Intelligent Efficiency Technology and Market Assessment

Ethan A. Rogers and Eric Junga

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529 14th Street NW, Suite 600, Washington, DC 20045

Phone: (202) 507-4000 • Twitter: @ACEEEDC

Facebook.com/myACEEE • aceee.org

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About the Authors

Ethan Rogers directs the day-to-day activities of ACEEE's Industry Program, coordinates the organization's work on intelligent efficiency, and is the program lead for the annual Intelligent Efficiency Conference and for the biannual Summer Study on Energy Efficiency in Industry. The industry team conducts in-depth analysis of energy use in the manufacturing sector and how it can be reduced through investments in efficient technologies and practices. The program also analyzes and reports on efficiency programs targeting the industrial sector, on opportunities to increase the use of combined heat and power (CHP) to meet the nation's energy needs, and on the ability of intelligent efficiency to transform all sectors of the economy. The team works collaboratively with businesses, government agencies, and public interest groups to advance sound energy efficiency policies and programs.

Eric Junga conducts research for both the Industry and Transportation Programs at ACEEE. He contributes to research projects on intelligent efficiency, smart and connected devices, and energy use in all industrial sectors. In transportation, Eric performs analysis for ACEEE's annual Greener Cars environmental friendliness rating and is active in several light-duty vehicle research projects aiming to increase vehicle and transportation-related energy efficiency. Before joining ACEEE, Eric worked for a print-media manufacturer on large offset presses, learned the intricacies of the energy markets, and participated in Industrial Assessment Center energy audits. He has a bachelor's degree in engineering physics and a master's in energy systems engineering.

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Executive Summary

In recent years, ACEEE has explored 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). These new sensory and control technologies enable energy savings through improved control of systems, facilities, organizations, and even communities. Many products and services make up intelligent efficiency, producing savings in every sector of the economy.

To help us make sense of this dynamic field, we focus on two basic questions:

- Just how is intelligent efficiency being used to save energy?
- To what extent is it being applied?

To answer these questions, we concentrate on four sectors in which intelligent efficiency applications are most common and where they are having the greatest effect on end-user energy consumption:

- Residential and nonresidential buildings
- Manufacturing
- Transportation
- Government services

We survey more than two dozen particular applications of intelligent efficiency across these four end-use sectors. We also describe a number of enabling and cross-cutting technologies, and we analyze the use of intelligent efficiency in utility-sector efficiency programs. In each case, we specify the information and control technologies applied, characterize how they are applied, and describe their benefits. Table ES1 outlines the applications and technologies we analyze.

Table ES1. Intelligent efficiency applications and technologies

Area	Application/technology
Buildings	Smart lighting
	Connected water heaters
	Residential building energy management
	Commercial building energy management
	Advanced metering infrastructure (smart meters)
	Automated load control
	Distributed energy resources
Manufacturing	Connected devices and the Industrial Internet of Things
	Integrated manufacturing processes
	Industrial energy management
	Grid integration and demand response

Area	Application/technology
Transportation	Real-time traffic management and data collection
	Autonomous vehicles
	Driver-assist technologies
	Multimodal smart device apps
	Real-time transit data
	Dynamic scheduling of mass transit
	ICT-enabled freight logistics
	Smart EV charging
Government and smart cities	Managing government operations energy use
	Helping residents use intelligent efficiency
	ICT-enabled city planning and improvement
Enabling and cross-cutting technologies	Wireless sensors
	Connected devices
	Internet of Things
	Information and control technologies
Energy efficiency programs	Intelligent efficiency as program measure
	Program design
	Project performance tracking
	Customer engagement
	Program management

BUILDINGS

The residential building sector is seeing rapid growth in the adoption of energy-saving networked devices. The sales of smart thermostats grew from two million units in 2013 to five million in 2015. The long-anticipated home energy management (HEM) market appears finally to have arrived, as customers look to new technologies that can make energy savings decisions for them to simplify their lives. Although only 5% of homes currently have some type of HEM systems, forecasters predict the number will rise to 19% by 2021.

Commercial building owners are also looking to technology to improve building performance and save money. Sales of building energy management system software products have increased from $0.7 billion in 2011 to $1.07 billion in 2015. Annual investments are forecasted to triple by 2024.

Buildings are becoming smart devices in and of themselves, able to communicate with the electric grid or with third parties that communicate with the grid. Networks are developing within organizations that enable optimization within and between their buildings. For superior control and efficiency, networks are linking buildings within campuses, communities, and even entire enterprises that stretch across multiple states and countries. One way building operators are saving money is by participating in electric utility demand-response programs where they reduce building electricity load upon request. Participation in demand response grew from 25% of commercial customers in 2012 to 38.6% in 2014.

Given increasing investments in renewable energy and electric vehicles, there is every indication that a more distributed and integrated local grid will become a reality in many communities. ICT and advanced metering infrastructure (AMI) make the prosumer possible, and the prosumer makes functioning energy markets possible at the local and regional levels. Prosumers also make the distributed grid possible.[1]

MANUFACTURING

We use the sales of Industrial Internet of Things (IIoT) devices as a proxy for gauging the trend in smart manufacturing investments. Analysts estimate that in 2015 there were 237 million IIoT devices—a number they expect to increase to 923 million by 2020. Investments in integrating manufacturing processes are also increasing annually, but it is not clear whether an inflection point has been reached that would indicate smart technology has gone mainstream. Forecasts by market analysis firms predict that investments in IIoT and industrial energy management will be greater and grow slightly faster than those for analogous products and services in the commercial and residential sectors.

TRANSPORTATION

The transportation sector started investing in intelligent efficiency earlier than many other sectors and is therefore further along the adoption curve. Although some of the transportation applications focus on increasing capacity rather than saving energy, our analysis concentrates on the latter. For example, we treat the use of ICT to collect real-time data for traffic management, to automate vehicle operation within transit agencies and freight logistics companies, to charge electric vehicles, and to power applications on smart devices.

The availability of instant information on the arrival times of trains, location of traffic jams, and location and availability of shared vehicles is saving people tens of millions of hours per year, reducing fuel consumption and associated pollution from vehicles by millions of tons per year, and providing hundreds of billions of dollars a year in economic benefits. The trends are for investments in these applications to continue at a steady pace in the near term.

GOVERNMENT AND SMART CITIES

We found that the greatest use of intelligent efficiency in the public sector is at the local level. Cities have a concentration of obligations greater than other levels of government; this has motivated many of them to look to technology for solutions to their challenges. Seventy-eight cities participated in the US Department of Transportation's Smart City Challenge. More than 38% of the 493 cities surveyed by International City/County Management Association (ICMA) reported deploying smart city technology related to energy. The market

[1] A prosumer is an early adopter of advanced technology—in this case, a customer who both consumes and provides energy services. In contrast to the centralized generation of the conventional grid, the distributed grid's generation sources are found throughout the network.

for smart city solutions is accelerating. Sales for Internet of Things (IoT) devices are predicted to triple between 2015 and 2020, and software sales are expected to double in the same time period.

ENABLING TECHNOLOGIES

Enabling technologies include the sensors, devices, communication equipment, networks, and operational and analytical software programs that enable the exchange and analysis of information, and the execution of commands. Sensors that can connect to local Wi-Fi networks and devices that can connect to the Internet to become part of the IoT are all enabling technologies. Adoption of IoT is increasing in all sectors of the economy. In 2015, there were about 10 billion connected devices globally; forecasters predict that there will be 26–50 billion by 2020 and 100 billion by 2030. Figure ES1 captures the rapid growth we have seen and can expect to see in the uptake of connected and networked devices.

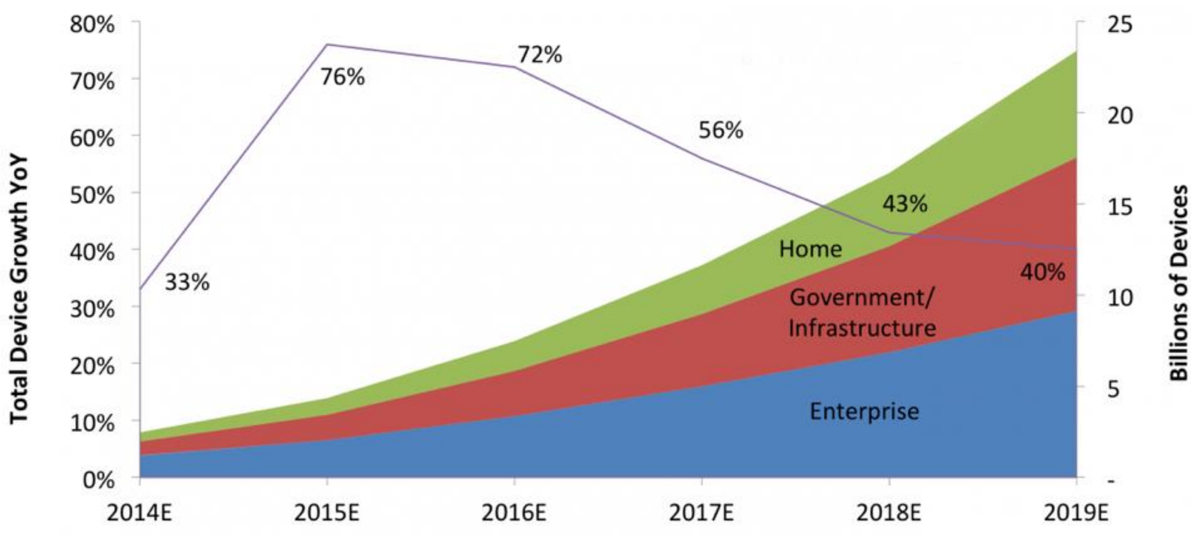


Figure ES1. Estimated number of installed IoT devices by sector. *Source:* Greenough 2014.

ENERGY EFFICIENCY PROGRAMS

Program administrators (the organizations that run energy efficiency programs) are experimenting with several intelligent efficiency technologies to save energy and improve program performance. Many new programs are being built around smart thermostats. These devices can be controlled by program administrators to reduce load during periods of peak demand and can save energy by learning a user's patterns and preferences and then adjusting temperatures to save energy when it will not affect the user's comfort. Navigant Research estimated that about 50,000 residential customers were engaged in some type of bring-your-own-thermostat (BYOT) residential energy management program in 2016, and similar programs could reach up to 20 million customers by 2024.

What is apparent from our research is how quickly the transformation of efficiency program design is taking place. The utility sector is often criticized for its aversion to change, but it has taken only 10 years for half of the country's residential customers to be engaged via energy efficiency programs that use some type of software as a service (SaaS) product. For example, in 2006, Opower signed its first contracts to provide utilities with analyses of their customers' energy data. Ten years later, they had contracts with more than 100 utilities, engaging more than 60 million customers.

Implementation of AMI (the technology backbone behind smart meters) is about one-third complete. Within a few years, most residential customers will have smart meters. This technology enables many new program designs that involve automated communications between administrator and customer. Programs that employ time-of-use rates or dynamic pricing are just a few of possibilities. In 2011, just under four million customers were on time-based demand response programs. That number had increased to almost seven million in 2014.

LOOKING AHEAD

For many intelligent efficiency applications, we are moving beyond the early adopter and fast follower stages and into mainstream adoption. On a national level, investment in enabling technologies such as the smart grid, Internet, Internet of Things, and Industrial Internet of Things continues to accelerate. Government spending is projected to lag other sectors but continue on an upward trend. In the transportation sector, intelligent efficiency is often a least-cost solution for increasing an existing system's capacity; it is also a mechanism for improving the user experience of vehicles and transportation systems. We can expect to see growth in the number of intelligent efficiency applications and in associated investments.

The trends we identify in this analysis indicate that organizations in the four sectors we profile as well as energy efficiency program administrators understand the potential of intelligent efficiency to produce new energy savings and other efficiency gains. Although it is likely that many of the intelligent efficiency applications we examined face barriers to faster adoption, every indication is that the markets for these technologies are well functioning and will continue to grow in the near and long term.

In addition to providing insights into the current state of the market, this report will form the basis for future research. We hope to repeat this analysis in a few years to assess progress; we also hope others will undertake their own analysis of ICT-enabled energy savings. We would welcome an ongoing discussion about intelligent efficiency applications and the data needed to track their progress and impact.

Intelligent Efficiency

In recent years, ACEEE has explored the benefits of intelligent efficiency, our term for the gains in energy efficiency enabled by the responsive, adaptive, and predictive capabilities of information and communications technologies (ICT). These new sensory and control technologies enable energy savings through improved control of systems, facilities, organizations, and even communities.

Simply making a device more efficient can save energy. LED light bulbs and hybrid automobiles are examples of this type of device-level efficiency. Even greater energy savings can be had by operating a device, process, facility, network, or even a city more effectively. We call this type of energy efficiency *system-level savings*. A high-efficiency motor can consume more energy if left on all day than an inefficient one that is properly controlled to run only when needed. No matter how fuel efficient, a car stuck in traffic or taking a longer route can consume more gasoline than one routed around congestion on a path that enables a more constant speed.

With conventional technology, individuals with the right set of skills and knowledge of their environment can make the wisest choices about how to operate equipment or a building, but are seldom able to because they do not have access to the information or the time to collect and analyze it. In contrast, intelligent efficiency enables people with far less expertise to more easily achieve this goal.

A smartphone application that identifies the most efficient route to a destination or alerts drivers to navigate around congestion is an example of intelligent efficiency. Commuters save energy by taking shorter routes, the transportation system is able to accommodate more cars, and society benefits from less pollution.

Another emerging intelligent efficiency device is the learning thermostat. These thermostats use machine learning to identify occupancy patterns and temperature preferences .[2] They automatically adjust the heating or air-conditioning and can reduce overall energy use without making the home less comfortable.

A third example is a smart manufacturing software platform that compares historical production data with current operating conditions. The software combines that information with anticipated orders and shipments of raw materials in a computer simulation; it then develops an operating plan to optimize the use of energy, raw materials, personnel, and equipment.

The common threads in all of these applications are a network that routes information between devices, access to multiple data sets relevant to any decision making, and data analytic software tools that turn data into information and provide the context for smart

[2] Machine learning is a form of artificial intelligence (AI). The term refers to the ability of computers to develop conclusions based on trends identified in historical data much as people do.

decisions. The networking of sensors, devices, controls, and data analytics is what makes ICT so powerful.

Sensors are examples of the enabling technologies that underlie intelligent efficiency. They collect the data that people used to read off meters. Wireless sensors are a key development, enabling the inexpensive collection of performance data from all types of devices, including older equipment without built-in connectivity.

Connected devices save energy through optimized operation by virtue of their ability to access data and logic. Just about any electronic or mechanical appliance can be a networked or connected device; the only requirement is that it have some ability to send and/or receive information. A connected water heater, for example, can communicate the water temperature data it collects from its sensor to a local area network (LAN), the Internet, or a communication network associated with a utility's distribution grid. Advanced connected devices can communicate with each other. The *Internet of Things* (IoT) refers to all the devices connected to the Internet that exchange information without human assistance.

Software applications in a computer, tablet, or smartphone can access and analyze data from connected devices and control their performance. Drawing on disparate sources, such as weather and traffic conditions, they can harvest data from the field as it is generated, analyze and synthesize the data, compare a system's current state with historical information, and share the results — all in near real time. They can also quickly analyze multiple options to identify the most efficient operating conditions, thus duplicating the wisdom of an experienced operator.

Focus of the Report

Many products and services make up intelligent efficiency, producing savings in every sector of the economy. Technologies and markets are evolving at such a rate that the descriptions and even the names of product categories are changing. The features and benefits of particular products (e.g., smart thermostats) continue to expand.

To help us make sense of this dynamic field, we focus on two basic questions:

- Just how is intelligent efficiency being used to save energy?
- To what extent is it being applied?

To answer the first question (which we might characterize as a qualitative assessment), we survey more than two dozen specific applications of intelligent efficiency across four end-use sectors. We also discuss a number of enabling and cross-cutting technologies, and we analyze the use of intelligent efficiency in utility-sector efficiency programs. In each case, we specify the information and control technologies applied, characterize how they are applied, and describe their benefits. For example, real-time data collection allows smartphone apps such as Waze and Google Maps to help drivers navigate and avoid traffic congestion (sometimes).

The second question leads to a quantitative assessment of intelligent efficiency's market penetration. Our working assumption is that the adoption of intelligent efficiency technologies, broadly speaking, is accelerating. We are less certain of the rate of acceptance by the various sectors of the economy. Which sectors are attracting investment and which segments of the economy have been slow to adopt intelligent efficiency? The transportation sector was an early adopter of ICT, because new innovations in data analytics increased the efficient flow of vehicles and freight. Is that trend continuing? Currently, the emergence of learning thermostats is an important focus of the residential sector. What fraction of the market have these thermostats reached already and how much of the market will they take? We know that many cities are looking to technology to lower operating costs and increase city services, but how widespread is this trend?

We have found that the answers to these questions do not come easily. The data needed to determine the current level of adoption of intelligent efficiency within individual economic sectors—let alone across the economy—do not exist in any one place. No one has analyzed the market adoption of intelligent efficiency as a whole, and no North American Industry Classification System (NAICS) code or Energy Information Agency (EIA) category covers it.

Despite these challenges, our report aims to characterize and quantify the current application of intelligent efficiency technologies. Where and how are they being used? How widespread is their application today, and where are they heading? We hope that the answers to these questions will help efficiency program stakeholders, policymakers, and researchers gauge the progress of intelligent efficiency, both overall and in specific markets and with specific technologies. Our findings are designed to guide developers of programs and policies, steering them toward promising opportunities and areas in which new policies are needed.

Analytical Framework

We chose four sectors in which intelligent efficiency applications are most common and where they are having the greatest effect on end-user energy consumption:

- Residential and nonresidential buildings
- Manufacturing
- Transportation
- Government services

After analyzing these sectors, we discuss the enabling and cross-cutting technologies that underlie many intelligent efficiency applications. In the report's final section, we describe the increasing prevalence of intelligent efficiency in utility efficiency programs, both as a set of measures and as a program design, marketing, and evaluation tool.

Intelligent efficiency applications are the units of our qualitative and quantitative analyses. These applications are energy measures made possible or made better by the use of some combination of sensors, connected devices, networks, data analytics, and systems integration.[3] Each application is a broad grouping of many similar products. For example, real-time traffic data collection supports both smartphone navigation programs and intelligent adaptive traffic signals. We selected the applications to analyze in this report using three criteria:

- They show the most common and promising uses of intelligent efficiency.
- They save a substantial amount of energy.
- They have market data we could use to characterize their adoption by end users.

Table 1 lists the applications and enabling technologies we chose.

Table1. Intelligent efficiency applications and technologies

Area	Application/technology
Buildings	Smart lighting
	Connected water heaters
	Residential building energy management
	Commercial building energy management
	Advanced metering infrastructure (smart meters)
	Automated load control
	Distributed energy resources
Manufacturing	Connected devices and the industrial Internet of Things
	Integrated manufacturing processes
	Industrial energy management
	Grid integration and demand response
Transportation	Real-time traffic management and data collection
	Autonomous vehicles
	Driver-assist technologies
	Multimodal smart device apps
	Real-time transit data

[3] We consider intelligent efficiency applications to be a class of energy efficiency measures. However two qualifications are necessary. Some applications do not save energy directly but track energy savings. They automatically collect, compare, and analyze energy use in near real time, enabling the reporting of energy savings and the calibration of systems to increase those savings.

Second, many applications of intelligent efficiency involve only the control of energy-consuming devices. Although the controller does not use much energy, it schedules and optimizes the performance of one or more devices that do. And, because of its access to logic, the controller can save energy in ways not possible without the use of ICT. So even though it is the end-use device (e.g., a motor or furnace) that ultimately uses less energy, the savings are made possible by the application of an intelligent control system. Therefore we qualitatively attribute the savings to the application's controlling function.

Area	Application/technology
Transportation (cont'd)	Dynamic scheduling of mass transit
	ICT-enabled freight logistics
	Smart EV charging
Government and smart cities	Management of government operations energy use
	Help for residents using intelligent efficiency
	ICT-enabled city planning and improvement
Enabling and cross-cutting technologies	Wireless sensors
	Connected devices
	Internet of Things
	Information and control technologies
Energy efficiency programs	Intelligent efficiency as program measure
	Program design
	Project performance tracking
	Customer engagement
	Program management

For each application, we chose one or more metrics to help us understand a technology's acceptance and provide some indication of market adoption. For example, our metrics for smart lighting systems include the percentage of commercial buildings with smart lighting controls and the number of these systems installed worldwide. We picked metrics based on data availability and interviews with stakeholders who told us what would be of greatest use. We used data from our literature review as often as possible. When we needed a metric to properly assess an application but data were not available, we queried people with experience in the field and asked for their sense of the market.

For each metric, individual data points are snapshots of how well one or more economic sectors accept a technology. Multiple data points form a rudimentary trend line that shows the technology's progressive acceptance. For example, in 2003, 1% of US commercial buildings had smart lighting controls; the percentage increased to 4% in 2012 and 12% in 2014 (EIA 2016b; Arnold and McCullough 2016).

As we mentioned earlier, these data points and trend lines are somewhat atomistic: They depict the penetration of individual applications within a sector, but not the sector's uptake of intelligent efficiency as a whole. In each section of this report, our analysis attempts to go farther by interpreting each snapshot and trend line, and what their combination means for each sector and for the entire economy. Where possible, we explain how the various indices overlap and interrelate. Our conclusion surveys all of the data and attempts to present a qualitative overview of their significance.

Buildings

Buildings represent about 40% of the energy consumed in the United States and are the focus of much of the energy efficiency programmatic activity in the utility sector. Investments in intelligent efficiency for use in residential and nonresidential buildings have steadily increased 30–60% per year over the past five years and are projected to continue to grow at 19–25% through 2024 (ABI 2013; Talpur 2015; Berg 2016; Statista 2016; AEE 2016). The use of connected devices in commercial buildings is expected to grow quickly. There were approximately 206 million at the beginning of 2015; the number may triple before the end of 2017 (Gartner 2015b).

The introduction of automation to this space is enabling energy savings that are not possible with device-level efficiency improvements. With today's connected devices and grid-integrated buildings, not only can systems operate more efficiently, but so can buildings and entire grids.

This section of the report begins with an analysis of connected devices. Then we discuss building energy management—first in the residential sector, then in other buildings—followed by an examination of how buildings can use ICT to interact with the electric grid. The six applications we have chosen to include here are:

- Smart lighting
- Connected water heaters
- Residential building energy management
- Commercial building energy management
- Advanced metering infrastructure (AMI)
- Grid-connected and demand-responsive buildings

Each of these applications involves an array of technologies, broad enough that we could gather data, but narrow enough to offer useful insights into intelligent efficiency use in the built space. We considered other applications, but because of insufficient significance to the sector or lack of data, we chose not to include them (see Appendix B).

SMART LIGHTING

Lighting system control has evolved from simple on–off switches to motion sensors and programmable control. A new generation of lighting systems, often referred to as *smart lighting*, consists of networked LED luminaires with advanced sensing and controls, and anticipatory data analytics. Advanced sensors can detect luminaire failure and send alerts through a lighting or building management system (King and Perry 2017). They save energy through the superior control made possible by occupancy sensing and continuous dimming that can adjust for ambient light and the needs of specific tasks. Using photo sensors to measure ambient light levels and then adjusting the amount of light coming from fixtures and windows to meet design levels can reduce energy use by 40–80% (Jackson et al. 2015). Fully integrating smart lighting systems with building energy management systems (BEMS) can achieve energy savings of up to 90% compared to conventional lighting systems (Gartner 2015c). In 2003, only 1% of US commercial buildings had advanced lighting controls; the number increased to 4% in 2012 and 12% in 2014 (EIA 2016b; Arnold and

McCullough 2016). Worldwide, smart lighting is projected to grow from 46 million units in 2015 to 2.54 billion units in 2020 (Gartner 2015c). Navigant Research (2016c) predicts sales of advanced lighting technologies to increase to $16.9 billion by 2024. Sales of networked lighting controls alone will increase from $2.2 billion in 2015 to $4.8 billion in 2024.

CONNECTED WATER HEATERS

There are about 45 million electric water heaters in the United States (Lazar 2016), making them the third largest source of residential electricity consumption, accounting for 9% of all electricity consumed by US households (Hledik, Chang, and Lueken 2016). About 42% of US households have electric water heating, offering electric utilities a potentially significant demand-side management (DSM) resource (Lazar 2016). Electric water heaters come in two basic forms: electric resistance water heaters, which use electricity in pulses to power a heating element that maintains a fixed volume of water at a constant temperature; and heat pump water heaters, which pull heat from surrounding air to continually heat water and tend to consume electricity at a low and consistent rate. Water heaters that are connected to an electric utility's communications network can participate in demand-response (DR) programs. The water heaters can help curtail overall system peak demand and serve as a form of energy storage. In the first case, water temperature is allowed to decrease in hundreds or thousands of units across a territory, thereby decreasing electric system load during a few hours of a few days of peak demand each year. In the second case, hundreds or thousands of units are instructed almost every day to heat water during off-peak hours and not to heat water during peak hours. Doing so provides grid operators a mechanism for leveling demand throughout the day and thereby lets them run their system more efficiently (Hledik, Chang, and Lueken 2016).

In addition to reducing peak load, utilities can use water heaters to bring more renewable energy onto the grid and provide other grid balancing services. Maui Electric uses its control of 6,300 water heaters to balance 30 MW of wind power on its grid (Lazar 2016). Mosaic Power, a third-party aggregator, manages minute-by-minute electric demand of nearly 7,000 water heaters as part of the Frequency Regulation Market of the PJM Interconnection's Mid-Atlantic grid (Mosaic Power 2017).

Thirty-five states have utilities with water heater load control programs (Tweed 2015b). More than 100 electric coop utilities have some form of water heater load control capability (Lazar 2016). Sales of electric water heaters have averaged a little over four million units per year. The experts we interviewed estimated that less than 5% of those have electronic controls and some type of built-in network interface. Given the ubiquity and flexibility of electric water heaters, it is likely that we will see greater use of them for grid balancing in the future.

BUILDING ENERGY MANAGEMENT

Particular types of connected devices (e.g., smart lighting controls) work together in a system. Once the system components are networked, the next step is to network the building's systems. Building automation has been around for many years. It has enabled building operators to reduce operating costs by centralizing the control of multiple systems. Energy management has been possible, but not always a focus of building automation. Many newer systems do focus on energy management, and they access external data sources (such as weather), employ data analytics, and contextualized information in user interfaces to optimize building energy performance.

There are two distinct markets for building energy management: residential and nonresidential. In the residential sector, the goal is to manage individual comfort in a room or home. This market is served by various thermostat products. The nonresidential sector includes offices, schools, hospitals, and other business and institutional buildings that can benefit from some level of centralized control.

Residential Building Energy Management

Thermostats are the most common residential energy management device. Thermostats have evolved from simple mechanical devices that maintained a preset room temperature to programmable thermostats that adjusted room temperature according to a programmed schedule to newer devices that connect to the Internet and may have analytical capability. These newer devices include connected thermostats, smart thermostats, and home energy management systems (HEMS). Products referred to as *connected thermostats* are usually simple devices with no internal logic that are connected to the Internet directly or through a local hub, such as a security system. Logic and external data sources can be accessed through the Internet, and the devices can be controlled remotely through computers or smartphones. Smart thermostats—sometimes called *learning thermostats*—are more expensive. They differ from traditional programmable thermostats in their ability to record people's temperature preferences, identify living patterns, and use that information to predict future behavior and optimize performance.

Programmable thermostats rely on their owner's ability and willingness to learn and schedule the device. Smart thermostats simplify the human interface by letting users enter simple inputs, such as "I'm cold right now" or "I'm too hot." The thermostat continuously monitors current conditions, compares them to past customer preferences, and modifies the heating or air-conditioning to meet the user's needs. Smart thermostats can also provide alerts to extreme weather; heating, ventilating, and air-conditioning (HVAC) problems; or required maintenance. With two-way connectivity, smart thermostats can also communicate with electric utilities and respond to requests to decrease energy use during times of peak grid load.

The number of deployed smart thermostats is steadily growing; our sources agree that this is the case and that it is growing at a considerable rate. Of the 10 million thermostats sold in 2015, 40% of them were smart thermostats. The ratio is expected to increase to 50% in 2017 (Hill 2015). IoT Analytics reported a 123% increase in unit sales of smart thermostats in 2015 (Lueth 2016). Berg Insight reported that the number of homes with smart thermostats grew by 78% to 4.5 million in 2015. IHS predicts that connected thermostats will grow by 22% through 2019 (Talpur 2015). Berg Insight is forecasting that 32.2 million homes in North America will have smart thermostats by 2020 (Berg 2016).

Many of the forecasts we reviewed predict that sales growth in this product category will continue. Some forecasts expressed concern that recent growth may reflect a surge of early adopters and early followers and that, at current prices, market acceptance of these products might reach a natural limit. For example, given the higher price of smart thermostats compared to standard thermostats, Navigant expects the market to be limited to around 10% of households (Walton 2016b). If this is true, at least two scenarios are possible: less expensive connected devices that communicate through a home energy hub ultimately might be more popular, or the price of smart thermostats might decrease enough to expand the potential pool of customers.

Recent changes in the sales channels for thermostats gives us some interesting insights. In figure 1, we can see that the retail and HVAC installer sales channels for smart thermostats are growing, while the utility program and security system sales channels are essentially flat.

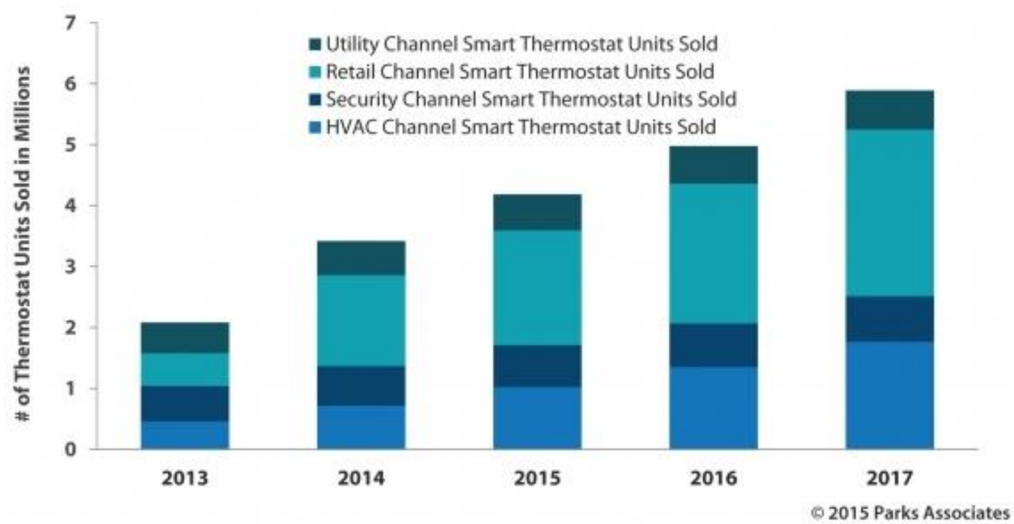


Figure 1. Smart thermostat units sold in United States 2013–2017. *Source:* Tweed 2015a.

As figure 1 indicates—and as we will discuss in the energy efficiency program section—some of this activity may be attributable to efficiency program subsidies. We are not sure whether future growth is dependent upon continued efficiency program support.

When a smart thermostat is integrated with other software and hardware in a home to form a network, and that network monitors energy usage, provides feedback, and enables control, it is a part of a HEMS. Each of the network devices can be referred to as a *HEM device* or *HEM technology*. A recent Pacific Gas & Electric report (Ford et al. 2016) identified 313 products and services that fit within the HEM product category (see figure 2).

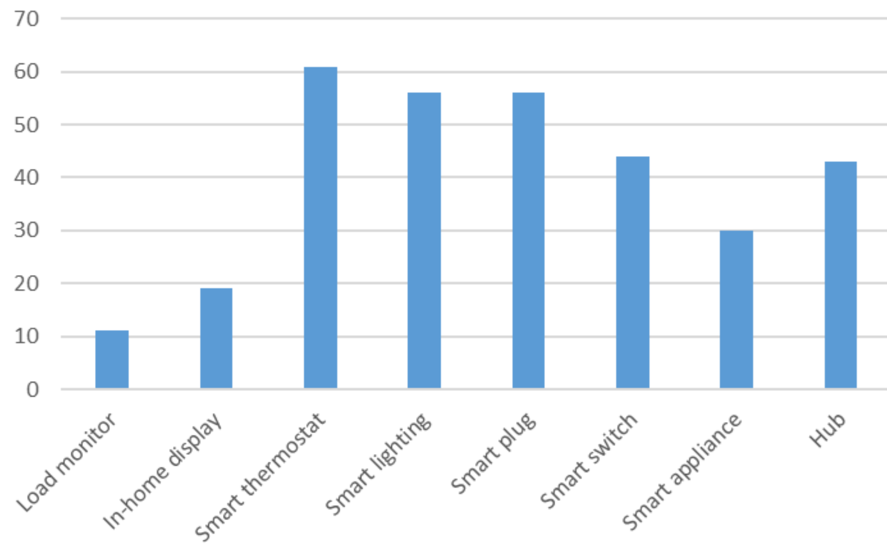


Figure 2. Number of various HEM technologies on the market (*n* = 313). *Source:* Ford et al. 2016.

Many market analyses have focused on growth of the larger HEMS set of products because it includes core technologies (such as smart thermostats, software, and network hubs) and other network and networked devices (such as lighting and smart plugs). The smart homes category is an even larger set of devices and software that includes HEM devices and entertainment, security, and connected appliances. The most inclusive category is IoT Residential or IoT Consumer, which includes portable and wearable networked devices. This category is of little use, however; sales of HEMS barely register when compared to sales of tablets, gaming systems, and fitness wearables.

It is, however, useful to compare the sales of energy-management-related HEMS products to those of smart home products (figure 3) because it tells us whether the popularity of energy management is less than, equal to, or greater than most other connected residential products.

Sales of HEMS in the United States grew rapidly from $44 million in 2011 to $495 million in 2015 (AEE 2016). Statista projects sales growth from $1.5 billion in 2016 to $4 billion in 2021, and market penetration growth from 6.7% of US households in 2016 to 19.3% in 2021 (Statista 2016). Figure 3 captures recent and predicted sales for networked devices in the residential sector. Sales of HEMS are increasing, but not at the same rate as smart home products.

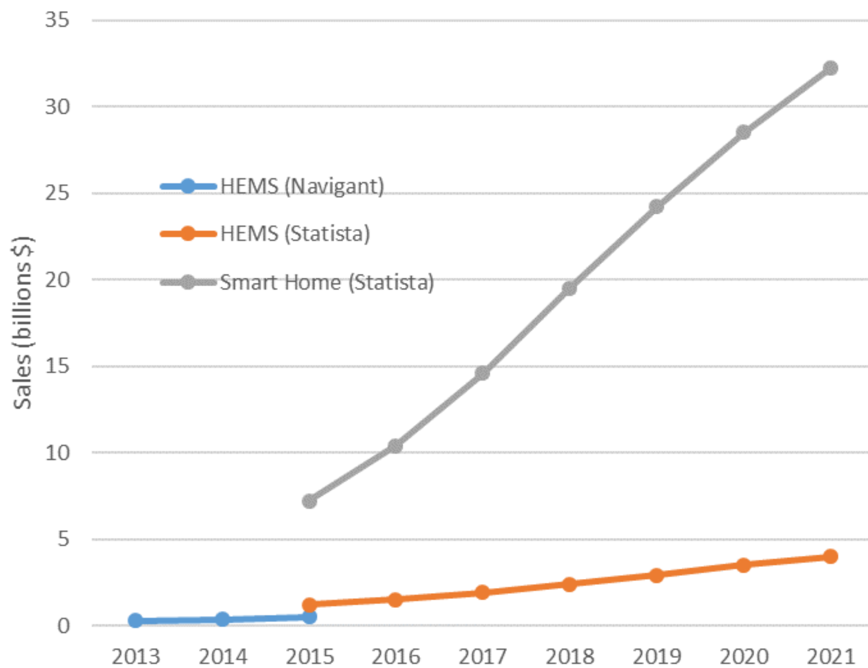


Figure 3. Growth in sales of residential applications. *Sources:* AEE 2016; Statista 2017a.

Although HEMS that function as hubs to route communications for multiple devices are more expensive, they can lower system-level costs. Smart thermostats that function as hubs and connect to the Internet through the home wireless router are likely to be the dominant technology for the next few years; however we can expect to see an eventual convergence of hubs, routers, and cable modems in the future.

A research question we were not able to answer is whether the more advanced residential energy management devices will eventually start to fill the needs of the commercial and industrial (C&I) sector. It will likely be possible in the near future to network multiple smart thermostats or other HEMS together to manage the energy use of small commercial buildings. It seems a likely area for market growth, and therefore something to look for in future research.

Commercial Building Energy Management

Commercial buildings represent 18% of US primary energy consumption, 36% of US electricity consumption, and 45% of US peak energy demand (EIA 2015b; EIA 2016a). This energy consumption comes from HVAC, water heating and cooling, lighting, and various computers and office equipment loads. Managing it is a key intelligent efficiency application. In 2015, 20% of commercial real estate had some level of intelligence (EIA 2015a). A fully integrated building can use 30% less energy than a building with systems operating independently (King and Perry 2017).

Commercial buildings are more complex than residential buildings and so are their building automation systems (BAS). A fully integrated smart building will combine efficient technologies with automated controls, networked sensors and centrally controlled management systems, and data analytics software and platforms. *Smart buildings* are buildings with networks that connect all of these systems and control them with advanced control systems. A smart building's performance can be continually optimized through monitoring-based commissioning (MBCx) so that, over time, it becomes more efficient (King and Perry 2017).

The industry uses various terms to describe nonresidential control systems:

- *Building automation systems (BAS)* remotely control and monitor multiple building subsystems, including heating, air-conditioning, and hot water.
- *Building management systems (BMS)* are often used interchangeably with BAS, but some consider them to be a more advanced generation of BAS.
- *Building energy management systems (BEMS)* monitor, analyze, and report energy data. Some systems link to external data sources and use machine learning to predict future operating conditions and recommend optimal operating set points.
- *Advanced building automation system (ABAS)* incorporate advanced sensing, device and subsystem integration, real-time data analytics, and enterprise systems integration, including building-to-grid communications.

A BEMS includes an energy management and information system (EMIS) comprised of a suite of software tools and services to manage commercial building energy use. Common components are energy information systems (EIS) that provide data analytics related to energy use, equipment-specific fault detection and diagnostic systems, benchmarking, and utility tracking tools (Better Buildings 2016).

Another increasingly common acronym is *IBMS*, which stands for integrated building management systems. IBMS combine data from multiple buildings systems (HVAC, energy, security, and life safety) with external data sources (weather, utilities, and transportation) (Clay Nesler, Vice President, Global Energy & Sustainability, Intel, pers. comm. March 6, 2017).

To remain consistent with past ACEEE reports, we use the term, *ABAS* in this report to represent building management systems that incorporate advanced sensing, use of EIS to perform real-time data analysis of energy use, and integration of building-to-grid communications with the management and control of building devices and subsystems. We use BMS, BEMS, and other acronyms per their use in the literature.

The most significant distinction between conventional BMS and newer ABAS is that the former react to external conditions, whereas the latter can predict them and adjust accordingly. ABAS give building operators the ability to track building performance, including energy use; to identify equipment faults; and to model future equipment performance. The systems continuously monitor and use machine learning to continuously improve building performance—a practice some refer to as *continuous commissioning*. Such systems are scalable and can monitor and control more than one building. For these reasons, we selected ABAS to be the intelligent efficiency application to give us insights into intelligent efficiency use in nonresidential buildings.

Building automation is making it possible to save energy through superior control of individual systems in many nonresidential buildings. Granderson, Lin, and Piette (2013) reported that C&I customers can realize a median energy savings of 17% from energy management systems that analyze interval energy data. They also concluded that a well-designed control system can increase building efficiency by up to 30% without needing to upgrade existing equipment (DOE 2015).

The EIA's *2003 Commercial Building Energy Consumption Survey* reported that 5% of all buildings had some type of building automation (EIA 2006). That increased to 14% in 2012. The percentage of 1,000–50,000 sq. ft. buildings with BAS increased from 9% to 25% over the same period. Buildings greater than 50,001 sq. ft. with BAS increased from 60% to 99% (EIA 2016b). Pacific Northwest National Laboratory estimated in 2012 that 75–80% of annual US building automation installations of any type were going into existing buildings. It also found that even though 6.8% of all commercial buildings had building automation, only 0.2% had BEMS (Bachman 2012).

Ideally, we would like to know the number of units sold at each level of complexity and how those numbers compare to the size of the US building stock. In lieu of sales volumes, sales revenues can suffice. Figure 4 shows existing and predicted global sales of BEMS (the term Navigant uses for energy monitoring and analysis software and services).

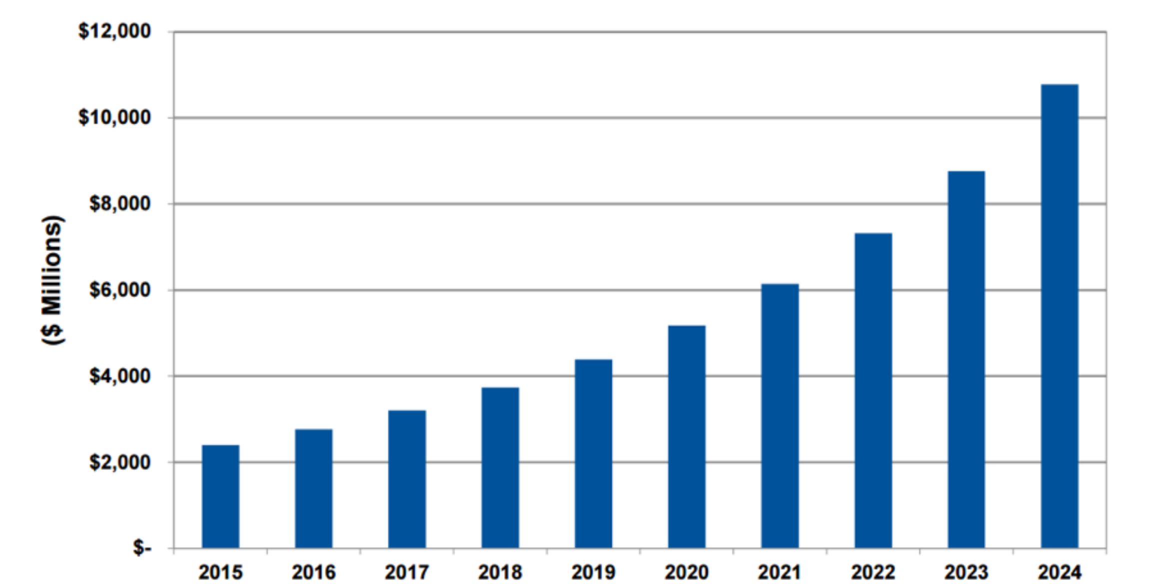


Figure 4. BEMS revenue, world markets, 2015–2024. *Source:* Navigant Research.

Keep in mind that, as with many technology products and services, the price of individual systems has either decreased for a given level of functionality or stayed flat as the functionality has increased. We should therefore be careful about assuming that more revenues mean a greater percentage of buildings are receiving new systems.

Navigant reports that global revenue in the larger building efficiency sector grew 50% between 2011 and 2015, totaling $63.6 billion in 2015 and up nearly 11% from 2014.[4] Global revenue from the narrower BEMS product category was $1.8 billion in 2011 and $2.8 billion in 2015; it is projected to reach $10.8 billion in 2024. US Revenue was $737 million in 2011 and $1.1 billion in 2015 (AEE 2016). Navigant projects revenue in North America to reach $3.1 billion in 2024 (Talon and Martin 2015).

ADVANCED METERING INFRASTRUCTURE

The smart grid—more formally known as advanced metering infrastructure, or *AMI*—is most visible to people as smart utility meters that enable an automated bidirectional data flow between the utility and customers. AMI also includes hardware and software that allow utilities more refined observation of their system and control of their infrastructure assets. Unlike conventional utility meters, which simply record energy consumption as it happens and must be read in person, smart meters are part of a network, the smart grid, that exchanges information between utilities and customers. Smart meters provide information that is more timely and granular than information from conventional meters. This information is useful for the utility and for customers in understanding consumption patterns and, as we describe later, it identifies opportunities to save energy and save money.

Although many of the applications we analyze in this report have applicability in more than one end-use sector, none is more cross-cutting than smart meters. AMI figures in the intelligent efficiency of residential and commercial buildings, cities, and utility energy efficiency programs. It even factors into charging stations for electric vehicles. Knowing the ratio of customers with AMI meters gives us insight into the status of the electric grid's transition, while knowing the total number of AMI meters nationally helps us assess the current potential for energy efficiency and DR programs that utilize AMI's two-way communication feature.

The rollout of AMI meters has been rapid, growing from 20.3 million in 2010 to 58.5 million by the end of 2014 (FERC 2016). As table 2 shows, the number of utility customers who use smart meters to exchange information with utilities is increasing at a steady rate; the table also shows fluctuations in the overall number of utility meters.

Table 2. Penetration of smart meters, 2007–2014

Date	Number of advanced meters (millions)	Total number of meters (millions)	Advanced meter penetration rates
Dec. 2007	6.7	144.4	4.7%
Dec. 2009	12.8	147.8	8.7%
Dec. 2011	38.1	166.4	22.9%
May 2012	35.7	144.5	24.7%

[4] *Building energy efficiency* here includes building automation as well as the energy monitoring and analysis of the BEMS category.

Date	Number of advanced meters (millions)	Total number of meters (millions)	Advanced meter penetration rates
Dec. 2012	43.2	145.3	29.7%
July 2013	45.8	145.3	31.5%
Dec. 2013	51.9	138.1	37.6%
July 2014	50.1	138.1	36.3%
Dec. 2014	58.5	144.3	40.6%

Sources: FERC 2014, 2015, 2016

The number of smart meters is increasing in all sectors. As of the end of 2013, 37.8% of residential, 36.1% of commercial, and 35.2% of industrial customers had been upgraded to AMI meters (FERC 2015). Spending on AMI slowed after an initial surge funded by the American Recovery and Reinvestment Act of 2009 grants. Projects in 2010 totaled $4.9 billion, whereas spending in 2016 was only $2.7 billion (DOE 2014).

What is also interesting is that, in 2013, the number of two-way AMI meters surpassed the number of one-way automated meter reading (AMR) meters for the first time (see figure 5). The balance of meters are standard electromechanical types. This shift represents an important tipping point. Going forward, we can anticipate that a majority of new meters will have two-way communication capability and thereby have the ability to support many important applications of intelligent efficiency.

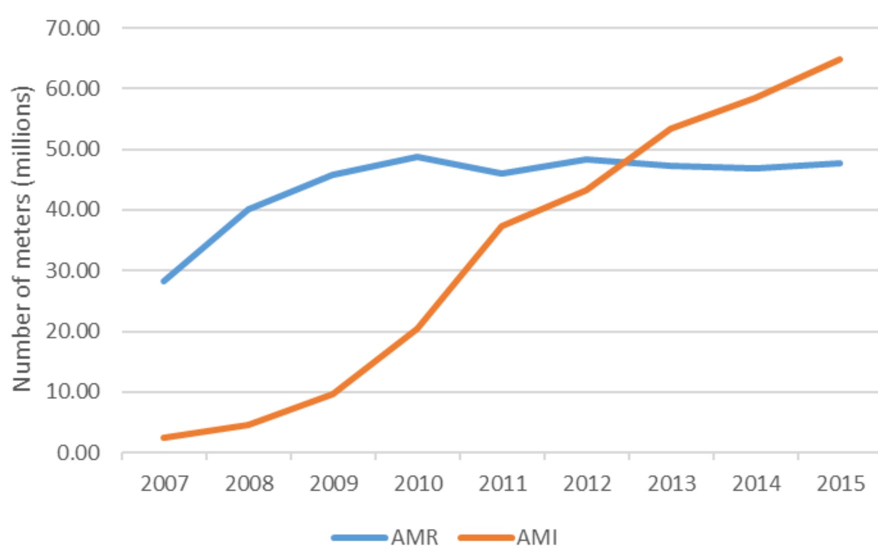


Figure 5. Deployment of AMR and AMI meters. The mismatch between the 2007 and 2009 values here and the values in table 2 may be due to different survey periods. *Source:* EIA 2015a.

GRID-CONNECTED AND LOAD-DISPATCHABLE BUILDINGS

In the Enabling Technologies section, we discussed the importance of AMI and smart meters in enabling DR, a temporary and voluntary reduction of electric energy consumption by customers. Utilities usually request DR when the electric grid or natural gas transmission pipelines are at peak capacity. Utilities either offer customers discounted rates for the right to require them to reduce their load or pay them in the form of a credit for reducing their load.

In the past, utilities often preferred to secure DR from their few large energy consumers because their capacity to reduce load was significant. Targeting these few high-usage customers is particularly effective when the processes for curtailing load requires extensive human interaction and manual manipulation of equipment. The volume of load reduction is also easier to quantify when dealing with fewer and larger loads. Knowing with precision how much load has been shed simplifies the management of flows across the grid.

Automated Load Control

Utilities have, since their inception, managed their system loads by communicating with customers. Early efforts were via telephone calls to large customers requesting a load reduction. More recently, many utilities established automated load control programs that send signals via cellular telephone networks to control the load of residential air conditioners and pool pumps. ICT can automate such a dispatch of hundreds or thousands of customer devices.

Programs that encourage or require customers to reduce their load upon request are referred to as *DR programs*. Utilities and transmission operators use these programs to balance loads and reduce the overall load on the grid during peak demand periods.

Now, with a grid-connected home and BEMS, any customer can be part of a DR program. BEMS, controlled by an appropriate software application, and in communication with the electric grid, can respond to grid signals to decrease or increase power draw in a dynamic fashion. They can even contribute ancillary services, such as frequency control and reactive power.[5]

To understand how connected buildings are changing the relationship between customers and utilities, we looked for one or more indices that reflect the volume or fraction of residential, commercial, and industrial customers participating in DR. Table 3 summarizes data from the Federal Energy Regulatory Commission (FERC) on the percentage of customers with smart meters and the respective DR volumes in 2012–2014. If smart meters are a precursor to increases in DR, we would expect to see a correlation between the two trends. However DR volume has recently decreased in the residential and commercial sectors, while the ratio of customers with smart meters has increased. The relationship between these two metrics is something to follow in the future.

[5] Ancillary services help keep the grid operating at a constant voltage and frequency. Common services are frequency regulation, load following, voltage control, and spinning reserve. See Chittum and Farley 2013 for more information on ancillary services.

Table 3. Sectorial penetration of smart meters and DR, 2012–2014

	Customers with smart meters (%)			DR provided to sector (MW)		
Sector	2012	2013	2014	2012	2013	2014
Residential	30.4	37.8	40.9	8,600	7,003	8,118
Commercial	25.2	36.1	38.6	6,462	5,124	6,215
Industrial	24.5	35.2	36.5	13,261	14,800	16,505
Weighted average/total	29.7	37.6	40.6	28,503	27,095	31,191

The totals include DR provided by the transportation sector. *Sources:* FERC 2014, 2015, 2016.

Broadly, changes in sales of equipment and services that enable DR tell us if, and by how much, the market is growing. Navigant found that sales of DR and enabling information technology products have seen steady annual growth, reaching $6.4 billion in 2015, up 12% from 2014 and 70% from 2011 (AEE 2016).[6]

Distributed Energy Resources

The final step is making a building part of the grid's supply and demand balance. Commercial, institutional, and industrial facilities have always invested in backup generation, but now, as prices of photovoltaic (PV) solar are falling, residential and institutional buildings are increasingly installing PV systems. Backup generation, PV, and other onsite generation technologies are forms of distributed generation (DG). Other examples include combustion turbines, fuel cells, and solar photovoltaic (Chittum and Farley 2013).

We have already discussed customers' ability to curtail energy consumption through demand response. DR is one type of distributed energy resource (DER). This category also includes DG systems that generate electricity at or near the point of use and independent of the utility grid, as well as other technologies such as energy storage that are located at a customer's site and enable a more dynamic control of energy use.

Another type of DER is electric vehicles (EVs). Because of their batteries, EVs can function as an energy sink or source that makes them ideal for addressing peak demand issues. From a building management perspective, an EV is a very flexible DER. EVs can be a balancing resource to intermittent sources such as onsite solar PV and wind.

A key enabling technology of DER is smart inverters that allow for two-way communication between the DER and the utility. A smart inverter can route excess power generated by a PV or other type of DG system to customer loads, the grid, or an energy storage system such as an EV. When a building needs power, the smart inverter signals the grid to supply power to

[6] Navigant's definition of demand response (DR) and enabling information technology includes building energy management systems, residential energy management systems, automated DR hardware and services, DR services, and home energy management systems.

the building. Smart inverters can be programmed to ride through power lags in DG or grid supplied power that could otherwise lead to power outages (Unger 2016).

DER enables prosumers to have a symbiotic relationship with their utilities.[7] A prosumer's building has one or more devices and systems that are DR responsive and can respond to instructions from grid operators or third parties to help balance the grid. Figure 6 represents a building that is fully integrated with the grid, both consuming and providing utility services. Through the Internet, the building can access weather information, energy market pricing information, and DR requests. The information technology and building management system balances multiple building loads with the power generated by the roof-mounted solar PV and a combined heat and power system. It even uses EVs to store energy and balance the building's overall load (Schneider Electric 2016).

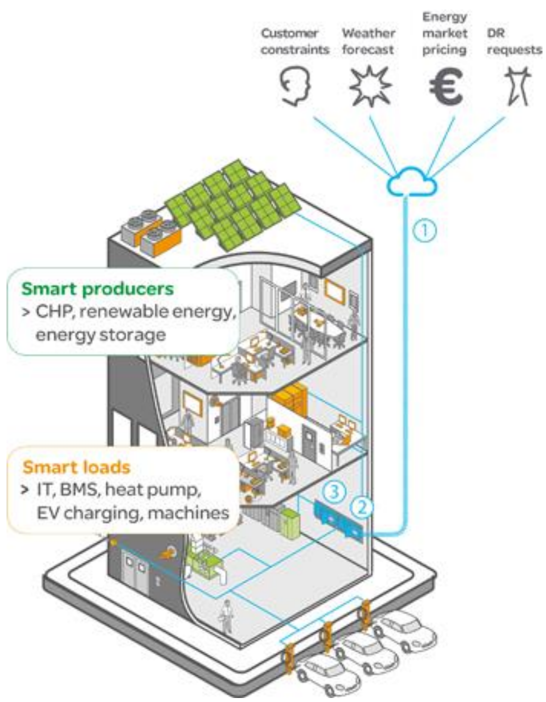


Figure 6. Connected building. *Source:* Schneider Electric 2016.

Commercial and residential buildings are connected to the grid at the distribution level, which is where they can have the greatest effect in balancing the grid. By balancing the peaks and valleys of their consumption with one or more DERs, they put less stress on the local grid. When multiple customers do this, the grid runs more efficiency and might even be able to accommodate more customers without new investments.

Well-balanced distribution grids can work together to balance the transmission grid that connects neighborhoods and cities, enabling new levels of efficiency in the larger utility system. The system can operate with less conventional generation, more renewable energy

[7] In this context, a prosumer is a customer who both consumes and provides energy services.

resources can be accommodated when available, and fewer transmission lines will be required.

In 2014, 116 organizations made investments in smart grids and 45 demonstration projects were conducted (SmartGrid.gov 2016). These data speak to a new utility grid that can support the services described throughout this report.

We can understand the smart grid's potential to facilitate DR by knowing the number of homes and businesses that have smart meters and how those numbers compare to the overall housing and building stock. In 2012, 29.7% of the 135 million US houses had smart meters. That percentage grew to 35.5% in 2015. The percentage of nonresidential buildings with installed smart meters nationally grew more rapidly, causing the overall ratio of buildings to climb even faster. In 2012, 29.7% of all buildings had smart meters. In 2013, that percentage grew to 35.5%, and to 43.0% in 2014 (EIA 2015a).

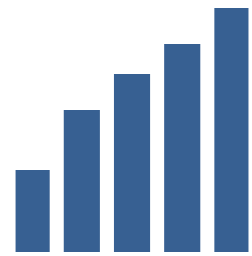
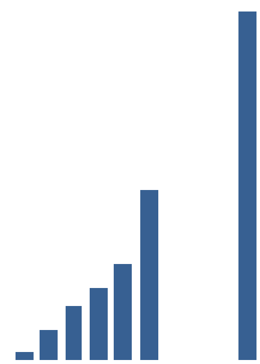
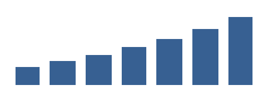
The number of commercial and institutional buildings that can respond to automated DR signals from their utilities are steadily increasing. In 2014, approximately 217,000 C&I buildings had automated DR. Navigant predicts the number will increase to 1.9 million by 2023 (Feldman 2014). The growth in sales of enabling information technology for DR mirrors this projection. In 2015, sales reached $6.4 billion—a 12% increase from the year before and a 70% increase since 2011.

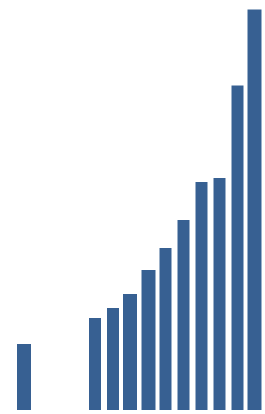
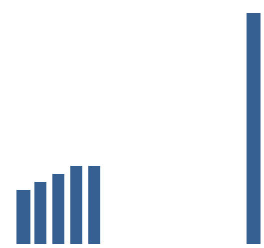
SUMMARY OF TRENDS

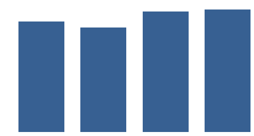
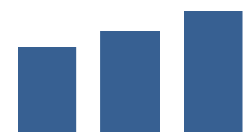
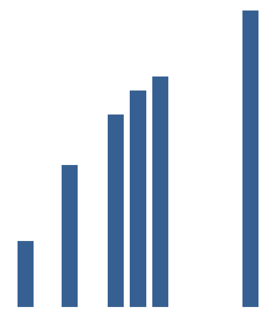
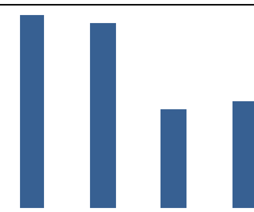
Table 4 summarizes the trends discussed in this section.

Table 4. Intelligent efficiency applications and adoption in the buildings sector

Application	Metric	Trend			
		Year	Value	Units	Graphic
Smart lighting	Commercial buildings with advanced lighting controls[1]	2012	4%		
		2014	12%		
	Smart lighting installations (global)[2]	2015	0.046	Billion units	
		2020	2.540	Billion units	
Water heaters	Electric resistance[3]	2016	4.2	Million units shipped	
	Connected water heaters[3]	2016	<0.2 (est)		

Application	Metric	Trend			
		Year	Value	Units	Graphic
Residential energy management	Number of smart thermostats sold[4]	2013	2	Million units	
		2014	3.5		
		2015	4.4		
		2016	5.1		
		2017	6		
	Number of homes with smart thermostats[5]	2015	4.5	Million homes	
		2020	32.2		
	Sales of HEMS[6]	2011	$44	Million USD	
		2012	$150		
		2013	$273		
		2014	$366		
		2015	$495		
		2016	$878		
		2020	$1,793		
Residential energy management	% of homes with HEMS[7]	2015	5.1%		
		2016	6.7%		
		2017	8.7%		
		2018	11%		
		2019	13.5%		
		2020	16.3%		
		2021	19.3%		
Commercial building energy management	Commercial buildings (1,000 to 50,000 sq ft) with building automation systems[8]	2003	9%		
		2012	25%		
	Commercial buildings (50,001– 500,000+ sq ft) with building automation systems[8]	2003	60%		
		2012	99%		

Application	Metric	Trend			
		Year	Value	Units	Graphic
Commercial building energy management (cont'd)	Sales of BEMS (global)[9]	2011	$1.80	Billion USD	
		2015	$2.50		
		2016	$2.75		
		2017	$3.13		
		2018	$3.75		
		2019	$4.38		
		2020	$5.13		
		2021	$6.13		
		2022	$6.25		
		2023	$8.75		
		2024	$10.80		
	Sales of BEMS (US)[10]	2011	$0.74	Billion USD	
		2012	$0.83		
		2013	$0.94		
		2014	$1.06		
		2015	$1.07		
		2024	$3.10		
Demand response	Automated demand response[11]	2014	217	Thousand buildings	
		2023	1,900		
	DR participation by sectors[12]	2012	30%	Residential	
		2014	26%		
		2012	23%	Commercial	
		2014	20%		
		2012	47%	Industrial	
		2014	53%		

Application	Metric	Trend			
		Year	Value	Units	Graphic
Demand response (cont'd)	Total DR capacity[12]	2012	28,503	MW	
		2013	27,095		
		2014	31,191		
		2015	31,754		
	Spending on DR equipment and services[13]	2011	$3.8	Billion USD	
		2014	$5.7		
		2015	$6.4		
Smart grid (AMI)	Buildings with smart meters (US)[14]	2012	29.7%		
		2013	35.5%		
		2014	43.0%		
	Smart meter installations[15]	2010	20.3	Million meters	
		2012	43.2		
		2014	58.5		
		2015	65.6		
		2016	70.0		
		2020	90.0		
	Spending on AMI (US)[16]	2010	$4.9	Billion USD	
		2012	$4.7		
		2014	$2.5		
		2016	$2.7		
	Spending on smart grid SaaS (global)[17]	2014	$1.7	Billion USD	
		2023	$11.2		

Sources: [1] EIA 2016b; Arnold and McCullough 2016. [2] Gartner 2015c. [3] Statista 2017a. [4] Kerber 2015. [5] Leuth 2016; Berg 2016. [6] AEE 2016; Statista 2016. [7] Statista 2016. [8] CBECS 2003; 2012. [9] AEE 2016; Talon and Martin 2015. [10] AEE 2016. [11] Feldman 2014. [12] FERC 2014; 2015; 2016. [13] AEE 2016. [14] EIA 2015a. [15] EIA 2015a; Cooper 2016. [16] DOE 2014. [17] Navigant 2014.

Table 4 shows how intelligent efficiency is changing the built space. Almost all the metrics show a rising trend. The pace of change appears to be linear across all applications, suggesting that the market and the policies that shape it are largely working. Investments by sector are steadily increasing and, in some instances such as HEMS, the rate of investment is increasing. This all speaks to a future with buildings that are highly networked. The trend we are seeing is toward greater connectedness, both in the networking of an increasing number of devices within buildings and in more buildings integrated with the electric grid.

Customers of all sizes are investing in connected devices and networks. We are seeing smaller buildings adopt the types of systems that made economic sense only in larger buildings in the past (Bachman 2012, DOE 2015). Sales of HEMS in the residential sector are growing faster than the more mature commercial building automation market. Smart thermostats, with their machine learning, have introduced the full manifestation of intelligent efficiency into the home. We will continue to see dynamic growth as the combination of connected devices and web-based apps accessible from computers and smartphones make it easier to track and control household appliances (Berg 2016; Statista 2016; AEE 2016).

Device control is moving in two directions: some decisions are pushed outward toward the Cloud, while others are going inward to local systems and devices. In the first trend, information (and often analysis) is conducted in the Cloud. This reduces onsite infrastructure investment requirements, but it also increases latency. The other trend compensates for this. Many devices and systems are now embedded with logic that can respond to local conditions and make decisions autonomously. These grid edge devices can still receive and communicate with centralized control, and the exchange can improve the quality of control.

Changes in the built space are reflected in other sectors. These overlaps help us see the larger picture of how investment in intelligent efficiency is changing the use of energy in our homes, businesses, and communities. Many of these investments are made possible by energy efficiency programs. As we will see later in the report, many programs are being built around smart thermostats, energy management systems, and automated dispatch. Such programs give customers the ability to monetize the energy efficiency and DR capabilities of their thermostats or BEMS.

Smart Manufacturing

The manufacturing sector has embraced automation since the 19th century. The very nature of modern manufacturing is to standardize materials, processes, and procedures—three variables that automation deals with very well, often better than people do. Smart manufacturing creates new opportunities to save energy by integrating information technology (IT) systems with operation technology systems. It uses Internet and Cloud services to connect devices, share information, and leverage big data and data analytics to improve the effectiveness and efficiency of business processes, especially manufacturing processes. A 2011 Smart Manufacturing Leadership Coalition (SMLC) analysis estimated that smart manufacturing technologies could improve energy efficiency by 25% and increase operating efficiency by 20% (SMLC 2011).

One of the challenges we faced in preparing a previous smart manufacturing report (Rogers 2014) was distinguishing contemporary automation from smart manufacturing. We settled on a definition that includes intelligent efficiency's three foundations:

- Networked
- Access to logic (data analytics and simulation)
- Use of logic to optimize energy use (anticipatory)

Given these criteria, we can break down the intelligent efficiency applications into connected devices, manufacturing process integration, and energy management. We can also consider automated DR programs to be an intelligent efficiency application, giving us a total of four applications:

- Connected and smart devices
- Integrated manufacturing processes
- Energy management
- Demand response

CONNECTED DEVICES AND THE INDUSTRIAL INTERNET OF THINGS

A connected device may or may not have logic of its own. However it will always be networked and, through the network, be controlled (at some level) by a centralized system that has access to logic and external data sets. Devices with internal logic that can perform local decisions are often called *smart machines*. They are more flexible than devices that are simply connected to a network (Beudert, Juergensen, and Weiland 2015).

Capturing market acceptance of connected devices in the manufacturing sector is challenging, as the variables related to enabling technologies and practices are not unique to smart manufacturing. However much of the networking of equipment in the manufacturing sector is referred to as the Industrial Internet of Things (IIoT), a subset of the Internet of Things discussed earlier, and considerable information is available on this topic. The term *machine-to-machine (M2M) communication* has a similar meaning, but it also includes interactions in networks outside the manufacturing sector.

Companies investing in IIoT saw an average 28.5% increase in revenues between 2013 and 2014 (Duke-Woolley 2016). Given such an upside, it is not surprising that *Business Insider*'s research service, BI Intelligence, predicts that the installed global base of manufacturing IIoT devices will swell from 237 million in 2015 to 923 million devices in 2020. Globally, investment in IIoT solutions by manufacturers is predicted to increase from $29 billion in 2015 to $70 billion in 2020 (Greenough 2016).

In its analysis, IHS examined the sales of a broad set of connected industrial devices and predicts that sales will increase from more than a billion units per year in 2011 to more than 7 billion in 2025. Figure 7 breaks down the types of connected devices important to the industrial sector and predicts future sales.

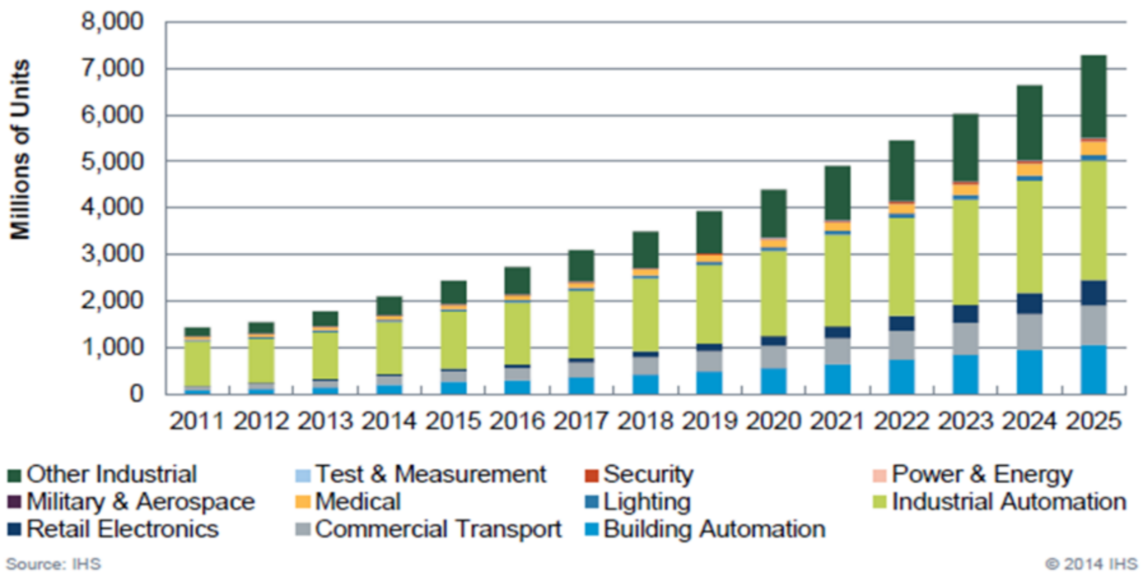


Figure 7. New shipments of IIoT-connectable devices. *Source:* Morelli 2014.

Manufacturers are also investing in mobile devices to give their workers ubiquitous data access. No longer will workers need to visit a machine to assess its performance. The connected device will provide updates through the network that are accessible via a mesh network on mobile devices such as tablets and smartphones. Global sales of four types of industrial mobile applications (control and visualization, workflow management, maintenance, and system integration) are expected to increase from less than $10 million in 2014 to $200 million in 2019 (Beudert, Juergensen, and Weiland 2015).

INTEGRATED MANUFACTURING PROCESSES

Manufacturing processes have been networked through supervisory control and data access systems and programmable logic controllers since the 1970s. These systems enable remote monitoring and control of production processes. Smart manufacturing software tools enable companies to incorporate historical data and external data sets into their analysis of production processes. They can do predictive modeling that recommends optimal production set points. They can also integrate in other management systems (such as enterprise resource planning, customer relationship management, and supply chain management systems) to discover new opportunities to improve the use of resources such as capital, chemical feedstocks, and water, as well as the optimal use and movement of materials (Milby, Keegan, and Baker 2017).

Analytical software products enable smart manufacturing. The development, supply, and service of software products have become growth areas in manufacturing automation. Vendors that used to provide only hardware are now providing software products and services as well. In some cases, software is replacing hardware in the smart manufacturing environments (Beudert et al. 2015). For example, software is used instead of gearing to speed up and slow down electric motors. Because software tools are indicative of smart manufacturing's predictive and analytical abilities, we can use sales of such products as a proxy for the growth of manufacturing process integration, which is a fundamental component of smart manufacturing.

Beudert, Juergensen, and Weiland (2015) and IHS refer to this as the *digitization of industrial control system design and simulation*. IHS tracked the sales of a range of software products that fill this role. Sales in the Americas are predicted to increase from more than $140 million in 2014 to $180 million in 2019. The summary table at the end of this section shows existing and predicted annual sales values for the Americas from 2014 to 2019.

INDUSTRIAL ENERGY MANAGEMENT

Industrial automation and process control usually yield energy efficiency improvements by increasing the efficiency of production. However energy efficiency may or may not be the motivation for such investments. To determine the industrial sector's level of interest in intelligent efficiency, we need a metric that speaks to energy efficiency investments specifically.

We can use the Department of Energy (DOE) EIA data to assess the number of manufacturing plants focused on energy management. In its *Manufacturing Energy Consumption Survey*, the EIA asks manufacturers about the employment of energy managers and use of automated building control systems. The survey revealed that 15,636 manufacturing plants, or about 9% of a total of 170,168, provide training for energy management (EIA 2010a).

The survey also revealed that 20,751 facilities (12%) in the manufacturing sector use some type of computer control to manage building energy use (heating, cooling, and lighting) and 28,139 (17%) use some type of computer control for production processes or major energy consuming equipment (EIA 2010b).

Advanced Energy Economy studied the economic impacts of various energy-related technologies, including nuclear power, renewable energy, EVs, and energy efficiency. It examined investments by various economic sectors and sales of products such as industrial energy management systems. Table 5 shows the increasing annual sales of this key component of smart manufacturing. In 2011, sales were $3.2 billion. By 2015, sales had increased to $4.3 billion (AEE 2016).

GRID INTEGRATION AND DEMAND RESPONSE

The next application we explore uses intelligent efficiency at the manufacturing plant level to effect system-level energy savings at the utility system level. The metric we chose to gauge this application is participation in DR and other grid integration programs.

We know from EIA that in 2010, 15,763 plants (9%) participated in some type of electricity load control or DR program (EIA 2010a). Almost half of them had some type of internal load control practice. Only 44% participated in a utility-managed DR program; a fourth utilized a third-party service provider.

The EIA data did not include information on the number of facilities responding to automated signals from a utility. However we can conclude from three data points—9% participation in load control, 9% use of building automation to manage building energy use, and 17% use of automated process control—that the fraction of manufacturing facilities that can receive and respond to an automated DR request is likely less than one-tenth.

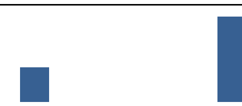
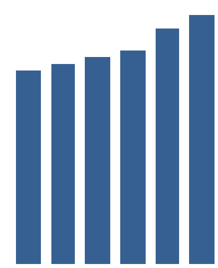
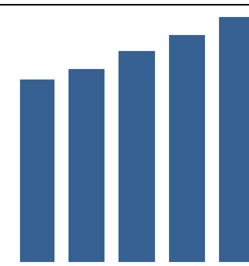
This value is much less than that of industrial customers with AMI meters. Described earlier in table 3, the percentage of customers increased from 24.5% in 2012 to 36.5% in 2014. Once again, we see no direct correlation between AMI uptake and DR participation.

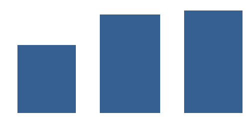
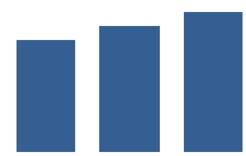
Given the number of facilities with AMI, there appears to be an opportunity to automate DR in this sector. DR volume increased from 13,261 MW in 2012 to 16,500 MW in 2014. Further research may yield an understanding of any barriers to automating DR participation in the industrial sector. To date, it appears to be an underutilized application of intelligent efficiency.

SUMMARY OF TRENDS

It is still early in the adoption of smart manufacturing technologies. The information we identified is largely tied to investments in the IIoT and electronic process and energy management systems. Table 5 summarizes these values.

Table 5. Intelligent efficiency applications and adoption in the manufacturing sector

		Trend			
Application	Metric	Year	Value	Units	Graphic
Connected devices and IIoT	Installed base of IIoT devices (global)[1]	2015	237	Million devices	
		2020	923		
	Spending on IIoT solutions (global)[1]	2015	$29	Billion USD	
		2020	$70		
Integrated manufacturing processes	Digitization of manufacturing control system design and simulation (Americas)[2]	2014	$140	Million USD	
		2015	$145		
		2016	$149		
		2017	$155		
		2018	$170		
		2019	$180		
Industrial energy management	Spending on industrial energy management systems (US)[3]	2011	$3.2	Billion USD	
		2012	$3.4		
		2013	$3.7		
		2014	$4.0		
		2015	$4.3		

Application	Metric	Trend			
		Year	Value	Units	Graphic
Grid integration	Number of plants participating in electricity load control, 2010[4]	In-house	7,565	Facilities	
		Utility	6,966		
		Third-party	3,471		
		Other	1,256		
		Total	15,763		
	% of industrial facilities with AMI[5]	2012	24.5%		
		2013	35.2%		
		2014	36.5%		
	Demand response from industrial sector[5]	2012	13,261	MW	
		2013	14,800		
		2014	16,505		

Sources: [1] Greenough 2016. [2] Beudert et al. 2015. [3] AEE 2016. [4] EIA 2010a. [5] FERC 2014; 2015; 2016.

Although it is still early, as the table shows, investments in technologies that enable smart manufacturing are accelerating. In general, manufacturers are increasingly expecting to have data available when and where they want it (Beudert, Juergensen, and Weiland 2015). We have become increasingly used to this in our office and home environments; similar expectations have also emerged in the manufacturing sector. Another expectation is plug-and-play connectivity and the ability of devices, regardless of vendor, to exchange data with other devices without special modifications.

We hoped to find quantitative data on the number of facilities purchasing smart manufacturing software and using it to integrate their supply chains. However, given that no widely accepted definition of smart manufacturing exists, we were not surprised that such information was not readily available. In 2011, the Smart Manufacturing Leadership Coalition (SMLC) estimated a 20% market awareness of smart manufacturing technologies and an adoption rate of around 10%. SMLC also predicted that 50% of the manufacturing sector would adopt some amount of smart manufacturing technology by 2020 (J. Davis, Chief Technology Officer, UCLA, pers. comm., July 16, 2015).

In lieu of data specific to intelligent efficiency, we looked to proxies to help us identify the adoption level of smart manufacturing. A possible proxy could be the number of companies using Cloud-based data analytics to optimize their production processes. Another is the SMLC, a collaborative dedicated to advancing the development and testing of open source smart manufacturing software platforms. The SMLC has 18 members that are manufacturers. A less technology-specific group, the Environmental Protection Agency (EPA) ENERGY STAR Industry Partners program, has 760 facilities as members, 460 of which are ENERGY STAR certified. While these values are hardly firm indicators of market adoption, they perhaps give us a sense of scale; most likely, only hundreds rather than thousands of facilities employ the latest process integration technologies.

We also sought out information on the number of companies claiming to serve the intelligent efficiency, or smart manufacturing, sector. In the Forbes list of companies, we found only two with intelligent efficiency in their portfolio. Although this is interesting, it is likely more indicative of the adoption of the term than the technologies.

We wanted to quantify the number of workers dedicated to smart manufacturing, but we abandoned our search because there was no commonly accepted definition of smart manufacturing jobs. We did find that the National Electrical Manufacturers Association (NEMA) Industrial Automation Control Products and Systems Section (1IS) has an initiative to create a roadmap for implementing advanced process manufacturing technology (that is, smart manufacturing) in the United States. The NEMA section behind this initiative represents the relay and industrial control industry, with its 32,873 full- and part-time employees (Quinn 2013). These professionals set up and operate the smart manufacturing control systems. Tracking changes in their numbers and how those changes compare with changes in overall manufacturing employment will help us understand much about how smart manufacturing technologies affect employment in the manufacturing sector.

Transportation

The transportation sector accounts for 28% of total US energy use and offers considerable opportunities to decrease energy consumption and emissions. All sectors rely on transportation, and each transportation mode faces its own unique challenges. ICT can play a significant role in reducing energy consumption in the transportation sector. In personal travel, ICT can make it easier for people to use alternatives to driving, move traffic away from peak travel times, consolidate commuters into fewer vehicles, and enable vehicle automation (Vaidyanathan 2014). Similar opportunities exist in the freight sector. ICT plays a critical role in improving the overall efficiency of the freight system by improving the load factor (ton-miles per vehicle-mile) of freight vehicles, reducing the overall number of ton-miles for businesses, and shifting goods to more efficient modes (Langer and Vaidyanathan 2014).

For this report, we focus on the following uses of ICT and intelligent efficiency in the transportation sector:

- Real-time data collection for traffic management
- Vehicle automation
- Multimodal smart device apps
- Transit and intelligent efficiency
- ICT in freight logistics
- EV smart charging

These six applications represent only a fraction of the potential energy savings in transportation using intelligent efficiency. We considered or hoped to consider other applications, but were unable to include them for various reasons (see Appendix B).

REAL-TIME TRAFFIC MANAGEMENT AND DATA COLLECTION

Real-time traffic data collection is crucial to the efficient use of roads and highways and to reducing energy consumption. Traffic is ever-evolving and sometimes unpredictable. Historic data can help determine where high levels of congestion exist, but granular, real-time data allow drivers to respond to congestion or poor road conditions immediately. Information that provides driver feedback on road conditions provides an opportunity to reduce energy consumption by limiting idling and stop/start driving, and shortening the length of trips. As of 2014, 63% of freeway miles are equipped with real-time data collection capabilities. These data are fed into route planning and traffic apps. In addition to providing directions, navigation applications such as Google Maps and Waze update drivers about road conditions and traffic situations. In 2013, Waze predicted that it would save its users more than 82 million hours of time in traffic and save more than 844,000 tons of CO_2 (Wauters 2013).

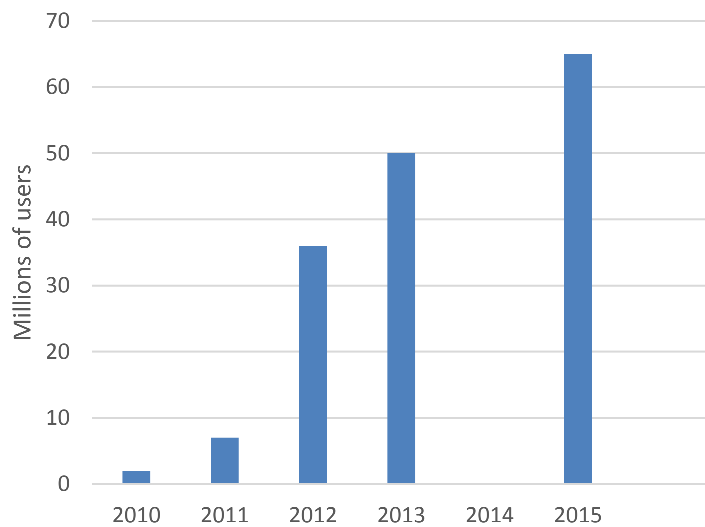


Figure 8. Growth of Waze user base. No data available for 2014.
Sources: Geron 2011; Wauters 2013; Goel 2013; Waze 2016.

Another category of ICT used to manage traffic and congestion involves intelligent infrastructure. At the most basic level, intelligent adaptive traffic signals sense traffic levels at intersections and can intelligently modify traffic patterns through signal timing, reducing congestion and backups on key corridors. The growth in US adoption of adaptive traffic signals is promising. Between 2010 and 2013, the number of such signals doubled. (DOT 2014). Vehicle-to-infrastructure (V2I) communication takes this concept a step further by enabling vehicles and infrastructure to use Wi-Fi networks to communicate with each other about road conditions, vehicle speed, and acceleration.

In any case, the importance of integrating ICT applications and real-time data into traffic management is clear; some suggest that the economic benefit from decreased congestion and smart parking is $223–506 billion per year (Manyika et al. 2015).

VEHICLE AUTOMATION

Autonomous Vehicles

Autonomous vehicles have generated considerable buzz in recent years thanks to the multiple benefits they can provide. Software and predictive learning allow for a level of efficiency and control beyond what is humanly possible, bringing potential improvements in safety, convenience, and fuel economy. With the continued focus on autonomous vehicles as a technology ripe for called-up deployment, it makes sense to start tracking numbers now. Metrics used to represent this emerging but imminent technology include number of vehicles and ratio of autonomous vehicle sales to sales of all vehicles.

Currently, autonomous vehicles are purely in the testing and pilot phase, and Silicon Valley companies such as Google and Uber have undertaken much of the research and development to date. Uber has incorporated autonomous vehicles into its fleet in Pittsburgh as part of a pilot program with the Carnegie Mellon University Robotics Center. Further, government agencies such as the DOT have started to focus on the potential safety and energy impacts associated with the operating these vehicles. The US DOT recently released a Federal Automated Vehicles Policy with input from policymakers, industry leaders, and other experts, with the aim of setting up a framework for autonomous vehicle deployment (DOT 2016).

Driver-Assist Technologies

While autonomous vehicles have the potential to revolutionize the transportation sector, mass production is still many years away. However we are already seeing incremental implementation of the technological building blocks that could lead to full automation in the form of driver-assist applications. These applications include vehicle-to-vehicle (V2V) and V2I technologies.

V2V and V2I allow real-time communications and cooperation with other vehicles and infrastructure through dynamic wireless data exchange. This data exchange has the potential to improve the safety and overall efficiency of the highway and roadway system and the vehicles that use it (DOT 2014). For instance, V2V systems let vehicles exchange information such as tire pressure, speed, and GPS location traditionally collected by onboard diagnostic systems. Vehicles can thus talk to each other about their speed, upcoming traffic conditions, and potential road obstacles, thus reducing emissions, fuel consumption, and the potential for congestion through applications such as adaptive cruise control (ACC). ACC uses a forward-looking radar sensor to adjust the speed of a given vehicle in response to the proximity and speed of the vehicle ahead. Cooperative adaptive cruise control (CACC) lets multiple vehicles platoon, i.e., closely follow a leader. A 2012 European case study of platooning involved five vehicles: one leading truck, one following truck, and three additional following cars. All vehicles, including the lead vehicle, realized a significant reduction of energy consumption of up to 16% (Jootel 2013) (figure 9).

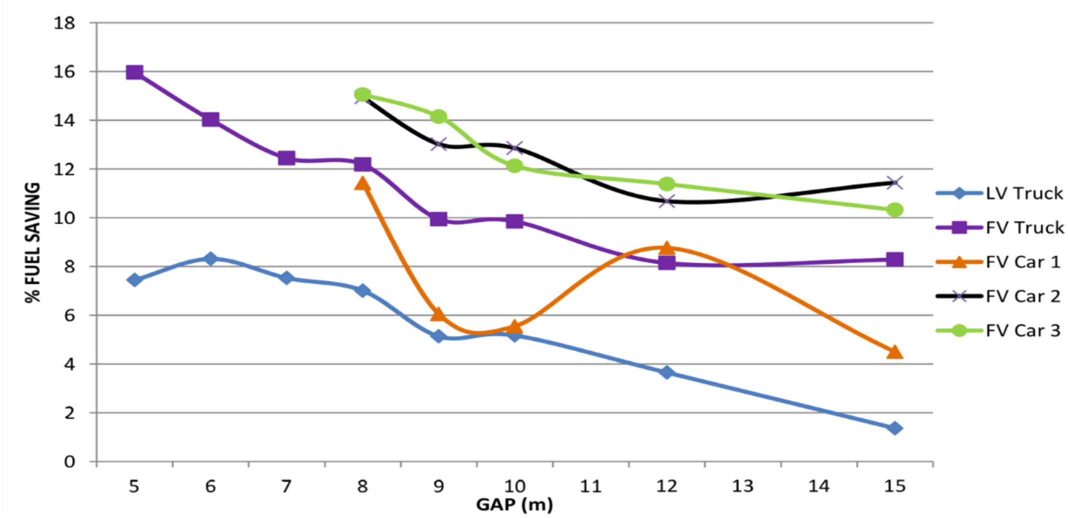


Figure 9. Energy savings from vehicle platooning. *Source:* Jootel 2013.

Driver-assist technologies can lead to substantial energy savings. Preliminary estimates show that ACC and CACC can reduce fuel consumption by approximately 16% (Vaidyanathan 2014). However it is important to note that, by improving traffic flow, these technologies allow more and more vehicles to access roads and highways, possibly offsetting some of the fuel savings demonstrated above.

Given the youth of the automated vehicle market, the most relevant metric for vehicle automation is the prevalence of the building blocks that lead to fully autonomous driving. While only 6% of vehicles sold in the United States had ACC in 2016 (Piotrowski 2016a), we expect that number to increase rapidly from simple market demand. Partially autonomous vehicle sales are projected to represent 25% of the automotive market by 2035 (BCG 2016). Global sales of fully autonomous vehicles are currently zero. Global sales of fully autonomous vehicles are projected to be 600,000 vehicles in 2025, then soar to 21 million vehicles by 2035 (Piotrowski 2016b).

MULTIMODAL SMART DEVICE APPS

We define *multimodal smart device apps* as software developed to improve, connect, or coordinate various modes of transportation. These apps can be installed on or used with a smartphone or other smart device. Their intelligence exists in the ability to give users immediate access to a shared pool of vehicles. This universe of multimodal apps covers car-sharing, bike-sharing, and ride-hailing services such as Uber and Lyft. We dedicate a separate section below to apps that cater to transit ridership.

The emergence of such services and their accompanying smartphone-enabled apps indicates increasing popularity, particularly among metropolitan residents who either do not want the cost and maintenance burden of owning underutilized personal vehicles or want a variety of mobility options at their disposal. Car-sharing programs rely on Internet-based platforms to give people access to a fleet of shared vehicles and let them identify the location of available vehicles, locate drop-off points, report issues with vehicles used, and pay for vehicle rentals. Likewise, the development of Internet-enabled and smartphone-based applications has been critical to the success of modern bike-sharing programs. Bicycle kiosks with multiple docks are equipped with technology that lets kiosks talk to each other and to a central server to ensure that staff can appropriately distribute bicycles (Sherman 2011). Additionally, users can download apps to locate and return bikes, and fobs used to unlock bike stations can be an important source of information on the frequency of trips, length of the average trip, and overall miles traveled per month. Ride-hailing services are also enabled by smartphones' hardware and software capabilities. Services such as Uber and Lyft connect riders with instantaneous access to rides that can be solo or shared.

Shared-use multimodal services have been growing steadily in recent years. For example, the Washington, DC, Capital Bikeshare installed 350 bike kiosks throughout the DC-Metro area, with more than 3,500 bikes available to anyone for a small fee or membership. Figure 10 shows the increased annual distance traveled by Capital Bikeshare users since its inception in 2010 (Capital Bikeshare 2016). While the benefits of bike-sharing are clear, the energy and vehicle-miles-traveled impacts of car-sharing and ride-hailing services are still largely uncertain. Although they give drivers alternatives to personal vehicle ownership, it is also possible that these services are seen as substitutes for more efficient modes of transport, like public transit, because of the convenience factor.

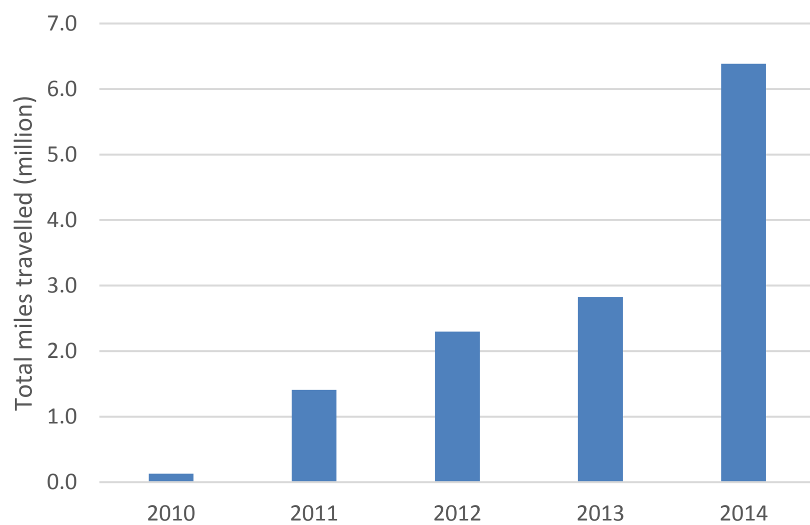


Figure 10. DC Capital Bikeshare total miles traveled. *Source:* Capital Bikeshare 2016.

Transit agencies generate travel data on a daily basis. Greatly enhanced open access data policies have increased the possibility of developing applications to optimize service and operations. Such applications can make transit a feasible alternative to driving by giving people the ability to track the progress of a bus or train and plan travel routes, for example (US PIRG 2013).

Real-Time Transit Data

Many US transit authorities offer commuters consumer-friendly transit information applications that make transit a much more reliable and efficient alternative to driving. These interfaces are also often smartphone-enabled, letting commuters plan on the go and change routes. In general, however, increased rider access to real-time transit information has had the greatest impact on transit ridership in metropolitan areas.

Driving is often viewed as the most convenient way to travel from point A to point B, because it gives people the ability to control their own schedules. To successfully shift daily travel from personal vehicles to public transportation, commuters need access to accurate, reliable, and real-time information. Taking advantage of up-to-the-minute data obtained from GPS systems on buses and trains, transit agencies are now able to provide commuters with dynamic information about arrivals, departures, and travel time (Vaidyanathan 2014).

According to a report by US PIRG and Frontier Group, more than 60% of all US transit agencies give commuters real-time information accessible instantly through their smartphones (US PIRG 2013). By capturing the real-time location of trains and busses, transit agencies can decrease the time commuters put into a trip. This savings can be as much as 70% of the total trip time if "buffer time" (that is, the extra time between a rider arriving at a stop and the train or bus departing) is completely eradicated (Manyika et al. 2015).

Dynamic Scheduling of Mass Transit

Many transit systems employ ICT to optimize overall effectiveness. This allows for "just-in-time" public transit. Mass transit agencies are increasingly using technologies that allow for both dynamic scheduling and dynamic routing. Dynamic scheduling lets transit agencies direct busses and trains toward high-demand stations based on historical and up-to-the-minute data. Likewise, dynamic routing gives transit operators information on real-time traffic conditions and routes vehicles directly to high-volume stops to maximize route efficiency and service. This can decrease headways (the time between trains or busses). Intelligent efficiency enters dynamic scheduling as the ability to collect real-time data on the vehicle, station, and passenger demand.

More than 25% of major transit agencies surveyed by the US DOT Intelligent Transportation Systems (ITS) (2014) planned to deploy computer-aided dispatch and automatic vehicle location capabilities that can enable intelligent and predictive dynamic scheduling. Of the 64 transit agencies surveyed, 14% planned to deploy scheduling system enhancements (figure 11).

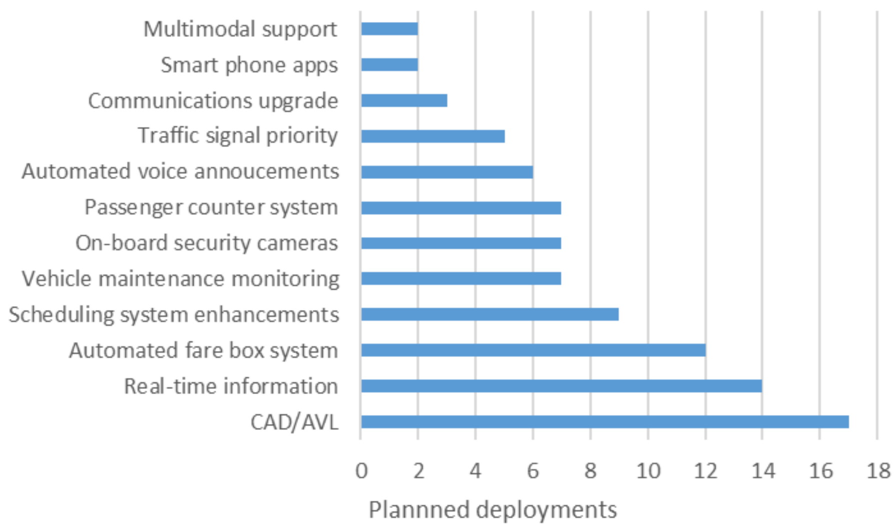


Figure 11. Planned deployments by transit agencies 2013–2016 (*n* = 64). *Source:* DOT 2014.

Historically, transit agencies have used dynamic mass transit scheduling to optimize fleet performance. We expect to see a steady increase in its use as transit agencies look for the most effective and affordable ways to improve service. The US DOT operates programs to accelerate ICT deployment through its Office. We expect this to compound with the decreasing cost of ICT devices and services to accelerate adoption of intelligent mass transit scheduling.

ICT IN FREIGHT LOGISTICS

The application of intelligent efficiency to freight movement covers a wide range of practices. Intelligent efficiency can improve vehicle efficiency and the overall efficiency of the entire freight journey.

The most significant role of ICT applications, however, has been in coordinating freight logistics. Continuous improvement in freight operation efficiency depends on using ICT applications to gather and analyze operational data. Similarly, the ability to track shipments, monitor performance at any level of detail, and respond accordingly in real time is the foundation for many logistics functions (Langer and Vaidyanathan 2014). Radio frequency identification (RFID) of goods and equipment and, more generally, automatic identification and data capture are particularly important technologies supporting this practice.

Additional efficiencies can be achieved when companies in a supply chain collaborate. Using ICT, businesses can coordinate and collaborate as they increasingly share transportation resources to minimize supply chain costs and impacts. Real-time data access can facilitate load bundling without delay to meet just-in-time demands.

ICT use will continue to grow in the freight sector. The emergence of companies such as Cargomatic that provide application-based services to help coordinate shipments and reduce the number of freight vehicles making make half-full journeys is evidence that the freight sector is changing. Railex, which provides services such as continuous temperature monitoring and guaranteed transit times, allows rail to re-enter specialty markets (such as fresh produce) long since ceded to trucking. Many high-profile companies are turning to real-time data to help make the best logistic decisions to maximize efficiency and minimize costs.

SMART EV CHARGING

As EVs become more integrated into the US vehicle fleet, a comprehensive charging station network will be needed to support their deployment. Additionally, more EVs on the road mean that the electric grid will see a growth in load and possible changes in peak load. The growth in EVs on the road represents an opportunity to use ICT to a) promote smart charging and b) enable vehicle-to-grid capabilities in an effort to maintain grid stability.

Smart EV charging stations are public or private EV charging stations with some level of intelligence and connectivity. Adding logic and communications to a charger creates the possibility of interaction with the electric power grid. Smart charging stations allow charging times to shift based on grid loads and the vehicle owner's needs, potentially delaying charging until the demand can be met efficiently and reliably by existing grid resources. This allows for a more stable load profile. As of 2016, deployment of smart EV charging stations is largely represented by small-scale trials. Only a few private and commercial smart chargers have been deployed in limited applications.

Smart charging also encompasses technologies that enable V2G connectivity. These technologies essentially convert EVs into energy storage devices. EVs therefore become a distributed energy resource and can participate in dynamic management of the grid, pulling or supplying energy as needed. The interaction between EVs and the grid enables temporary load shedding (DR), commonly reserved for large C&I loads. Electric vehicles can supply power or ancillary services to the grid, adding stability and decreasing reliance on inefficient peaking power plants.

V2G technology is not yet widespread; only a few pilot programs exist to demonstrate this technology's benefits. The Department of Defense unveiled the first V2G-capable fleet in the United States in 2015, for use on the Los Angeles Air Force Base. This year, Nissan hinted at future plans for a V2G-capable version of the Leaf that will be available for mass consumption. V2G programs could also generate revenue from the sale of capacity to utilities. In 2015, V2G generated $335,000 (California ISO 2014) of revenue, which is projected to increase to $20.7 million by 2024 (Navigant 2014).

SUMMARY OF TRENDS

Table 6 summarizes the trends we have seen in the transportation sector.

Table 6. Intelligent efficiency applications and adoption in the transportation sector

Application	Metric	Trend		
		Year	Value	Units
Real-time traffic management and data collection	Arterial agencies employing adaptive traffic signals[1]	2014	18%	
	Economic benefit from decreased congestion and improved parking[2]	2015	\$223–\$506	Billion USD
	Time saved by drivers using navigation apps[3]	2013	82	Million hours
	CO_2 emissions avoided by drivers using navigation apps[3]	2013	844,000	Tons
	Arterial highway agencies with smartphone apps that report traffic data[1]	2010	0	
		2013	8%	
Vehicle automation	Sales of autonomous vehicles[4]	2016	0	Vehicles
		2025	600,000	
		2035	21,000,000	
Multimodal smart device apps	Total miles travelled (example: DC Capital Bikeshare)[5]	2010	0.13	Million miles travelled
		2011	1.41	
		2012	2.3	
		2014	6.38	
Real-time transit information	Potential time savings for riders of public transit[2]	2015	70%	% of average
	Reduction in passenger wait time per trip[2]	2015	15%	% of average
Use of ICT by transit agencies	Agencies planning to deploy automated vehicle location capabilities[1]	2014	>25%	
	Agencies planning to deploy scheduling system enhancements[1]	2014	14%	
	Annual economic benefit from improved schedule management[2]	2015	\$13–\$63	Billion USD

Application	Metric	Trend		
		Year	Value	Units
Use of ICT in freight logistics	Shipping cost reduction from substituting rail for long-haul trucks[6]	2014	10–20%	% of average
	Trucks removed from highways[7]	2014	250	Per 70-car train
	CO_2 emissions avoided[7]	2014	135,000	Tons per 70-car train
Smart EV charging and vehicle-to-grid	Revenue from vehicle-to-grid integrated smart chargers[8]	2015	$0.335	Million USD
		2024	$20.7	
	Vehicles with automated cruise control, US[9]	2016	$0.06	Billion USD
	Market value of partially autonomous vehicles[9]	2025	$42	

Sources: [1] DOT 2014. [2] Manyika et al. 2015. [3] Wauters 2013. [4] Piotrowski 2016a. [5] Capital Bikeshare 2016. [6] Kulisch 2014. [7] Freight Rail Works 2014. [8] California ISO 2014; Navigant 2015b. [9] BCG 2016.

These applications touch only the surface of intelligent efficiency in transportation, but they indicate a strong trend toward increased integration and automation. The number of devices and services is clearly growing; as in other sectors, the adoption rate is largely linear. However we expect it to become exponential with the increasing availability of open source data, autonomous technologies, and EVs, and as individual applications inevitably integrate with each other.

The sales and projected sales of technologies provide insight to a sector that is largely driven by market forces. Consumers are clearly willing to adopt technologies such as smartphone apps to improve their commutes. As intelligent efficiency improves the quality of public transit, more people will favor this more efficient mode of transportation. Smart transportation applications are also critical enablers of other sectors. For example, smart cities could not exist without smart transportation.

Intelligent efficiency can improve all aspects of the transportation sector. Once-isolated systems are now forming a single connected transportation network. Integration with buildings and the grid provide major revenue opportunities. Finally, transit agencies are including these technologies with infrastructure improvement; severely constrained infrastructure investment dollars mean agencies and city planners will increasingly look to intelligent efficiency as the affordable solution.

Government and Smart Cities

Cities comprise all energy-consuming sectors, from residential and commercial buildings to manufacturing and every mode of transportation. It is no surprise that urban areas account for most of the energy consumed worldwide—about 64% of global primary use in 2013 (IEA 2016). At the same time, cities also have great potential energy-saving opportunities.

The term *smart city* indicates a local government's use of ICT to improve public services and infrastructure. The 2016 US DOT Smart Cities Challenge made it clear that cities, industries, and other partners aim to implement ICT in city and government solutions. Many of the cities participating in the Smart Cities Challenge face similar problems with similar solutions. Cities are using intelligent efficiency to improve their sustainability by incorporating sensors and data in the planning, evaluation, implementation, and operation of city branches. Communication and collaboration between normally dissociated devices can improve city functions while raising the quality of life of residents. ICT is solving problems ranging from energy use, traffic flow, and air pollution to residents' health and safety. Every branch of a city can benefit from ICT, and many will find new ways to use ICT that are not captured in the following projections and discussion.

By leveraging utility sector energy efficiency programs, or even implementing the programs themselves, cities directly embrace utilities in their efforts and can engage in state energy policy to shape programs that serve their businesses and citizens. Municipally owned electric utilities can lead community efforts when operated as an extension of city government. Austin Energy, the municipally owned utility in Austin, Texas, sets energy and emission goals that are consistent with the city's Climate Action Plan (Ribeiro 2015). Many municipally owned utilities have increased energy efficiency investments; Austin Energy increased its energy efficiency spending to $20,483,000 in 2013, up from $14,318,000 in 2011. This changes the dynamic for how energy efficiency programs are implemented, expanding the potential reach of a program, as well as the number of benefits to the city.

We find that every level of government has at one point implemented many of the smart building applications mentioned earlier in this report. The benefits of intelligent efficiency in any one level (federal, state, or local) can easily translate to the other levels. For example, a 2013 Center for Climate and Energy Solutions report outlines how the federal government implemented real-time monitoring to optimize the use and maintenance of its fleet of more than 660,000 vehicles to reduce fleet fuel consumption and vehicle miles traveled, and improve trip routing (Ye and Seidel 2013). This ICT technology is similarly beneficial to local governments; for them, fleet reliability and utilization are perhaps even more critical.

Unlike our discussion of other sectors, ICT in government and cities is often difficult to break down. Many intelligent efficiency applications come together both to enable a transition to smart infrastructure and provide services in a city. Although some applications deserve a mention here, we feel that individual applications are best discussed with their respective sectors.

The benefits of the devices or services that make a city smart are captured only when viewed as a collective. Further, some of these benefits exist only as a result of private investment. For example, grid-connected BEMS are utilized for private benefits, but provide benefits to a city when installed in aggregate.

As in other sectors, government and smart city data were sometimes hard to come by. In addition, the ICT applications discussed in other sectors often provide benefits to a city that may not be captured in the data we did find. It also may be difficult to determine whether a city implemented a device, software, or service specifically to save energy. Yet even when the motivation for an investment is not energy efficiency, energy savings is often a benefit. For example, a city may wish to install new streetlights with built-in wireless networks and sensors to measure air quality. However, as a result, the lights might be upgraded to LEDs with a clear energy-saving potential.

Given these issues, this section is largely a discussion of how ICT itself can improve the functions and quality of life in a city, rather than a display of specific technologies. Most applications can be grouped by their primary motivation. With that in mind, we break down the benefits of ICT into the following categories:

- Managing energy use in government operations
- Helping residents use intelligent efficiency
- Using ICT for city planning and improvement

MANAGING ENERGY USE IN GOVERNMENT OPERATIONS

Smart buildings, EVs, distributed energy generation, and smart manufacturing provide different benefits to the city than they do to any individual players. At the city level, they all become parts of one system and contribute to making the city a more desirable place to live and work. Of 493 city respondents in the 2016 International City/County Management Association (ICMA) Smart Cities Survey, 38.7% were actively deploying smart city technologies related to energy. Nearly 80% of responding cities were actively assessing, planning, or initiating pilot programs (ICMA 2016). Groups such as Envision Charlotte, a public–private collaboration between the electric utility, city, and various business partners, formed to confront sustainability in the city. The partnership installed shadow meters on 61 of the 64 major buildings in the city’s downtown, reducing energy use by measuring and tracking it. In the program, building managers pledged to reduce their energy by 20%, while also encouraging economic development (Envision Charlotte 2017).

Cities can save energy in their own municipal buildings and also wish to reduce energy use in the buildings of community residents and businesses. They can accomplish both reduction goals by investing in BEMS for their own buildings and creating or supporting energy efficiency programs that sponsor intelligent efficiency investments for their businesses and residents. Some communities encourage investments in EV charging stations and set targets for renewable energy or pollution mitigation. Cities such as Chicago are using open data for revitalization efforts in distressed neighborhoods (Manyika et al. 2015). Demonstrating the benefits of such efforts encourages further adoption. Indeed, awareness of the technologies and their benefits have been the prominent drivers in the adoption of smart city programs. In the ICMA city survey, for example, public demand was the primary factor in motivating communities to implement smart city programs (ICMA 2016).

As a result, every level of government can apply intelligent efficiency to both their own operations and community energy use. Leaders want their communities to thrive, and to be desirable places to live and work. Internally, they want their own buildings to be energy efficient and well-functioning community resources. They also want their businesses to be competitive and stable.

We can get a sense of how popular government adoption of intelligent efficiency is through the number of past and proposed initiatives that require or encourage it. Communities are welcoming collaboration with other cities and the private sector. An example is the EcoDistricts group, which assists partner communities in adopting energy efficiency as part of its sustainable neighborhoods goals. The 11 participating communities include Washington DC, where a 138-block area is aiming for a 20% reduction of energy consumption by 2020 (EcoDistrict 2016). Cities are also openly sharing data with other cities. The National Neighborhood Indicators Partnership (NNIP) exists to help its 27 partner cities share data and lessons to strengthen decision-making capabilities (Konz 2017). The federal government has implemented its own wide-reaching policies. For example, the General Services Administration (GSA) has mandated that federal agencies use Cloud-based email platforms rather than locally operated servers. The GSA's own migration of email to the Cloud has reduced associated energy use by more than 85% (Ye and Siedel 2013).

HELPING RESIDENTS USE INTELLIGENT EFFICIENCY

Residents of smart cities often feel a sense of pride in their communities' accomplishments, and for good reason. With improved services and health, cities are using smart projects to attract new businesses and residents. For example, Denver International Airport, the 15th largest airport in the world, is building what it claims is the nation's first commercially operated microgrid. The project consists of solar generation and energy storage, and is expected to not only reduce energy costs and reduce peak demand on the grid, but will provide backup generation to buildings. While the immediate impact on Denver's citizens is relatively small, the project showcases the commercial viability of various technologies (Wood 2015). As a result, the city of Denver proudly used the project in promotional material for the US DOT's 2016 Smart City Challenge (DOT 2016).

Because the definition of what makes a city "smart" is fuzzy, it is difficult to count an absolute number of smart cities. Nevertheless, there are examples of what makes a city smart, or what can lead to making a city smart. For example, the investment by local electric utilities and companies to support Green Button,[8] automated benchmarking, and the rollout and use of AMI can indicate an effort to increase access to intelligent efficiency. In 2015, the total number of US customers with Green Button and Green Button Connect access was about 60 million (GBA 2015), up from 36 million in 2012 (Cooper, Han, and Wood 2012). The DOE provides a continuously updated list of regional utilities providing automated, downloadable data to its customers (DOE 2017).

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[8] Green Button/Green Button Connect is a voluntary program for utilities that gives customers access to their energy use data. These data can be used for a variety of services to manage and decrease their energy consumption (Green Button 2016).

An additional indicator of the number of cities that claim to be (or are becoming) smart cities, is the US DOT's Smart City Challenge. The DOT pledged to give one city up to $40 million to help the agency define what a smart city actually is by integrating many of the technologies discussed in this paper. The DOT received 78 applications for the Smart City Challenge (figure 12), indicating that at least 78 cities think of themselves in these terms (DOT 2016).

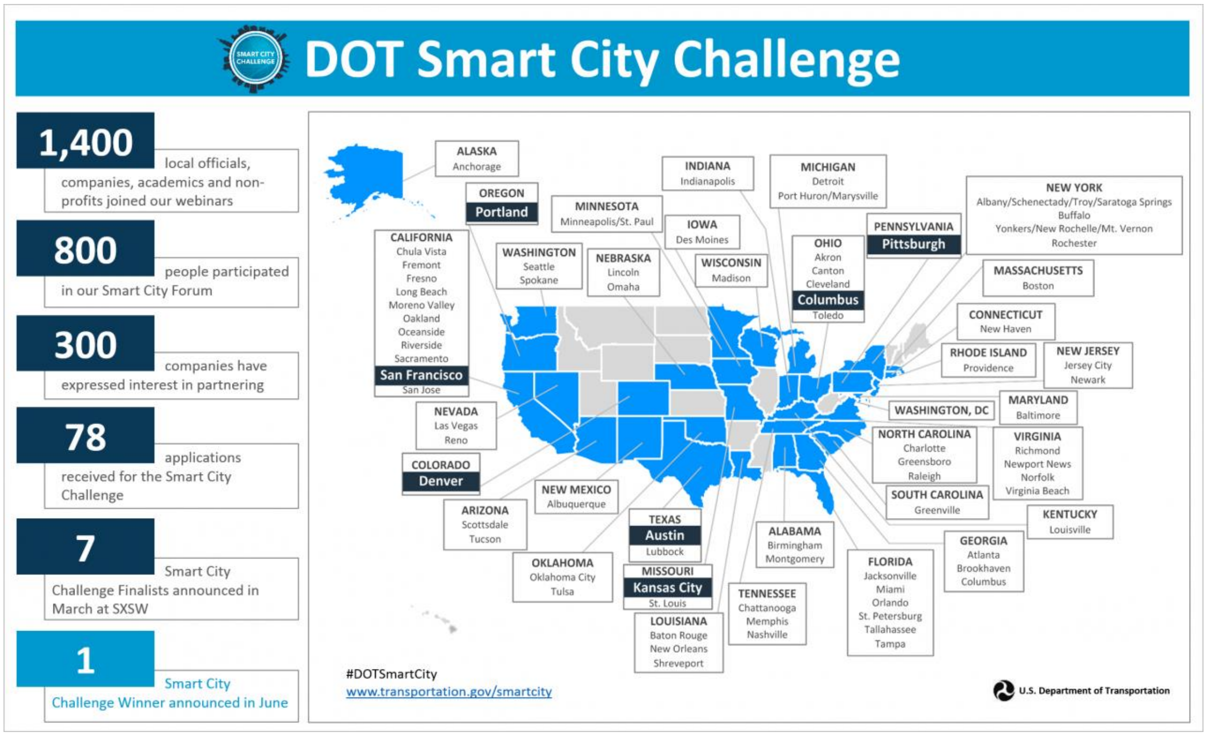


Figure 12. DOT Smart City Challenge. *Source:* DOT 2016.

Smart city solutions can improve public health and safety, and many public services. The public health benefits by improving water and air monitoring with ICT alone are expected to be $403–693 billion in 2025 (Manyika et al. 2015).

USING ICT FOR CITY PLANNING AND IMPROVEMENT

A city's growth and rapid development reinforces the importance of addressing the needs of its citizens and businesses. City planning and improvement becomes proportionally more difficult with a growing population and demand for government services. The pressure to seek the best solutions and the demand to do more with less is driving the natural adoption of ICT in both analytics and solutions.

Data analytics are a primary example of how cities are improving resource planning. The number of cities using such tools is growing. Everything from smart meters to audio sensors can alert the city to address issues such as water conservation. Shanghai implemented embedded sensors throughout its water pipeline to provide real-time water pressure and quality information, identifying risks and responding proactively to leaks and quality issues. Another example is the city government of Toulouse, France, which uses social media to determine the most urgent needs of its citizens. Millions of comments on social media are collected and analyzed, allowing the city to focus on what matters most. By aggregating comments and considering their context and sentiment, a city can improve its response time to infrastructure issues. Toulouse, for example, has improved its response time on road maintenance from 15 days to 1 day, and has begun developing other strategies to address residents' needs (Shockley and Callahan 2015).

Cities are also using ICT to change how they communicate with residents. Using social media platforms, cities are empowering greater civic engagement. The city of Austin added Reddit, a popular social news website, to its portfolio of social media outreach. Austin's city employees communicate with residents directly through social media, addressing their concerns and openly discussing city-run services. Somerville, Massachusetts, sought to engage citizens directly with city services. By integrating the city's 311 information system into its Facebook page, citizens can engage with the city and submit work orders and requests directly to the appropriate employees. Civic engagement has increased in both Austin and Somerville, bolstering public opinion on the cities' accessibility (Royden 2016). While social media engagement may not lead to well-defined ties to energy efficiency, it is just one of the important building blocks to help cities make better decisions, that is, to be smarter.

Overall, we believe cities will increasingly turn to ICT solutions. The promise of greater engagement, increased resident satisfaction, and the resulting influx of business may be the primary driver for increased adoption of the breadth of technologies. The annual global economic impact potential from the transition to smart city solutions and services is expected to be between $930 billion and $1.7 trillion by 2025 (Manyika et al. 2015). With so many cities actively moving toward being smart, the sales of products and services in the government sector is so significant that it has become a subset of the IoT. Sales of IoT devices and services related to smart cities alone reached $51.96 billion in 2015, and is expected to grow to nearly $147.51 billion in 2020. Because ICT offers so many benefits, we expect growth to boom; the overall value of the smart cities market is expected to grow from $312.03 billion in 2015 to $757.74 billion by 2020 (MarketsandMarkets 2016), and we expect to see many new players in the sector.

SUMMARY OF TRENDS

Table 7 summarizes the trends we have seen in the government and smart cities sector.

Table 7. Intelligent efficiency applications and adoption in the government and smart cities sector

Application	Metric	Trend		
		Year	Value	Units
Managing energy use	Energy savings from cloud-based email platforms[1]	2013	85%	% of existing average
	Cities deploying energy-related smart city technology[2]	2016	38.7%	% of survey respondents (*n*=493)
	Cities assessing, planning, or initiating energy pilot programs[2]	2016	80%	
Helping residents use intelligent efficiency	Residents with Green Button access[3]	2012	36	Million residents
		2015	60	
	Cities participating in Smart City competitions[4]	2016	78	Cities
	Public health benefits from improving water and air quality[5]	2025	$405–$693	Billion USD
Using ICT for city planning and improvement	Improvement in response time to infrastructure issues[6]	2015	93% decrease, from 15 days to 1 day on average	
	Economic impacts from transition to smart cities (global)[5]	2025	$930–$1,700	Billion USD
	Sales of IoT devices in smart cities sector (global)[7]	2015	$51.96	Billion USD
		2020	$147.51	
	Value of market for smart city devices, software, and services (global)[7]	2015	$312.03	
		2020	$757.74	
	Water leak reduction[5]	2025	50%	% of existing average
	Increase in retail sales due to traffic mitigation (US)[8]	2013	6%	% of existing average

Sources: [1] Ye and Seidel 2013. [2] ICMA 2016. [3] Cooper, Han, and Wood 2012; Green Button Alliance 2016. [4] DOT 2016. [5] Manyika et al. 2015. [6] Shockley and Callahan 2015. [7] MarketsandMarkets 2016. [8] Huitema 2013.

We expect the market for smart-city-enabling technology to grow as cities find new ways to use ICT to improve or enable public functions. This growth should occur quickly in cities that have already shown interest in integrating ICT solutions. That, in turn, will catalyze adoption in other cities and towns. The economic impacts described in the previous case studies are sufficiently large to encourage more cities to make similar investments in technology and infrastructure.

Integrating the function and output from many independent systems promises major changes in how cities operate and plan for the future. Citizens and businesses who embrace these technologies will realize improved commutes, cleaner air, more reliable government services, and many other benefits. Using new solutions powered by cutting-edge technology, the future city is likely to be a smart one.

The use of ICT by government agencies in general and local governments in particular also has the potential to affect energy use in other economic sectors. As new sensors and intelligent efficiency applications are adopted, new data streams emerge. Government agencies are finding new ways to use these data streams to improve their operations, and they are making them available for others to use. Many of the new uses and innovations resulting from this sharing will create increasingly energy-efficient buildings, transportation systems, and communities.

Enabling and Cross-Cutting Technologies

In addition to drilling down into particular end-use sectors, we can also track adoption trends for the enabling and cross-cutting technologies that underlie virtually all intelligent efficiency applications.

WIRELESS SENSORS

Wireless sensors enable inexpensive collection of performance data from all types of devices, including older equipment that does not have built-in connectivity. Navigant estimates global revenue from sales of wireless sensors will grow from $188.2 million in 2016 to $745.2 million in 2025 (Navigant 2016d). As costs decrease, the number of sensors that can be purchased with a given budget increases. Therefore the increase in sales reported by Navigant is likely indicative of even faster increases in units sold.

CONNECTED DEVICES

The universe of connected devices can be broken down into those that are *networked*, such as speakers or microphones, and can be controlled through a network; those that are actual *network devices*, such as printers, that have network addresses; and those that are *smart*, such as learning thermostats, that are embedded with some level of internal logic.

Many of the connected devices associated with energy efficiency are part of a building's HVAC or control system (as we described earlier in the Buildings section's subsection on energy management applications).

The balance of this section will cover the volumes of all types of connected devices in residential and nonresidential buildings. Values include devices that are integral to a building's operation, such as its HVAC and control systems, and those that are not, such as kitchen appliances, entertainment systems, and other miscellaneous equipment.

Plug loads are the energy used by equipment that we plug into wall outlets, including appliances, computers, and other devices we use in our homes and work places. Because they can be unplugged, they are typically portable and generally not integral to a building's operation. When analyzing energy end uses in buildings, these devices are categorized as plug loads. Even a smart appliance is a form of plug load.

A simple nonelectronic device such as a lamp can become part of an intelligent efficiency application if it is connected to a smart control. A smart plug load control consists of an auto-controlled receptacle or power strip that utilizes some combination of time scheduling, motion sensing, or load detection to turn down or turn off power and thereby save energy (King and Perry 2017). Because the logic is embedded in the plug load control, not the end-use device, we consider it the intelligent efficiency application.

In the residential sector, Park Associates (2015) reports that 20.7 million units of smart home devices were sold in the United States in 2015. By Park's estimate, 10% of all US households have at least one smart home device, with no single type of device in more than 6% of homes. About one-third of smart product owners have a centralized controller such as a smart thermostat or home security system (Karlin et al. 2015; Kerber 2015). Statista had consistent findings a year later. Figure 13 shows the adoption rates in 2015 for several connected devices common to the residential market.

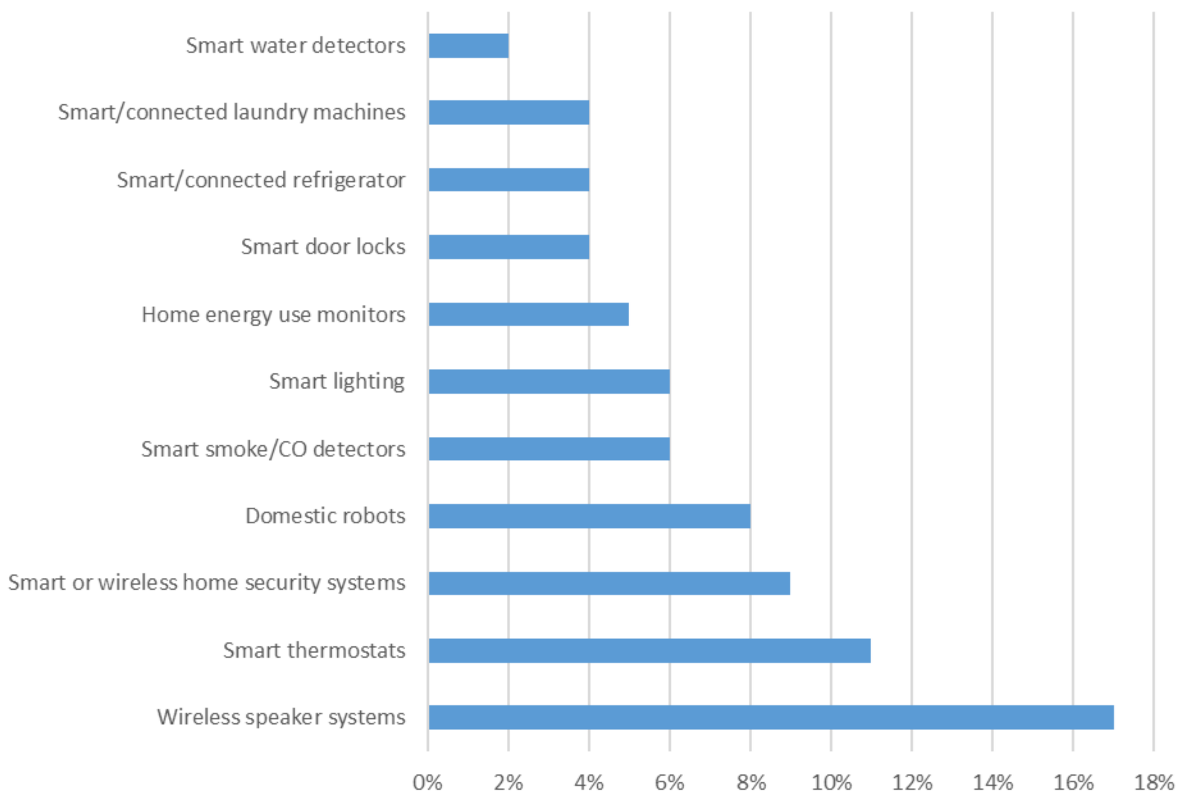


Figure 13. Prevalence of connected devices in US homes. Percentage of people with one or more connected devices in their homes in 2015 (*n* = 2,225). *Source:* Walton 2016b.

The adoption of connected devices in the residential sector is accelerating. Market penetration of connected devices in the United States was only 18.6% in 2015, but grew to 24.9% in 2016; the number is projected to increase to 60.7% in 2021 (Statista 2017a). The number of connected devices is expected to grow from 294 million in 2015 to more than a billion in 2017. Interestingly, the commercial sector is currently smaller than residential: approximately 206 million connected devices were installed in commercial buildings worldwide in 2015. However this number is expected to triple by the end of 2017 (Gartner 2015b).

INTERNET OF THINGS

As we noted earlier, the IoT refers to the connection of numerous devices through the Internet to each other, and their ability to interact without human input. Not all connected devices are part of IoT. For example, a TV may be part of a home entertainment network that is not connected to the Internet.

However the number of Internet-connected devices in homes and businesses continues to increase at a steady rate (Statista 2016). Around 2008–2009, a milestone was passed when more devices than people were connected to the Internet (Evans 2011). In 2015, there were 10 billion connected devices globally; there will be 26–50 billion by 2020, 100 billion by 2030, and 500 billion over the following decades (Camhi 2015; Evans 2011; Gartner 2015b; IEA 2014). The devices connected to networks in homes and offices are estimated to consume more than 600 Terawatt-hours (TWh) per year of electricity, more than all of Canada consumed in 2011 (IEA 2014).

Figure 14 is typical of industry projections of growth in connected devices. As the figure shows, BI Intelligence predicts that the business sector (which it calls *enterprise*) will be the destination of almost half of all network devices. The balance is split by the government and consumer (home) sectors. Year-over-year purchases are currently increasing at more than 70% per year but are predicted to slow—if that word can be used here—to only 40% year over year in 2019.

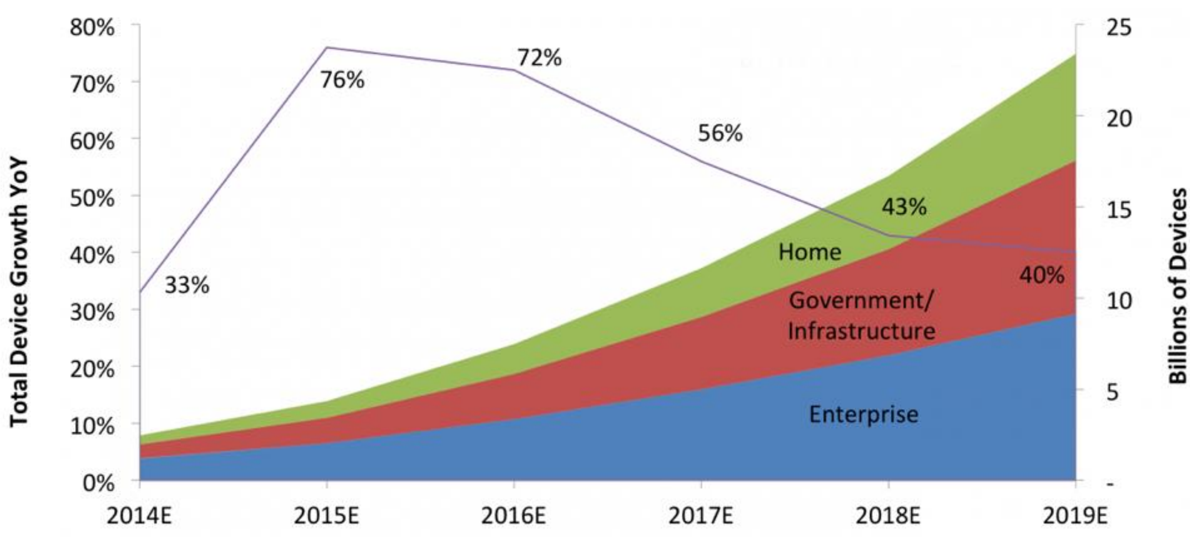


Figure 14. Estimated number of installed IoT devices by sector. *Source:* Greenough 2014.

INFORMATION AND COMMUNICATIONS TECHNOLOGIES

ICT lies at the heart of intelligent efficiency, and we have tracked its use in particular areas and applications. We can also get a general sense of its increasing prevalence by tracking the increasing value of nonresidential computers, telecommunications equipment, and software. Table 8 shows these trends.

Table 8. Value of nonresidential ICT

Equipment	Year	Value ($ billions)	Yearly change
Computers and peripheral equipment	2010	174.3	n/a
	2011	172.2	–1.2%
	2012	178.5	3.7%
	2013	182.7	2.4%
	2014	187.6	2.7%
	2015	185.2	–1.3%
Communication equipment	2010	563.9	n/a
	2011	574.9	2.0%
	2012	561.4	–2.3%
	2013	591.3	5.3%
	2014	609.5	3.1%
	2015	631.3	3.6%
Software	2010	539.4	n/a
	2011	562.4	4.3%
	2012	588.0	4.6%
	2013	615.9	4.7%
	2014	638.4	3.7%
	2015	670.3	5.0%

Values in nominal dollars. *Source:* BEA 2016.

The value of computers and supporting equipment has increased or stayed flat for the past few years. Communication equipment is doing slightly better, while software is doing quite well, with much stronger growth. This could indicate that software is supplanting investments in hardware, that new software is being used on old hardware, or that software is becoming more expensive. Research by Zinnov grouped global sales of IoT into devices and services and predicts that the 2016 sales of $54 and $66 billion, respectively, will grow to $110 and $143 billion in 2021 (Zinnov 2016). This research indicates a greater opportunity for SaaS for the near future. Although it is unclear what this trend means for the energy efficiency sector, it is something to look for and track in the future.

As first identified in Laitner, McDonnell, and Ehrhardt-Martinez (2014), we can infer the trend in ICT energy use by using the electricity consumption of personal computers (PC) and commercial office equipment as a proxy for energy consumption of the Internet and other ICT networks. Consumption had been trending down for the past decade, as indicated in table 9 below, even though ICT investments continued to increase. What is also interesting to note in table 9 is that, in 2008, energy use by ICT and office equipment was predicted to grow from 6.5% of total electricity consumption to 7.6% in 2015, but in fact it was only 5.5%. The current Annual Energy Outlook (AEO) prediction is that energy consumption will gradually increase but at a slower rate than the rest of the economy; as a result, the ratio will continue to decrease until 2030. After 2030, the prediction is that ICT will become such a large part of the economy that its portion of national energy consumption will start to increase (Laitner, McDonnell, and Ehrhardt-Martinez 2014; EIA 2017).

Table 9. AEO projections for personal computer and office equipment electricity use, 2008–2017

	2008		2012		2015		2030		2040	
Projection	TWh	% total	TWh	% total	TWh	% total	TWh	% total	TWh	% total
AEO 2008 (2005–2030)	243	6.50%	281	7.10%	311	7.60%	419	8.60%	n/a	n/a
AEO 2011 (2008–2035)	n/a	n/a	191	5.10%	199	5.20%	246	5.70%	n/a	n/a
AEO 2014 (2011–2040)	n/a	n/a	134	3.60%	125	3.30%	123	2.80%	134	2.90%
AEO 2017 (2015–2050)	n/a	n/a	n/a	n/a	206	5.50%	189	4.80%	200	4.80%

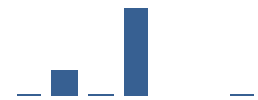
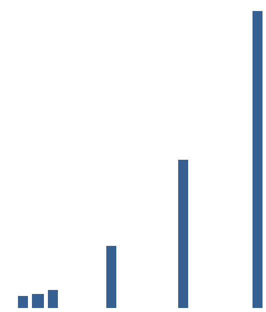
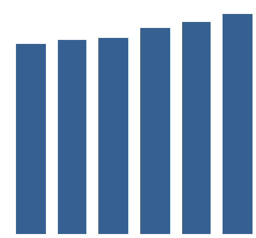
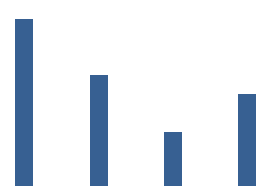
AEO data reflect electricity use by residential and nonresidential personal computers and commercial office equipment. *Sources:* EIA Annual Energy Outlook (various years); Laitner, McDonnell, and Keller 2015.

As Laitner, McDonnell, and Ehrhardt-Martinez (2014) point out, these values are not proof that ICT services are enabling greater levels of energy efficiency throughout the economy, but rather that individual devices are becoming more efficient and that collectively they represent a decreasing fraction of total domestic energy consumption. However, in AEO 2008, EIA projected that the country might use about 4,880 Gigawatt-hours of electricity by 2030 (Laitner, McDonnell, and Keller 2015). In AEO 2017, the projection for 2030 was only 3,946 GWh (EIA 2017). These numbers indicate a trend toward a more efficient economy and, by extension, greater investments in energy efficiency.

SUMMARY OF TRENDS

Table 10 summarizes the trends we have seen in wireless sensors, connected devices, the IoT, and ICT.

Table 10. Adoption trends for intelligent-efficiency-enabling technologies

Application	Metric	Trend			
		Year	Value	Units	Graphic
Connected devices	Sales of wireless sensors (global)[1]	2016	$188.2	Million USD	
		2025	$745.2		
	Residential market penetration of connected devices (US)[2]	2015	18.6%	% of homes	
		2016	24.9%		
	Number of connected residential devices (US)[3]	2015	294	Million units	
		2017	1,000		
	Number of Internet-connected devices (global)[4]	2014	3.8	Billion devices	
		2015	4.9		
		2016	6.4		
		2020	21		
		2025	50		
		2030	100		
ICT and IoT	Value of ICT investments (US)[5]	2010	$1,277.6	Billion USD	
		2011	$1,306.5		
		2012	$1,327.9		
		2013	$1,389.9		
		2014	$1,435.5		
		2015	$1,486.8		
	Sales of IoT devices (global)[6]	2016	$54	Billion USD	
		2021	$110		
	Sales of IoT services (global)[6]	2016	$66		
		2021	$143		
	Predicted national electricity consumption in 2030[7]	2008	8.60%		
		2011	5.70%		
		2014	2.80%		
		2017	4.80%		

Sources: [1] Navigant 2016d. [2] Statista 2017b. [3] Gartner 2015b. [4] Gartner 2015a; Evans 2011; IEA 2014. [5] BEA 2016. [6] Zinnov 2016. [7] Laitner, McDonnell, and Keller 2015.

Energy Efficiency Programs

ICT is transforming energy efficiency programs. In a 2016 analysis of 51 of the nation's largest utilities, ACEEE found that 34 are engaged in some application of intelligent efficiency (Relf, Nowak, and Baatz 2017).[9] Most importantly, an increasing number of programs directly support intelligent efficiency measures such as smart thermostats and energy management systems. ICT is also changing how energy savings are tracked, how programs are evaluated, and how customers are engaged.

We identified six applications of intelligent efficiency that are improving the way energy efficiency is delivered through ratepayer- and taxpayer-funded programs:

- Intelligent energy efficiency and DR measures
- Program design
- Project performance tracking
- Customer engagement
- Program management

Although these six applications do not comprise all the use of intelligent efficiency within efficiency programs, they do sufficiently capture the ubiquity of ICT within the sector. Their adoption speaks to the changes we are seeing in energy efficiency measures, program design, implementation, evaluation, and administration.

INTELLIGENT EFFICIENCY AS A PROGRAM MEASURE

Many of the energy measures that programs are funding include intelligent efficiency. Smart thermostats are the most common, but commercial BEMS, energy information management systems, and connected water heaters are also becoming the focus of utility-sector energy efficiency programs. Often the features that make a measure eligible for financial incentive are its abilities to connect to the Internet, to report performance, and to respond to signals from a utility to turn down or turn off.

Utilities are often most interested in the ability to participate in DR events, which gives utilities flexibility in how they address periods of peak electrical demand. DR may or may not result in a net energy savings for an end user. In some cases, such as the connected water heaters previously discussed, the total electricity consumption stays the same; some of it is simply moved from one time of day to another. However DR does enable a utility to operate its system more efficiently, which results in energy efficiency benefits (Kushler et al. 2006).

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[9] The report uses the category *emerging program areas*, which includes using data analytics to identify customers or segments of a service territory to target programmatic activities (geo targeting); to provide energy use feedback in real time; or to provide incentives for high-efficiency electronics and residential learning thermostats.

The ACEEE analysis and comparison of 51 utilities by Relf, Nowak, and Baatz (2017) found an average peak demand reduction of 0.76% and a median reduction of 0.57% of total peak demand. ACEEE intends to repeat this comparison of utility energy efficiency programs so it will be possible to track changes in the number of utilities and the volume of peak reduction in the future.

Many intelligent efficiency applications have the ability to both save energy and participate in DR events. Smart thermostats are a popular intelligent efficiency measure with program administrators; we describe the features and benefits of smart thermostats and HEMS in the Buildings section above. Early pilot programs gave customers smart thermostats at little or no cost. More recently, customers typically supply their own and receive a rebate or discount for allowing the utility to connect to it and send occasional DR requests (Miziolek 2015). Relf, Nowak, and Baatz (2017) found that 24 of the 51 large utilities they surveyed have implemented learning thermostat programs.

The first pilots of this "bring-your-own-thermostat" (BYOT) started in 2012. Navigant (2016b) estimates that there are currently 50,000 customers engaged in such programs and that they represent $12.5 million in annual program rebates. The ultimate size of this BYOT market is estimated to be 20 million customers, or about 10% of the residential market, and it could total $3 billion in discounts to customer billing.

Smart lighting is another application that energy efficiency programs are using financial incentives to encourage. Relf, Nowak, and Baatz (2017) found that 18 out of 51 utilities are providing incentives for advanced lighting systems and controls. This is also a metric to track as ACEEE repeats it comparison analysis in the future.

PROGRAM DESIGN

In conventional efficiency programs, data are often gathered manually and then analyzed using software tools. The availability of granular energy consumption data from smart meters and connected devices, and the power of new software tools to automatically collect and analyze large volumes of data using Cloud-based analytics, has resulted in new types of efficiency programs. The very essence of these programs are the software tools.

A common type of energy efficiency program provides customers with an analysis of their energy use. Improving accessibility to energy use information can help people understand and manage their energy bills better, and ICT is making this possible. Program administrators are using websites to give customers' access to their historical energy use information, and web-based programs let customers compare their energy use with that of similar customers and generate energy savings recommendations. The reports are often called home energy reports (HER), and the programs are also referred to using that acronym. Relf, Nowak, and Baatz (2017) found that 30 of the large utilities they surveyed provide some type of HERs to their customers.

The practice of comparing customer energy use with their peers is called benchmarking. Some utilities have developed their own benchmarking software tools for customers to gauge their energy use, while others use tools developed by the federal government. For example, the EPA created the ENERGY STAR Portfolio Manager for commercial buildings.[10] Customers can automatically upload utility data to the EPA Portfolio Manager website, where the software program will analyze and compare their energy use. Thirty-two (63%) of the utilities participating in the Relf, Nowak, and Baatz (2017) survey offer customers the EPA Portfolio Manager tool. The Consortium for Energy Efficiency (CEE), a trade organization for energy efficiency program administrators in the electricity and natural gas sectors, found that 58 out of its 261 members (22%) offer the Portfolio Manager tool (CEE 2016a). The CEE survey is likely closer to representing the situation nationally, since the ACEEE analysis compared only the nation's largest energy efficiency programs.

Another website-based benchmarking tool is Green Button Connect. Launched by the White House in 2011, the Green Button Challenge is a voluntary program that encourages utilities to provide consumers electronic access to their energy information. The Energy Services Provider Interface (ESPI), the standard that makes Green Button possible, has been adopted by dozens of US utilities and currently serves 60 million homes and businesses. It allows customers to easily download their energy data in a standard format (GBA 2015; Murray and Hawley 2016). Of the 51 Relf, Nowak, and Baatz (2017) survey participants, 23 (45%) provide access to the Green Button program. Thirty-three (13%) of CEE's members provide the Green Button tool (CEE 2016a).

Using data analytics to crunch large data sets, utilities and partners can track the progress of energy savings of an entire set of customers over time. In such programs, customers are divided into two groups: one of that is engaged by programmatic activities (the treatment group) and one of that is not (the control group). The treatments encourage users to invest in certain energy savings measures, adopt certain energy conserving practices, or take advantage of an energy efficiency program offering. The encouragements or nudges come in the form of emails, billing inserts, advertisements, telephone calls, and texts. A common mechanism is to send customers a comparison of how much energy they are using compared to their peers.

Some of these types of programs attempt to modify customer behavior, and are often referred to as behavior programs. What does or does not constitute a behavior program is beyond the scope of this report.[11] What is important here is the use of automation, big data, and data analytics to achieve reliable and reproducible energy savings. These are key characteristics of intelligent efficiency. Thirty of the 51 utilities surveyed by Relf, Nowak, and Baatz (2017) reported having behavior programs. A 2013 ACEEE survey identified 300 programs that could be categorized as behavior programs (Mazur-Stommen and Farley 2013).

Opower, now part of Oracle, was a pioneer that became a dominant player in the use of data analytics to manage and direct customer engagement. Launched in 2007, it had contracts with 45 utilities; by 2010, it was engaging two million customers (Overly 2010). By May of

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[10] ENERGY STAR Portfolio Manager®: www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager

[11] The typology of behavior programs is covered in detail in Sussman and Chikumbo 2016.

2016, when Opower was purchased by Oracle, it had contracts with more than 100 utilities engaging 60 million customers globally (Oracle 2016a). Tendril, another early entrant into this market, has tested its software on at least seven million homes. Recent market entrant EnergySavvy has analyzed more than one million homes with its software tools (Mizolek 2015).

Given that there are approximately 128 million directly served residential electric utility customers in the United States (EIA 2016a), it appears that close to half of them are currently being reached through customer engagement software services. Domestic spending by utilities on residential DR programs reached $580 million in 2015 (Opower 2014). Global spending on the analytics for behavior and DSM was $214.7 million in 2015 and is projected to increase to $2.5 billion in 2024 (Navigant 2015a). In 2014, Opower estimated that behavioral DR programs had the potential to reduce energy demand by 4,700 MW nationally (Opower 2014).

Another type of program model made possible by data analytics is one in which the time and locational value of energy on the wholesale market is communicated to customers in near real time. This is often referred to as *dynamic pricing* because the energy price is fluid. These programs continually communicate the changing value of energy to customers in a way that lets them automatically respond. An intermediate step to dynamic pricing is time-of-use (TOU) rates. Such pricing also encourages customers to use less energy during peak demand times, but does not require the continuous two-way communication of dynamic pricing. TOU rates can reduce overall energy consumption (Baatz 2017).

The number of residential customers on dynamic or TOU rates is low. Four percent of the 128 million US residential customers are currently on TOU rates (Chitkara et al. 2016). However the proliferation of AMI is driving more utilities to offer such rates to customers. This will be an important metric to track in the future. The number of customers on dynamic pricing rates globally is expected to increase from around 3.4 million today to 113.3 million in 2025 (Navigant 2016b). We can see this trend developing in recent FERC staff reports. In 2015, FERC reported that 3.7 million customers were enrolled in time-based DR programs. That number increased to 6.9 million in 2014 (FERC 2015, FERC 2016).

PROJECT PERFORMANCE TRACKING

The practice of using computers to track energy consumption has been around for a while. What is new is the ability to determine energy savings remotely and in near real time. AMI meters provide energy use data at higher granularities. New data analytic software programs can disaggregate these use data to identify individual loads within a building and then track their performance over time.

Cloud-based analytics, connected devices, and building management systems are enabling end users and program administrators to collect energy savings information in an automated fashion. Once a baseline has been established, energy savings can be tracked as they happen. Some analytical products even let the comparison baseline change dynamically in concert with changes in device, system, or facility use. For example, a smart BEMS with access to historical energy information and contextual information (such as weather) can compare a building's energy performance after energy measures are implemented to a comparable day prior to the upgrade.

Remote building analytics can compare the interval data from a smart meter to the building's performance prior to project implementation and to other similar buildings to arrive at a gross energy savings value. Such information can be collected at the building level and, with sufficient information on individual energy measures, can track energy savings of multiple energy measures without a person ever entering the building or taking an onsite measurement.

We were unable to identify data that quantify the number of utilities or program administrators using SaaS for this purpose. Other useful metrics would be the number of customers engaged and the volume of energy savings achieved via such services. We do know that US spending on evaluation, measurement, and verification (EM&V) was $140 million in 2015 (CEE 2016b). A goal for future research would be to quantify the percentage of overall EM&V spending that goes to SaaS.

CEE, a trade organization for energy efficiency program administrators in North America, has tracked the types of programs its members offer larger C&I customers. It paid particular attention to programs offering continuous improvement training and technical assistance, such as strategic energy management (SEM) and energy management information systems (EMIS). SEM facilitates systematic attention to energy management in an organization, while EMIS involves software that automates the collection, analysis, and reporting of energy savings. Combining the two can maximize results (Rogers 2014).

Only 16 of CEE's members offer SEM programs, but 28 offer EMIS-based programs (CEE 2016a). Of the SEM programs, almost half also offered EMIS support in 2014. That increased to 75% in 2016, showing a greater support for including energy management software in program offerings (Burgess 2016). We can infer from this trend that program administrators find the automated reporting that EMIS affords to be of value.

CUSTOMER ENGAGEMENT

Today, it is relatively easy to determine the effectiveness of a marketing campaign or of rebates. In the past, energy efficiency programs reached customers through mailers included with monthly bills or through phone calls and visits. Now, they also use instant messages, emails, and social media. Much of this can be automated and, as such, it can be correlated with customer responses. Further, a change in a customer's energy consumption can be matched to program engagement. The new software programs enable program administrators to answer questions such as, "How many customers who visited our website and who received home energy reports later reduced energy consumption?" Something that was tedious to do for one customer in the past is now easily done for thousands.

Identifying customers and opportunities to save energy is being simplified by applications such as remote building analytics, which do remote building energy audits and load disaggregation. New software tools can also personalize communication with customers, informing them of actions they can take to save energy and report on any changes in their energy use.

Utility investments in customer service do not directly save energy, but they enable other utility investments and efficiency programs to be more effective. As a result, the amount that utilities spend on customer service and engagement software tools for energy efficiency program purposes is not called out in a specific budget line item, but is included in the budget for customer information systems (CIS). Navigant predicts spending on CIS software purchases and upgrades, services, maintenance fees, SaaS, and analytics in North America will increase from approximately $706 million in 2014 to more than $1.3 billion by 2023 (Hardcastle 2015; Elberg and Woods 2015). International Data Corporation (IDC) predicted that spending on SaaS solutions would constitute 14.2% of all software spending and 18% of all application spending in 2016 (Abbo 2015).

Oracle surveyed 100 executives of utilities of various sizes and found that 45% of the utilities are currently using Cloud-based analytics and another 52% anticipate doing so within the next three years. Of the utilities surveyed, 89% send meter data management information to the Cloud and 69% use a Cloud-based CIS (Davis-Van Atta 2016).

Greentech Media tracked more than 200 data analytics developments in North America between 2010 and 2014. It found that utilities see value in improving their grid operations and managing their enterprises, but a majority of their focus is on consumer analytics (see figure 15). They found that the trend was consistent regardless of the utility's size or whether or not it was investor owned (St. John 2014b).

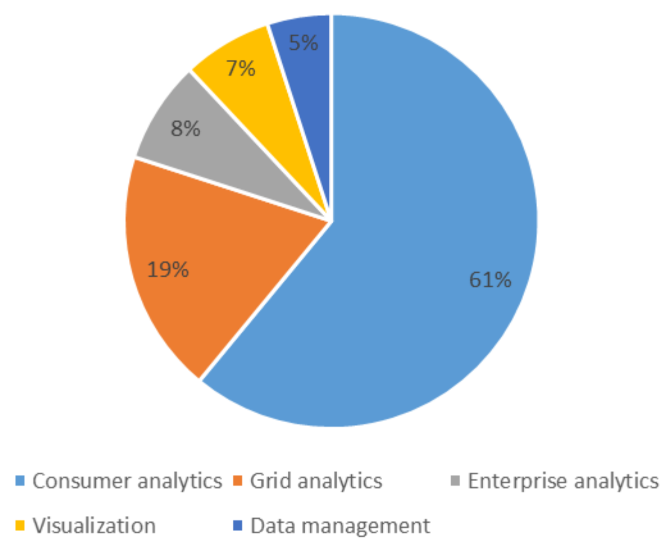


Figure 15. Announcements by North American utilities of analytical software investments, by submarket, 2010–2014. *Source:* St. John 2014b.

Greater investment in Cloud-based analytics is likely as public utility commissions are showing a greater understanding and acceptance of benefits. A 2017 Oracle survey of 76 public utility commission staff members and commissioners found that 69% are amenable to shifting Cloud investments from operations and maintenance (O&M) budgets to capital expenditures. Survey respondents reported that 40% of recent rulings favored treating SaaS investments as capital, while only 21% were against doing so.

These survey numbers align with the recent issuances of solicitations for customer analytics. Over the two-year period 2015–2016, close to 25 utilities and program administrators released RFPs focused on customer analytics related to DSM and program effectiveness. Some of these solicitations included a larger strategic focus on customer engagement, but the DSM piece was a key business objective of each solicitation (E. Mazmanian, Vice President, Market Development, First Fuel, pers. comm., November 11, 2016).

PROGRAM MANAGEMENT

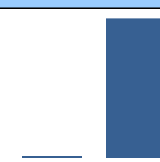
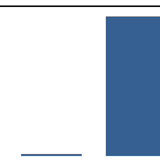
The ability to digest and analyze large volumes of data is also helping program administrators monitor individual program performance. Administrators thus can see trends earlier and improve program performance sooner and with greater effect.

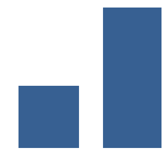
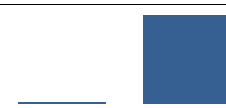
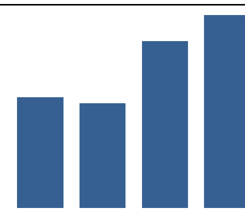
As with customer service, the software programs used by program administrators are not always specific to managing and tracking the performance of individual programs. We continue to search for information on the number of programs being evaluated using SaaS analytical tools. Absent such granular information, we can use utilities' overall investments in data analytics discussed earlier as a proxy; use of Cloud computing for efficiency programs is likely to track with overall investments in Cloud computing.

SUMMARY OF TRENDS

Table 11 captures the data points we have discussed in this section.

Table 11. Intelligent efficiency applications and adoption in energy efficiency programs

Application	Metric	Trend			
		Year	Value	Units	Graphic
HEMS as an energy efficiency measure	Customers engaged[1]	2011	0	Residential customers	
		2016	50,000		
		2024	20,000,000		
	Rebates[1]	2011	$0	Million USD	
		2016	$12.5		
		2024	$3,000		
	Utilities implementing residential learning thermostats[2]	2015	47%	% of programs surveyed (*n*=51)	
Smart lighting as measure	Programs with offerings[2]	2015	35%	% of programs surveyed (*n*=51)	

Application	Metric	Trend			
		Year	Value	Units	Graphic
Program design	Portfolio Manager[3]	2016	22%	% of programs surveyed (n=261)	
	Home energy reports[2]	2015	59%	% of programs surveyed (n=51)	
	Green Button[2]	2015	45%		
	Behavior programs[2]	2015	59%		
Program design: behavior programs	Utilities using Opower analytics[4]	2006	0	Number of utilities	
		2007	45		
		2016	100		
	Customers engaged by Opower[4]	2006	0	Number of customers (millions)	
		2007	2		
		2016	60		
Program design: time of use and dynamic pricing	Spending on DR[5]	2015	$580	Million USD	
	Spending on DSM[6]	2015	$214.7	Million USD	
		2024	$2,500		
	Customers on dynamic rates, (global)[7]	2015	3.5	Million customers	
		2025	113.3		
	Customers enrolled in time-based DR programs[8]	2011	3.98	Million customers	
		2012	3.74		
		2013	5.98		
		2014	6.90		
Project energy savings tracking	EMIS[9]	2016	11%	% of programs surveyed (n=261)	
	SEM[9]	2016	6%		
	SEM support of EMIS[10]	2014	47%	% of SEM	
		2016	77%	% of SEM	

		Trend			
Application	Metric	Year	Value	Units	Graphic
Customer engagement	Spending on CIS software[11]	2014	$0.71	Billion USD	
		2023	$1.30		
	Use of cloud-based analytics[12]	2016	45%	% of utilities surveyed (*n*=76)	
		2020	97%		
	Use of cloud-based analytics for meter data management, customer info [12]	2016	89%		
		2016	69%		
Data analytics	Consumer analytics[13]	2010–2014	61%	% of deals tracked (*n*=200)	
	Grid analytics[13]		19%		
	Enterprise analytics[13]		8%		
	Visualization[13]		7%		
	Data management[13]		5%		

Sources: [1] Navigant 2016a. [2] Relf, Nowak, and Baatz 2017. [3] CEE 2016a. [4] Overly 2010; Oracle 2016b. [5] Opower 2014. [6] Navigant 2016b. [7] Navigant 2016b. [8] FERC 2014; 2015; 2016. [9] CEE 2016b. [10] Burgess 2016. [11] Elberg and Woods 2015. [12] Oracle 2016a; 2017. [13] St. John 2014a.

This picture of the efficiency program space overlaps with the picture we have created for the use of intelligent efficiency in buildings, industry, and smart cities. Indices such as the number of smart thermostats incented by programs, the number of demand-responsive devices and facilities, and the associated energy savings automatically measured by ICT-enabled programs all have relevance in the other sectors. We can see the trends in one reflected in the trends of the others.

What is apparent is how quickly the transformation has taken place. The example of Opower speaks to the growth in use of big data and data analytics. The utility sector is often criticized for its aversion to change, but it has taken only 10 years for half of the country's residential customers to be engaged via energy efficiency programs using SaaS products.

We contemplated quantifying the number of companies offering SaaS products in this space, but the number of mergers and acquisitions might be an equally valuable metric. The market has grown rapidly and is now in a stage of consolidation. The number of customers and the value of energy consumed by them fix the market size. What will future growth look like? As the sector reaches a point at which almost all customers are reachable, what will efficiency programs do next to improve their efficacy? Continuous SaaS product innovation is likely part of the answer.

We are still in search of more data on the prevalence of utility use of SaaS products and services. These data are key to gaining a more complete understanding of how intelligent efficiency is transforming the energy efficiency program sector.

Looking Ahead

OVERVIEW

The uptake of intelligent efficiency is accelerating within and across sectors. The number and types of connected devices inside residential and nonresidential buildings continue to climb, both in terms of number of units per building and in absolute terms. Manufacturing is forecasted to make the greatest investments in IoT over the next decade. Utility use of various software products and Cloud computing is accelerating. The transportation sector was an early adopter of intelligent efficiency and continues to lead in exploiting ICT capabilities. Government use of intelligent efficiency appears to be greatest at the local level. Smart cities incorporate multiple technologies and practices, many of which are applications of intelligent efficiency and can contribute to making cities and their governments more energy efficient. Finally, spending by utilities in the program space will be substantial.

As table 12 shows, sales of IoT devices are accelerating in all sectors.

Table 12. Forecast revenues from IoT

Devices	Value
US residential IoT	$17.7 billion in 2025
US residential building energy management	$1.8 billion in 2020
US smart lighting	$16.9 billion in 2024
Global commercial building energy management	$10.8 billion in 2024
Global spending on smart grid	$11.1 billion in 2023
Global spending by industry on IIoT solutions	$70 billion in 2020
US spending on commercial energy management	$3.1 billion in 2024
US industry spending on energy management	$4.3 billion in 2015
US sales of devices and software for smart cities	$0.76 billion in 2020
Global spending on analytics for DSM programs	$2.5 billion in 2024
Spending on customer utility information services	$1.3 billion in 2023

IHS Analytics divided IoT investments into different groups than we did, but their findings support the same conclusions. As figure 16 shows, total IoT investments are accelerating, but not all sectors are increasing at the same rate. Investments in the industrial sector are predicted to increase more rapidly than other sectors over the next few years.

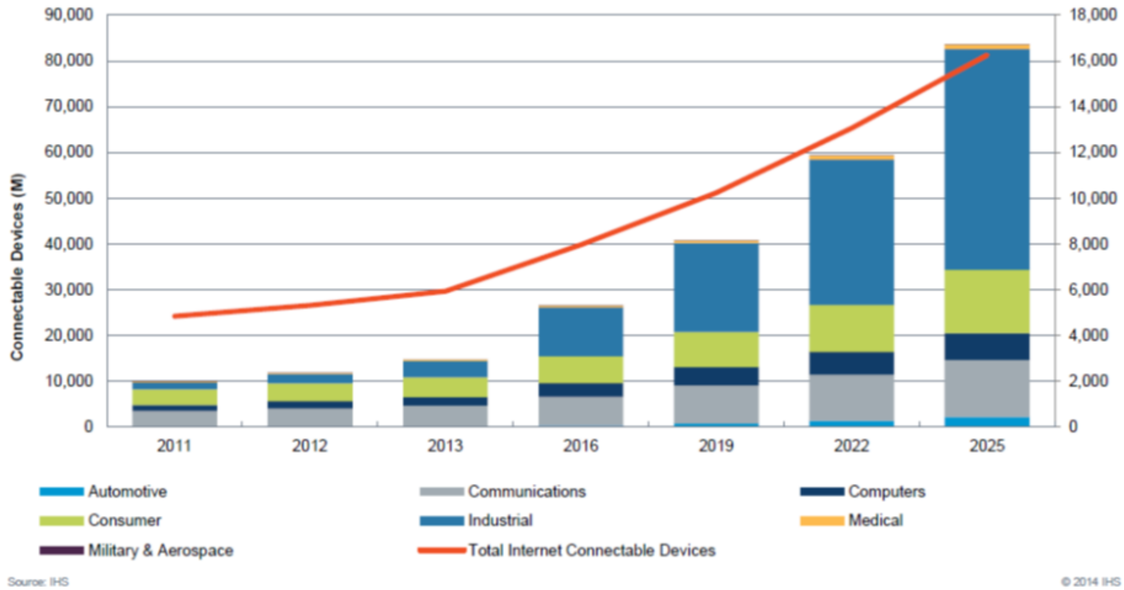


Figure 16. Forecast growth in IoT. *Source:* Byrne 2015.

We are moving beyond the early adopter and fast follower stages and into mainstream adoption. On a national level, investment in enabling technologies such as the smart grid, Internet, IoT, and IIoT continues to accelerate. Given increasing investments in renewable energy and EVs, every indication is that a more distributed and integrated local grid will become a reality in many communities. Implementation of AMI is about one-third complete and is creating new markets for energy management services. ICT and AMI make the prosumer possible, and the prosumer makes functioning energy markets possible at the local and regional levels. Prosumers also make the distributed grid possible.

Some markets are more open ended than others. Although cities are where many of the needs and opportunities for intelligent efficiency meet, spending by government is projected to lag. By contrast, the appetite for transportation services is only increasing. Intelligent efficiency is often a least-cost solution for increasing capacity of an existing transportation system, and it also improves user experiences of vehicles and transportation systems.

At the same time, year-over-year growth in US electricity consumption is slowing even as the number of customers is increasing, indicating a separation between energy consumption and economic growth (EIA 2016c). As a result, companies serving the energy sector will need to think beyond increasing the number of customers to growing their business by providing more value so that they can increase their sales per customer. Intelligent efficiency provides a path for energy companies to move from providing a commodity product to a differentiated energy resource service.

A comparison of the anticipated size of the markets for ICT indicates a greater portion will be for non-energy-management-related investments. Yet significant investments will also be made in energy management in the residential, commercial, and industrial sectors. The long-anticipated HEM market appears to have finally arrived as customers are looking to technology to simplify their lives by reducing the number of decisions they have to make and simplifying the process for making and acting on them.

Energy use by networked devices is of great interest to many policymakers, and many of them will certainly track it in the future. However predictions continue to overestimate future energy use by ICT. As a ratio of the nation's energy use, the current trend is flat. It is reasonable to assume, however, that it will increase; sales of connected devices continue to climb and, as they do, the collective energy they use will rise.

Applications of intelligent efficiency are overlapping across end-use sectors of the economy. When viewed collectively, the data we gathered capture a move to apply technologies from one area to another. The lines between buildings and transportation start to blur as cars and homes plug into each other. The interests of utilities and cities merge as limited resources and the demands of citizens require leveraging existing resources across systems.

Metrics related to building management are prevalent in each sector. The tables in each section of this report reflect the existing and future levels of buildings' connectedness. The number of smart meters, investments in energy management, IoT, connected devices, and EV charging stations all have a buildings component. It is likely that metrics related to building integration will be leading indicators of changes in other sectors.

Building management systems and smartphones will likely be two key links in how intelligent efficiency propagates throughout our economy in the future. These platforms will tie people's homes, places of work, and transportation choices to the cities they live in and the utilities that serve them. And people will access all of this through the same devices. The same smartphones they use to order an Uber will connect them to their HEMS and let them know how much energy their solar panels are providing to the grid.

BUILDINGS

Intelligent efficiency seems to be steadily penetrating the residential and nonresidential building markets. Homeowners and property managers are following a traditional adoption curve, with early adopters testing out expensive versions with few features and more than a few bugs. We can anticipate more conservative purchasers will follow as product features standardize and prices decrease.

Smart thermostats represent an increasing portion of thermostat sales, indicating a transition toward more powerful products. Smart thermostats are far from mainstream, but we may have reached an inflection point. Some customers apparently see them as the new smartphone in terms of novelty and ability to simplify part of their lives. What is not apparent is whether the majority of the market will value the added functionality.

Alternatively, customers might group themselves across a range of technologies: those with the most powerful and expensive learning thermostats; another segment with connected devices that are less expensive, but have many of the same remote access features; and a segment with conventional thermostats. Multifamily housing is likely to stay in this last group for a while due to split incentives.[12]

Commercial buildings are continuing to adopt increasing numbers of advanced control systems. Building automation is evolving, providing on-premise and Cloud-based platforms for systems integration, data analytics, and advanced applications. Energy management is just one of the many features it provides. Overall, pricing should come down as the technology improves. However the price of building management systems could stay flat as the number and value of product features continues to increase. This would follow the pattern of other technologies such as computers and cell phones: computers have stayed in the $500–1,500 range and phones in the $200–600 range for many years.

If the price of existing nonresidential BAS does not decrease, residential products may be adapted to meet the needs of smaller nonresidential buildings. Multiple HEM devices could be networked together to provide building operators with a suite of features and benefits similar to that of larger, integrated systems.

As described in King and Perry (2017) buildings are becoming smart devices (supersystems) in and of themselves, with the ability to communicate with electric grids or with third parties who communicate with grid operators. Networks that enable local optimization are developing within buildings and factories. When connected with outside networks, they enable enterprise, campus, or even regional optimization. We are definitely seeing the emergence of networks of networks. Fully integrated buildings open up many possibilities for coordinating with smart city initiatives and utility-sector DR and efficiency programs.

MANUFACTURING

Investments in smart manufacturing continue at a steady pace, as innovation in IIoT technology continues and prices for sensors and controls decrease. People in the sector agree that a transition is happening or is about to happen. At this point, however, investment is accelerating just slightly year over year (figure 7). It is as yet unclear whether this sector has hit an inflection point that would indicate accelerated uptake of smart manufacturing technologies. Likely barriers that are forestalling this change are the dominance of proprietary systems, the lack of open source platforms, and a number of safety concerns around the integration of production operations with other systems.

In contrast to smart manufacturing, the use of ICT to manage industrial energy use is established, and we expect it to continue to increase. Grand View Research forecasts revenue from sales of HEMS, BEMS, and industrial energy management systems (IEMS) to grow steadily through 2024 (figure 17). Sales of IEMS will comprise half of those sales.

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[12] Split incentives occur when one party incurs an expense and another reaps the benefit. A common example is an apartment rental arrangement. Property owners might be reluctant to make an energy efficiency upgrade because they will not realize the lower energy bills, while renters will not make the investment because it is not their property and they will not realize the increase in property value.

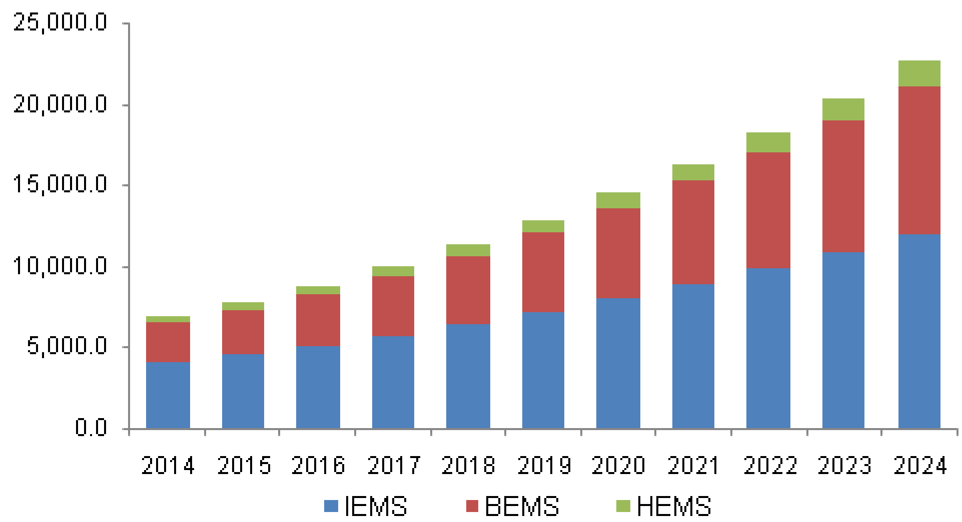

Figure 17. US energy management systems market revenue by product, 2014–2024 (USD million). *Source:* Grand View Research 2016.

We also expect more manufacturing facilities to integrate their load management with electric utility DR programs. Industry represents the only sector to show continued year-over-year growth in the volume of peak DR from 2011 to 2014 (see table 3). Greater integration of buildings and processes at manufacturing facilities will enable more flexible load control. The emergence of third-party aggregators and regional energy capacity markets is likely to prompt more companies to participate in DR events (Rogers et al. 2015). Many companies may want to participate in capacity markets and DR programs, but they will be cautious in how they automate such participation. Therefore integration will likely happen one plant at a time.

TRANSPORTATION

The transportation sector started investing in intelligent efficiency earlier than other sectors and is therefore further along in its adoption. Transportation has realized many benefits as a result. Operating costs for both freight and human transport in terms of freight ton-mile and passenger-mile are down to some extent. The capacity of existing transportation systems has risen, and pollution and other risks have declined. The sector gives every indication of continuing to increase its investments in intelligent efficiency. Our roads, rails, airports, and harbors will be capacity constrained without such investments.

Smartphone apps are the intelligent efficiency application that has grown most rapidly over the past few years. They give customers direct connection to the technology that was previously available only to companies and agencies. People rely on their smartphones to hail rides, reserve shared bikes and cars, and check real-time arrival and departure information for buses and trains.

Autonomous vehicles are another promising technology. We have confirmed that autonomous vehicles can reduce the amount of fuel used per passenger-mile or freight ton-mile. They also have the potential to increase the capacity of most highways and city streets once a critical mass has been reached. What is much less certain is the overall impact of these new technologies on energy use in the transportation sector.

SMART CITIES

Our conversations with vendors and other stakeholders have led us to conclude that local governments are deploying a broader range of ICT than other levels of government. Cities use intelligent efficiency to lower costs, improve services, and make their communities healthier and cleaner. Governments are investing in intelligent efficiency to solve specific problems, and they are also flexing their creative muscle as they use technology in ways beyond its original intentions. We can expect investments in intelligent efficiency to increase in this sector as local governments face increasing pressure on energy budgets and resources. While particular data for smart city ICT uptake may not exist, we can use the metrics we describe for other sectors throughout this report as proxies. They suggest that the market for smart city solutions is accelerating. For example, sales of smart city-related IoT devices will triple between 2015 and 2020, and overall sales of devices and software will double between 2015 and 2020 (table 7).

Cities are also aware that the moniker *smart city* has cachet. More and more places are labeling themselves smart cities because they know the concept has value to residents, businesses, and visitors. Many of the cities that did not win awards in the recent Smart Cities Challenge competitions are still going forward with the plans they outlined.

ENERGY EFFICIENCY PROGRAMS

Efficiency programs are experimenting with various technologies. Smart thermostats are one of the most common intelligent efficiency program measures. Available data indicate that they do save energy, but there is some debate on how much energy they can save. There is little disagreement, however, on their efficacy as a DR tool. They contribute to overall utility system efficiency by enabling residential customers to participate in DR events.

Efficiency programs that utilize some level of Cloud computing and data analytics are serving almost half of all US residential electricity customers. Utilities are starting to treat AMI and Cloud-based data analytics as necessary components of their IT infrastructure.

Program content is changing to incorporate the use of ICT at every level. Home energy reports are just one of the program elements that use AMI, big data, and data analytics. A few programs are conducting measurement and evaluation in real time during the customer engagement and implementation phases. The use of analytic tools to measure project performance will aid program evaluation. More information is needed on the popularity of automating program evaluation, but like other applications of intelligent efficiency, its use appears to be accelerating.

Remote building analysis is becoming more common as the tools become more powerful and their efficacy confirmed. We did not find the data we would have liked in this area, but there was consensus among the people we interviewed that these tools are in common use and that use is accelerating.

Utilities are also using ICT to help manage their efficiency programs. We had initially thought they were approaching these technologies one at a time, but we discovered that they are actually purchasing comprehensive CIS software programs. These include energy program SaaS products as apps that are either part of the platform or a third-party addition. Spending on CIS is definitely on an upward trajectory.

Missing Data and Future Research

The amount of data on intelligent efficiency uptake varies by application. While some applications had considerable national and global sales data, we found very little for others. Often this was because a particular application of intelligent efficiency resides within a broader application of technology. For example, energy management is just one component of building automation, and remote building analytic software is often part of a larger suite of software applications that sell as a bundle. Further analysis may help us tease out the fraction of the CIS software bundles that comprise remote building analytics; for now, we are left with gaps in our understanding. We found similar data gaps in other sectors that limited the depth of our analysis, especially with respect to the use of intelligent efficiency in government. Table 13 lists a few data points that we feel would greatly enhance our understanding of the uptake of intelligent efficiency.

Table 13. Examples of gaps in data for intelligent efficiency uptake

Sector	Metric
Buildings	Number of commercial and institutional buildings with BAS/BMS, BEMS/EMIS, and ABAS, by building use and size
	Spending in the commercial sector on building automation by building use and size
	Energy savings attributable to building automation
	Number of buildings capable of responding to automated DR signals
Smart manufacturing	Sales of smart manufacturing platform software
	Number of facilities with smart manufacturing software platforms
	Number of manufacturing plants participating directly and through third parties in energy markets
Transportation	Prevalence of on-board intelligent controls in personal vehicles (e.g., GPS-enabled maps, eco-driving coach/feedback programs)
Smart cities	Number of cities benchmarking their buildings
	Number of cities providing benchmarking tools to residents
	Number of city functions that have been automated (payment for street parking, payment of traffic tickets, and so on)

Sector	Metric
Efficiency programs	Spending on energy-efficiency-related SaaS
	Number of programs using SaaS
	Number of customers engaged
	Spending on software to monitor and report energy savings
	Number of programs that use remote building analytics

In addition to providing insights into the current state of the market, this report is intended to be the basis for future research. We hope it will initiate further analysis of the use of ICT to save energy. To that end, we welcome an ongoing discussion about the applications of intelligent efficiency and the data needed to track its progress and impacts.

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Appendix A. Methodology Considerations

We considered several research methods for assessing the uptake of intelligent efficiency in the US economy. In addition to a literature review, we also considered surveying more than a hundred experts on their sense of the market and using some type of Delphi technique to determine the current state of adoption of various intelligent efficiency applications.

We abandoned the plan to use surveys after realizing that, before issuing a survey, we would have to first identify and narrowly define each application; one person's definition of a smart thermostat may not be another's. Smart manufacturing is a typical example of the challenge we faced: a survey question asking people to estimate the percentage of manufacturing firms that utilize smart manufacturing would require several paragraphs of explanations and definitions. We were thus justifiably concerned that survey recipients would neither read nor respond to the questions.

Our research started with a list of intelligent efficiency applications and possible metrics for each. We settled on a plan to identify half a dozen or more applications within four to six sectors of the economy. For each application, we would seek out two or more metrics that could be used to characterize the current state (or possibly the current rate) of adoption.

As we discuss in the report, many of the applications are relevant to more than one sector. For example, AMI investments affect buildings, cities, and efficiency programs. Using more than one metric for an application lets us characterize its uptake in different sectors. In some instances, knowing the number of customers using an application is most useful. In others, it is more useful to know the percentage of service providers that offer it.

For example, the type of value we use to capture AMI's effects will vary for different segments of the economy. Knowing the total number of smart meters nationally gives us insight into the volume of investment in modernizing the electric grid. The percentage of customers with smart meters helps indicate the changing status of the electric grid and the potential for energy efficiency and DR programs dependent upon or improved with smart meters.

As table A1 shows, we developed a matrix of metrics to capture the relationships among applications, sectors, and indicators.

Table A1. Matrix of metrics

Application	Buildings	Smart manufacturing	Transportation	Government and smart cities	Cross-cutting	Energy efficiency programs
Connected and IoT devices	Average number per building per building type	% of connected devices			Number of connected appliances	Number of connected appliance programs
Building energy management	% of buildings by type			% of government buildings		Number of programs targeting BEMS
AMI	% of buildings				Number of meters	Number and % of utilities
Automated demand response	Volume of DR, % of sites by sector	% of facilities, volume of DR provided	Potential for EVs	% of cities participating		Number of programs, % of national load
Distributed energy resources	Number of buildings with DG	Fraction of plants by size	Number and ratio of smart EV chargers	Number of cities with EVs and with smart chargers		Number of programs, volume of energy resources
Industrial Internet of Things		Number of devices, volume of sales				
Production energy management		% of plants				
Real-time traffic data collection and management			Miles of roads	Number of metro areas		
Autonomous vehicles			Number of vehicles, % of vehicle sales			
Driver-assisted technologies			Number of vehicles, % of vehicles sold			
Dynamic scheduling of mass transit			% of mass transit systems	Number of cities		

Application	Buildings	Smart manufacturing	Transportation	Government and smart cities	Cross-cutting	Energy efficiency programs
Dynamic control of freight logistics			% of freight shipped			
Helping residents with energy efficiency				Number of cities helping with benchmarking		
Using ICT in city planning				% of metro areas		
Intelligent efficiency as a measure						Number of programs, volume of energy savings
Building ICT into program design						Number and % of program administrators
Project performance tracking						Number and % of program administrators
Customer engagement						Number of customers, % of customers, volume of load
Program management						Number and % of program administrators

Appendix B. Excluded from the Analysis

It is important to bound the scope of analysis in any project such as this. Our original scoping analysis included many economic sectors not included in this report. Early on, we eliminated sectors that generally

- relate to the supply side of energy, such as petroleum, mining, agriculture, and electricity generation and transmission
- involve few applications of intelligent efficiency
- are outside of ACEEE's expertise in end-use energy efficiency

Utilities are making considerable investments in ICT to improve the management of their assets and the dispatch of power and fuel. However we have not considered the application of ICT in the management of utility generation and transmission infrastructure. These investments are focused on internal efficiencies and do not directly affect end-user energy consumption, though they do affect customer energy costs.

We also limited our analysis of enabling technologies. Technologies such as the Internet and smartphones are integral to many intelligent efficiency applications. However not all devices connected to the Internet and not all smartphone applications have an energy efficiency component. Therefore we sought out information on enabling technologies only if it was relevant to our understanding within a sector. For example, software as a service (SaaS) is an enabling technology for many intelligent efficiency applications in the energy efficiency program sector. We did not look at the entire SaaS market in the utility sector, but instead looked only at the use of SaaS to enable common intelligent efficiency applications that are changing the program sector.

Product or service substitution made possible by ICT is often considered a form of intelligent efficiency. For example, a smartphone uses sensors and access to networks and logic to provide the same benefits as a telephone, stereo, camera, radio, and newspaper subscription. It can also replace maps and a whole host of mapping products and services. These substitutions involve multiple levels of energy savings. To consider all types of product substitutions that have resulted from ICT would be unmanageable in a report of this scope. That said, we did include some applications, such as those associated with transportation, because they have introduced new services into the market. Examples include traffic congestion identification and avoidance, and multimodal apps. These applications are not substitutes for a prior technology, as the benefits provided are completely new.

We did not include the use of automation in the service industry. The automated ordering and checkouts in grocery stores, restaurants, and other retail establishments are often used to collect data that can later be used to improve efficiencies and increase sales. Our understanding is that energy savings are not a key feature of these applications.

We have not addressed intelligent efficiency in the healthcare field, other than as it is captured in the applications relevant to nonresidential buildings. It is likely that ICT is being used in healthcare to create process efficiencies (such as patient processing) that have the co-benefit of energy savings. But because the energy savings are likely not significant by location or collectively by sector, and because ACEEE does not have expertise in the healthcare field, we did not consider healthcare-specific applications in this analysis.

We did not address the use of ICT in the financial sector to track investments in energy efficiency because we felt it would be hard to differentiate this use of ICT from other uses of such technology. We do feel this topic is worthy of a separate analysis.

PATENTS

Previous work has used patents as an indicator of the amount of innovation occurring within a field of research. We considered this metric, but ultimately rejected it. We include it here to demonstrate how it might be used and why we decided not to use it.

There is no ICT category, let alone an intelligent efficiency category, for patents, so we would have to use a proxy to get a sense of the level of innovation in this space. Clean energy technologies include renewable energy, technologies that reduce the emissions of conventional energy sources, and (of course) energy efficiency. Figure B1 shows a rapid increase in the number of clean energy patents starting around 2009. It is fair to assume that a significant fraction of these patents were for intelligent efficiency products. A focused analysis of these patents might be able to determine the number of patents for intelligent efficiency at a more granular level.

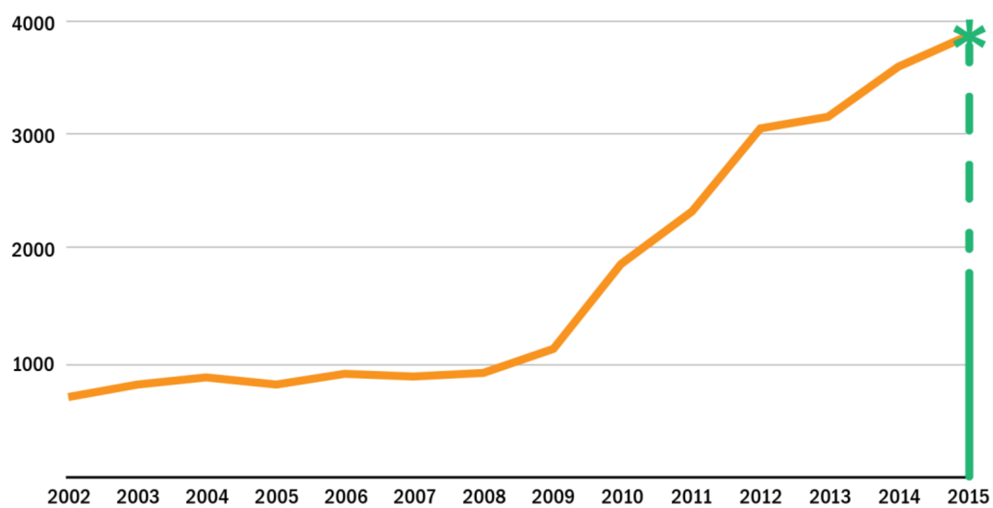

Figure B1. US clean energy patents. 2015 estimate based on first half year-over-year growth. *Source:* Randall 2015.

While the trend in clean energy patents is promising, we concluded that these patents are not the ideal proxy for innovation in intelligent efficiency. These data may misrepresent the trend in clean energy innovation because the US Patent and Trademark Office (USPTO) began expediting the review of clean energy patents around 2009, which drove an increase in the patents filed in this category. At the same time, the number of these patents may underrepresent actual innovation. Many companies do not apply for patents because they want to protect their intellectual property until it is market ready.

In fact, the USPTO issued 322,448 patents in 2015 (USPTO 2015), so (as figure B1 shows) clean energy technology represents only a fraction of US innovation. As indicated by many of the applications selected in this analysis, much of the innovation around intelligent efficiency is happening in other sectors, such as telecommunications. Building automation requires software, communication capabilities such as Wi-Fi and Bluetooth, and many sensor and actuator technologies. None of these technologies is strictly clean energy or intelligent efficiency; it is the innovative combination of them in particular applications that makes them so.

Appendix C. Trend Lines and Rogers Curves

A trend line gives us a snapshot of a technology's adoption rate, but it does not tell us why a technology is or is not being adopted. Therefore we were careful to limit our conjecture on policy implications from the shape of a trend line. With that qualifier, we offer the following interpretations for consideration. An adoption rate that is linear over two to five years might indicate a properly working market and policies that are neither inhibiting progress nor overly stimulating it. Perhaps more could be done to accelerate adoption, but the status quo could be considered acceptable. A flat trend line could indicate a flat market that is facing barriers and may require a policy solution. It could also mean that a technology is not market ready yet, is flawed, or has been wrongly positioned in the market place. A trend line that is growing exponentially could indicate a market that is either doing quite well without government action or one that is overly stimulated by government subsidies. Our intent in proposing these possible interpretations is not to draw any hard conclusions but to stimulate a discussion.

Some may find it useful to understand where each application is along a typical adoption curve. Two parameters are commonly used to capture the diffusion of a new technology: customer adoption and market share. Everett Rogers was a pioneer of what is now called *the diffusion of innovation*, or diffusion theory. The Rogers curve breaks customers into five groups: innovators, early adopters, early majority, late majority, and laggards.

Figure C1 represents the adoption of an intelligent efficiency application by successive groups of consumers (shown in blue) and its market share in (shown in yellow). As the figure shows, a technology will eventually reach the saturation level, at which point it will become the incumbent technology.

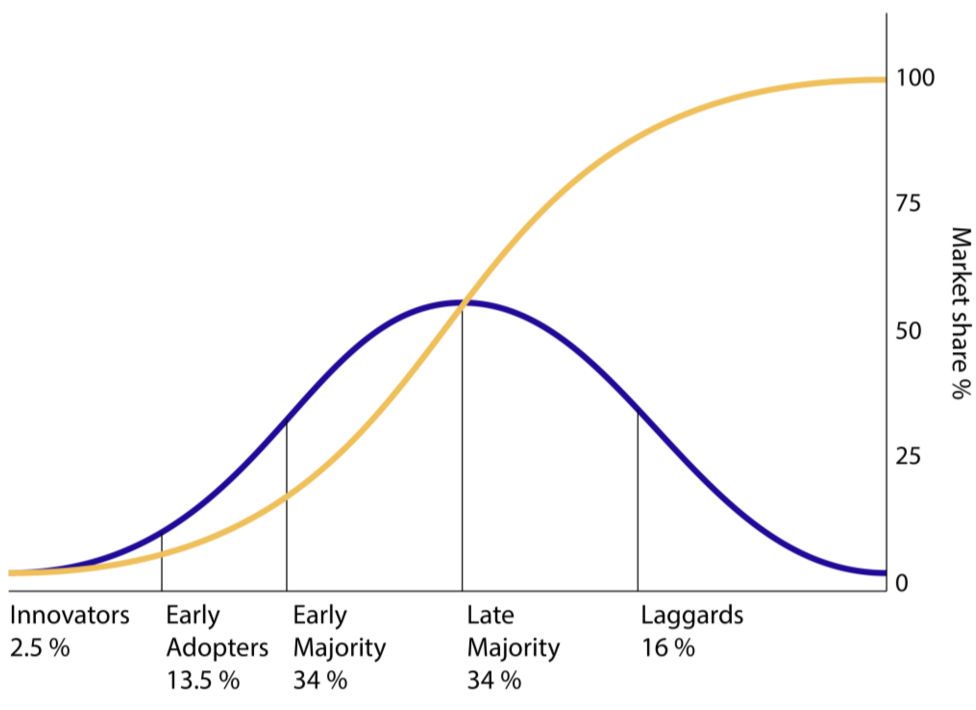

Figure C1. Rogers product diffusion curves. *Source:* Rogers 1983.

Future research could investigate where along a Rogers curve an application lies. With sufficient information, multiple applications could be plotted along either of the two curves.