, and operated.

The American Council for an Energy Efficient Economy (ACEEE) has conducted an international meta-analysis of energy savings resulting from 36 programs using advanced metering and other customer feedback tools to residential consumers (Ehrhardt-Martinez et al. 2010). ACEEE found that these programs harvest energy savings, with the best results (12 percent) attributed to programs providing real-time feedback at the appliance level. The authors noted that advanced metering is likely to play an important role in meeting the data demands of feedback programs. They conclude that if broadly implemented in the United States, feedback programs could provide the equivalent of 100 billion kWh of electricity savings annually by 2030.

Figure 1 is taken from the ACEEE study and shows how both the quality and frequency of the data provided to consumers impacts the level of energy savings.

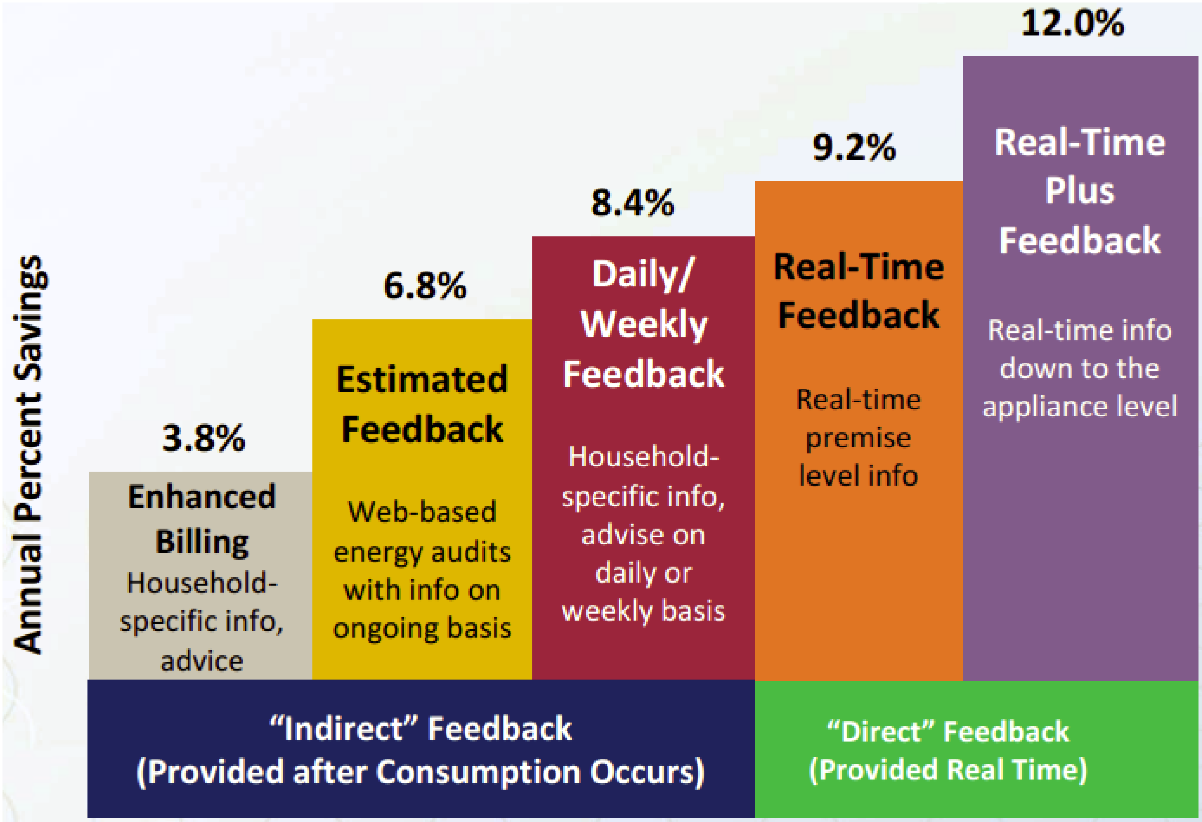

Figure 1. Estimated Savings for Various NILM Benefits

The ACEEE study and other reports have shown that real-time feedback to consumers on power consumption has saved 12 percent of annual electricity consumption in the U.S. (Ehrhardt-Martinez 2010, Iwayemi and Zhou 2011, Smith 2014, GridTalk 2013). The average annual electricity consumption for a U.S. household is 10,837 kWh. In the Pacific Northwest, average annual electric use for a single family household is 12,415 kWhs based on the RBSA (p 122, Baylon et al. 2015). The point here is not to compare and contrast these estimates, but rather to point out the scale of the potential savings from NILM. Twelve percent of the two estimates amounts to about 1300 kWh savings per home for the national number and 1490 kWh regionally.

The approximation of total annual savings assuming that NILM reaches half the homes is as follows:

- 1300 kWh x 123 million single-family households x 50 percent = 80 Billion kWh nationally
- 1490 kWh x 4.250 million single-family households x 50 percent = 3 Billion kWh in the Pacific Northwest

Multiplying these savings by average residential electric rates results in an estimate of total potential annual dollar savings to consumers:

- 80 billion kWh x 12.36 cents per kWh = $9.9 billion nationally
- 3 billion x 9.19 cents per kWh = $275.7 million regionally in the Pacific Northwest

Average residential prices are taken from the Energy Information Administration state profile for the State of Washington (EIA 2016). The estimate of 80 billion kWh savings is less than, but consistent with, an earlier national estimate that a 10 percent to 15 percent reduction in national residential electricity use may result in energy savings of 200 billion kWh (Iwayemi and Zhou 2011) or the ACEEE estimate of 100 billion kWh (Ehrhardt-Martinez et al. 2010). Pratt et al. (2010) estimated potential savings of 155 billion kWh in the U.S. from combined residential and small commercial buildings resulting from "direct impacts of the conservation effect of consumer information and feedback." These variances are likely from different assumptions about market penetration rates and the assumed rates at which the measures are adopted.

6.3 Benefits of Enabling Demand Side Management and the Smart Grid

The ACEEE report offers the following definition of demand side management: "Demand side management includes a wide range of utility efforts to understand and manage customer demand for energy resources, with the goal of reshaping the quantity or pattern of energy use (Ehrhardt-Martinez et al. 2010)." Demand response is one type of demand side management and offers tremendous value to utilities.

Demand response programs seek to shave peak system energy requirements so the utility can avoid the purchase or generation of electric power in order to meet peak periods of consumption. Off-peak prices to utilities generally reflect the cost of maintaining output from baseload generators, such as coal, nuclear, and hydroelectric plants, while on-peak prices reflect the more expensive price of generation from intermediate and peak generators, or purchasing power on the market. In addition, at times of scarcity, demand response could represent a safety valve to avoid brown outs or black outs.

Over time, the interaction between utilities and consumers is expected to become more complex and beneficial. Robert Pratt and other researchers at PNNL describe the coming evolution in the delivery of electricity as part of the smart grid (Pratt et al. 2010). Pratt describes the smart grid as:

> "The application of information technology that enables more visibility and control of both the existing grid infrastructure and new grid assets, such as customer demand response and distributed energy resources consisting of small generators and electricity storage devices. The smart grid's much higher fidelity control is provided through high-speed, two-way communication, sensing, and real-time coordination of all assets down to the customer meter and the end-use devices. Thus the smart grid is not characterized by a single technology or a device, but instead is a vision for a distributed, internet-like system that will
>
> - provide better control of existing grid infrastructure assets
> - provide additional functionality and benefits from existing assets
> - integrate new (often small, widely distributed) assets into the existing operational paradigm
> - engage these new assets to provide entirely new benefits to the grid."

Pratt's report goes on to describe enabling assets necessary to support smart grid applications. Among these are energy management and control systems and networks. NILM can play an important role in these types of systems. As suggested earlier, this role will be especially important during the long transition period that will take place before a comprehensive internet of things is in place.

NILM technologies can do much to enable demand response and ease the transition to a smart grid. The data collected from NILM can identify loads to control and verify that expected reductions are occurring. Real-time monitoring would allow utilities to better understand how load shifting strategies are working and if consumers simply change the time that an appliance is operated (reducing kW at a particular point in time) or if they actually reduce energy consumption (reducing kWh). In cases where there is not a long history of curtailing or partially curtailing a particular type of appliance operation for demand response, such as heat pump water heaters, NILM could evaluate how well the appliance responds to curtailment and quantify how much power reduction occurred and how much of that power reduction translated into energy savings.

Pratt points out that smart grid value rests on cost-effective grid operations and improved reliability. The report also quantifies additional energy and carbon dioxide emission benefits. The report's recommendation for residential and small/medium commercial buildings is to:

> "Pursue development of analytic software-based technologies that either are needed for, or could contribute to, cost-effective automated energy management. They include those that: enhance… system operation in residential and small commercial buildings, automate fault detection and diagnostics, automate commissioning, enable price-based controls, and enable coordination and integration with other systems."

These same economic and environmental needs apply to the demand response and load shifting programs that are in place or currently planned. Smith (2014), of San Diego Gas and Electric, describes the following outcomes that could accrue from NILM related to demand response:

- Refine customer rebate and incentive programs
- Improve relationships with customers
- Understand customer behavior to improve capacity planning
- Identify/verify appliances that could participate in demand response
- Allow customers to take advantage of rate structures.

Demand response and load shifting programs bring value to both utilities and consumers. Development of the smart grid will see these types of programs having a growing role in utility operations. NILM can be an important enabling agent for these types of programs. NILM can also quantify the relationship between demand side management and energy efficiency. This report does not attempt to monetize the value that NILM may bring, but as Smith's description points out, there is alignment between what NILM can offer and what utilities need to implement these programs.

7.0 Conclusions

This paper explores how utilities, researchers, and consumers could benefit from a lower cost approach to submetering. The paper describes examples of how identifying end-use loads in small bank buildings (less than 5000 square feet) played an outsized role in achieving energy savings. With the potential to reduce the cost of submetering by thousands of dollars per building, NILM offers the opportunity to expand subject populations to gain greater confidence in evaluations, load shape studies, and building commissioning.

NILM are an emerging technology with multiple manufacturers either offering products or planning to do so. These products, along with services that may be offered in consort with them, could replace traditional, expensive approaches to submetering and eliminate the need for expert installation to acquire end-use load data. Services may include automated analysis to identify loads, identify operating schedules, and quantify energy consumption. NILM vendors focus on the residential market, but could also serve small commercial buildings. This point is also made by Pratt (2010).

NILM vendors, utility representatives, and researchers have developed three high-priority use cases for NILM technologies, as follows:

1. Inform residential customers and utilities about energy use and load shapes of individual electrical appliances.
2. Enable M&V for utility demand response (verify individual electrical appliances have modified consumption accordingly in response to DR command) and efficiency programs (verify savings from efficiency measures via more efficient end-use technologies).
3. Enable diagnostics and preventative maintenance of electrical appliances/systems for improved building operations.

NILM technology could, in itself, serve as an energy-efficiency measure and could enable demand-side management programs, including demand response and other load shifting strategies. This data could enable improved building management, but could also be used to evaluate the performance of installed measures and identify loads where measures may be applicable. Reduced costs could mean that larger populations can be included in building stock assessments and measure evaluations. Larger sample sizes increase confidence in results.

As NILM data improves in quality, low-cost empirical data could translate into less reliance on models to identify and evaluate candidate measures in buildings, which would better align efficiency and demand response program outcomes with expectations. A data-driven approach could also replace or reduce the cost of energy audits.

Based on studies of programs around the world, ACEEE has shown that real-time feedback to consumers on power consumption can save 12 percent of electricity consumption annually. If NILM could reach half of the homes, annual savings could approximate $10 billion in the U.S. and $275 million in the Pacific Northwest. Similar savings could be expected for small commercial buildings, but these buildings have been historically difficult for utilities to reach with efficiency programs and impact estimates are not available, although the examples in this paper describe real-world impacts resulting from monitoring studies of bank branches.

With technology advancements, the internet of things and the development of a smart grid could combine to provide new relationships between utilities and consumers. NILM could help speed up the adoption of these new approaches to demand side management and building operations by providing insight into the operation of existing appliances and end uses that otherwise could be excluded from the internet of things and utility demand response applications.

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