A DEFINING FRAMEWORK FOR INTELLIGENT EFFICIENCY

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June 2012

Report Number E125

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Executive Summary

Energy efficiency has been a major contributor to meeting U.S. energy needs for the past four decades, reducing environmental burden of our energy use while stimulating our economic growth. Our finite fuel supplies are proving increasingly uncertain, expensive, and with serious environmental consequences. Against this backdrop, the inefficiencies and energy waste in our homes, businesses, and communities is untenable. We must lighten the load.

The potential for new energy efficiency remains enormous. A large portion of our past efficiency gains came from improvements in individual products, appliances, and equipment, such as light bulbs that illuminate our world, electric motors that drive our equipment, or the cars and trucks that move us and our things. While discrete, device-level technology improvements will continue to play an important role, looking ahead we must take a systems-based approach to dramatically scale up energy efficiency to meet our future energy challenges.

System efficiency opportunities produce energy savings that dwarf component-based efficiency improvements by an order of magnitude. System efficiency is performance-based, optimizing the performance of the system overall—its components, their relationships to one another, and their relationships to human operators. One of the cornerstones of systems-based efficiency is information and communication technologies (ICT), such as the internet, affordable sensors and computing capacity that are the foundation upon which systems efficiency are built. We can make great strides using these readily available technologies. If homeowners and businesses were to take advantage of currently available information and communications technologies that enable system efficiencies, the United States could reduce its energy use by about 12-22% and realize tens or hundreds of billions of dollars in energy savings and productivity gains. In addition, there are technologies that are just beginning to be implemented that promise even greater savings.

System efficiencies rest on a combination of technology and behavioral "intelligence" that reacts dynamically to its surroundings. The efficiency of a system is a function of both 1) how its energy use is managed within the *technologies* and how they interact with one another, and 2) the choices made by the *people* involved. We characterize this new convergence of technology and behaviors that saves energy as *intelligent efficiency*.

WHAT IS INTELLIGENT EFFICIENCY?

Intelligent efficiency is a systems-based, holistic approach to energy savings, enabled by information and communication technology (ICT) and user access to real-time information. *Intelligent efficiency* differs from component energy efficiency in that it is adaptive, anticipatory, and networked. Opportunities for *intelligent efficiency* exist along a continuum with technology and human behavior at either end. Increased "intelligence" along this spectrum of technology and behavior falls into three broad categories:

- **People-centered efficiency** provides consumers with greater access to information about their energy use as well as the tools to reduce it. In this type of *intelligent efficiency*, technology makes individuals' energy use visible, thus guiding them toward making major efficiency gains. For example, consumers can observe their home energy monitor to understand when and how much energy they use in order to modify their behavior. Human behavior becomes an integral part of the system.

- **Technology-centered efficiency** encompasses "smart" technologies that optimize energy systems in buildings, industries, and transportation systems. Here, automated systems optimize energy use and can anticipate energy needs, while human engagement is largely limited to the initial programming and commissioning of the system. For example, an automated and anticipatory building system uses the weather forecast to predict air conditioning needs and pre-cool an office building, and then adjusts cooling loads to the occupancy of each individual room. In manufacturing, automated controls of industrial boilers can maintain optimal efficiency by making adjustments faster than an operator could, which saves energy, lowers emissions, and ensures reliability. Human behavior is largely removed and the workings of the system made invisible, while sensors, monitors, and other controls work together to achieve efficiencies unobtainable by human operators alone.

- **Service-oriented efficiency** provides consumers with the option to substitute one material-based service, for example, in-person conferences, for an information and communication technologies-enabled service that uses less energy, such as video teleconferencing. This concept is often referred to as "**substitution**" or "**dematerialization**." In this type of *intelligent efficiency*, people themselves choose to what degree they utilize information and communication technologies to use less energy while accomplishing the same goals.

Communication and energy infrastructure, such as a campus of buildings, an entire city, or the electric power grid, allow a scaling up of *intelligent efficiency*, amplifying the benefits by coordinating all systems. Through *intelligent efficiency,* smart grids, cities, transportation systems, and communications networks can become the new normal across the United States and will undergird national and regional economies that, even in the face of increasingly scarce resources, grow and thrive.

MODELS OF INTELLIGENT EFFICIENCY

Across the country, we have already started to experience the benefits of *intelligent efficiency*. The ten case studies in this report document examples of how we currently use *intelligent efficiency* to some extent in our homes, buildings, industry, and transportation sectors.

- *Residential Case Study: Smart Refrigerator Controls, Links to Electric Grid.* Home appliances are increasingly making use of technology-centered efficiency such as smart controls and communication technologies to improve their efficiency levels. Some products, to meet upcoming federal efficiency standards for residential refrigerators, are making use of technologies such as variable speed compressors and fans that use sensors and controls to optimize operation, which may shave at least 5% from the device's energy use. Looking forward and filling out the vision of *intelligent efficiency,* "smart" appliances such as refrigerators will be able to communicate with the electric grid by receiving a real-time price signal from the utility and adjust their operations in response, opening up new opportunities for energy savings.

- *Urban Case Study: Envision Charlotte.* Through a collaborative partnership, Duke Energy, Cisco and Verizon are working on a project to dramatically raise energy awareness in Charlotte, North Carolina, by enabling people-centered *intelligent efficiency*. The initiative calls for interactive video monitors installed in the lobbies of downtown office buildings that display, in near real-time, the collective energy used by buildings in the city's core. The monitors give tenants the information they need to better manage energy consumption in the offices, providing information about energy usage, energy efficiency ideas, and tales of the most efficient "energy champions" in the building. Duke Energy anticipates that the project will produce a 20% drop in power use by 2016.

- *Manufacturing Case Study: Plant-Wide Optimization.* Manufacturing plants are full of complex systems, and managing energy consumption requires both a detailed understanding of real-time information about what the systems are doing and how these systems interact. New information technologies and advanced sensors and controls—examples of both people- and technology-centered *intelligent efficiency*—can improve system efficiencies and integrate controls across multiple, interacting systems. Both Schneider Electric and Rockwell Automation, for example, offer services to manufacturing firm to improve plant-wide optimization and increase both energy efficiency and productivity; they anticipate seeing as much as a 40% drop in the use of electricity and a 35% reduction in oil and gas usage.

- *Public Transportation Case Study: Priority Lanes, Dynamic Messaging, and Telecommuting.* To relieve congestion on major highways, the Twin Cities metropolitan area (Minneapolis and St. Paul, Minnesota) is implementing a toll system using priority lanes with differential pricing, dynamic messaging about traffic, and information about public transit options (all examples of people-centered *intelligent efficiency)* and telecommuting (service-based *intelligent efficiency).* The dynamic message system communicates with drivers in real time about the availability of lanes, toll rates, travel speeds, and public transit alternatives. The *eWorkPlace* initiative focuses on getting employers to encourage the use of telecommuting and flexible work arrangements, which helps relieve traffic congestion while also reducing energy consumption. Between March 2009 and March 2010, 30 employers and more than 3,000 employees in the Twin Cities were participating in the initiative.

- *Institution Case Study: Department of Defense (DOD).* The Department of Defense has identified energy efficiency in its military installations, which account for about 25% of DOD's total energy costs, as a key strategy to reduce energy costs, decrease the impact of fossil fuel price volatility, and boost installation energy security. DOD's energy efficiency efforts are ramping up to achieve 30% energy savings by 2015, as required by Executive Order, and DOD has turned to several examples of people- and technology-centered *intelligent efficiency* to help reach this goal. The Installation Energy Test Bed Initiative, for example, is assessing and supporting new technologies in facilities related to energy control, management, monitoring, modeling, and decision making. For example, DOD is demonstrating advanced energy management systems and software to assess and control electricity demand and consumption at Naval Station Great Lakes in Illinois. If DOD were to expand this project alone to all facilities, it would reduce heating, cooling, ventilation, and lighting costs by 20% or $200 million per year.

BARRIERS TO INTELLIGENT EFFICIENCY

Tremendous potential exists for greater adoption of *intelligent efficiency* to save energy and create new economic opportunities, but significant barriers exist.

Societal

- Homeowners, business owners, and policymakers lack in-depth awareness of the opportunities and benefits of *intelligent efficiency*.
- Human nature dictates that most of us approach new, complex technologies with uneasiness, initially.

Financial

- Implementing *intelligent efficiency* approaches often involves significant up-front costs.
- Split incentives are sometimes in play, where the cost and benefits accrue to different parties, for example, landlords and tenants in both the residential and commercial arenas.

Structural

- There is a lack of a workforce skilled in managing intelligent energy systems.
- Data on national energy usage is incomplete, inconsistent, and insufficient.
- Data on the measurable benefits of efficiency measures is in short supply or non-existent.
- Consumers have privacy concerns related to the sharing of data.

POLICY RESPONSE TO BARRIERS TO INTELLIGENT EFFICIENCY

In response to these barriers, policy and policymakers can facilitate the deployment of systems built around *intelligent efficiency* in several key ways, by:

1. Expanding **leadership** by policymakers to educate their peers and the public, and for leaders in the public and private sectors to lead by example by implementing *intelligent efficiency* in their own operations.
2. Enhancing **information infrastructure** including making more detailed and timely energy data available, ensuring that the communications systems required to allow access to this information are in place for all consumers, and investing in the development of the human capital required for continued innovation.,
3. Redefining **regulatory business models** under which public and private entities operate, in order to send a signal to markets to promote greater system efficiencies.

Conclusion

The promise of *intelligent efficiency* is great, offering a path to achieving major, long-term energy reductions, increased productivity, and job creation in every region of the country. Just as we have achieved energy efficiency over the last 30 years from devices, we need to expand now to energy efficiency gains that are systems-based and performance-focused. "Intelligence" in the energy-using systems in our homes, buildings, factories, and farms optimize these systems, allowing us to achieve the promise that energy efficiency holds for our future. *Intelligent efficiency* rests on carefully considered combinations of relying on technologies (not humans) where that maximizes efficiency, and inviting human interaction where that is optimal. In this systems-based approach, energy usage is made visible (to people) or invisible (automated by technology) according to the need. *Intelligent efficiency* represents a pivotal opportunity in a time of constrained resources to step up our energy efficiency game, and to lay the foundation of a thriving U.S. economy.

Acknowledgments

Thank you to our Advisory Group for supporting this work (in alphabetical order): Carl Blumstein (California Institute for Energy and Environment), Arkadi Gerney (Opower), Paul Hamilton (Schneider Electric), Chris Hankin (Information Technology Industry Council), Matt Hourihan and Matt Stepp (Information Technology and Innovation Foundation), Stephen Harper (Intel), Philip Kaufman (Rockwell Automation), Rich Lechner (IBM), Clay Nesler (Johnson Controls), Bill Parks and Colin McCormick (U.S. Department of Energy), Chris Payne (Lawrence Berkeley National Laboratory), Larry Plumb (Verizon), Gene Rodrigues (Southern California Edison), Michael Terrell (Google), Dominic Vergine (ARM), and Mark Wagner (Johnson Controls).

In addition we express our appreciation to our colleagues Steven Nadel, Glee Murray, Naomi Baum, Ethan Rogers, and Eric Schwass for their comments and advice in the development of this report. We also acknowledge the contributions of our developmental editor Karin Matchett (Science Writing and Editing) and ACEEE's editor Renee Nida.

Introduction

Energy efficiency has been a major contributor to meeting U.S. energy needs for the past four decades, reducing environmental burden of our energy use while stimulating our economic growth. Our finite fuel supplies are proving increasingly uncertain, expensive, and with serious environmental consequences. Against this backdrop, the inefficiencies and energy waste in our homes, businesses, and communities is untenable. We must lighten the load.

The potential for new energy efficiency remains enormous. A large portion of our past efficiency gains came from improvements in individual products, appliances, and equipment, such as light bulbs that illuminate our world, electric motors that drive our equipment, or the cars and trucks that move us and our things. While discrete, device-level technology improvements will continue to play an important role, looking ahead we must take a systems-based approach to dramatically scale up energy efficiency to meet our future energy challenges (see Elliott et al. 2000; Elliott and Shipley 2006).

System efficiency opportunities produce energy savings that dwarf component-based efficiency improvements by an order of magnitude. System efficiency is performance-based, optimizing the performance of the system overall—its components, their relationships to one another, and their relationships to human operators. One of the cornerstones of systems-based efficiency is information and communication technologies (ICT), such as the internet, affordable sensors and computing capacity that are the foundation upon which systems efficiency are built. We can make great strides using these readily available technologies. If homeowners and businesses were to take advantage of currently available information and communications technologies that enable system efficiencies, the United States could reduce its energy use by about 12-22% and realize tens or hundreds of billions of dollars in energy savings and productivity gains. In addition, there are technologies that are just beginning to be implemented that promise even greater savings.

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WHAT IS INTELLIGENT EFFICIENCY

Intelligent efficiency is a systems-based, holistic approach to energy savings, enabled by information and communication technology (ICT) and user access to real-time information. The benefits of *intelligent efficiency* go above and beyond those of conventional efficiency, which are more discrete improvements in the energy savings of individual pieces of equipment and components within buildings, manufacturing plants, campuses, and vehicles. *Intelligent efficiency* takes advantage of a "dual intelligence," inviting and encouraging human involvement where that may increase efficiency, and discouraging or removing human involvement in cases where well-designed technological systems can more easily increase efficiency.

Opportunities for *intelligent efficiency* exist along a continuum with technology and human behavior at either end. At one end of the spectrum are measures in which consumer decisions play the dominant role in determining efficiency or waste. At the other end, you might have a fully automated system controlling end-use devices, where human input, other than in programming and commissioning the system, is not needed—or even desired. Thus, *intelligent efficiency* “invites” individuals’ engagement with a system when this improves efficiency and “disinvites” engagement when it does not.

Key enablers of *intelligent efficiency* have been the emergence of affordable sensors and controls, computational capability, the ability to share large amounts of data, and a growing awareness among energy researchers and practitioners of what consumers want and how they interact with the technology that they increasingly depend on. Information and communication technology (ICT), and the access to near real-time information that this technology enables, provides a foundation for *intelligent efficiency* that allows systems to be optimized to a degree never before seen. By intelligently combining efficiencies achieved by either technologies or human behavior, systems built around *intelligent efficiency* can balance the needs of the user with reduced energy usage to achieve efficiencies that dwarf those obtained through a focus solely on the devices themselves.

Increased intelligence along this spectrum of technology and behavior falls into three broad categories:

- **People-centered efficiency** provides consumers with greater access to information about their energy use as well as the tools to reduce it. In this type of *intelligent efficiency*, technology makes individuals’ energy use visible, and thus guides them toward making major efficiency gains. For example, consumers can observe their home energy-display to understand when and how much energy they use, and as a result modify their behavior. Similarly, when energy use is reported at the level of organizations or communities, members’ awareness of energy use is expanded and placed in context. Human behavior is invited into the system in new ways by making energy use visible and modifiable.
- **Technology-centered efficiency** encompasses “smart” technologies that automate and optimize energy systems in buildings, industries, and transportation systems. Here, automated systems optimize energy use and can anticipate energy needs, while human engagement is largely limited to the initial programming and commissioning of the system. For example, an automated and anticipatory building system uses the weather forecast to predict air conditioning needs and pre-cool an office building, while adjusting cooling loads to the occupancy of an individual room. Human behavior is largely removed and the workings of the system made invisible, while sensors, monitors, and other controls work together to achieve efficiencies unobtainable by human operators alone.
- **Service-oriented efficiency** provides consumers with the option to substitute one material-based service, for example, in-person conferences, for a service based on information and communication technologies that uses less energy, such as video tele-conferencing. This concept is referred to as “**substitution**” or “**dematerialization**.” In this type of *intelligent efficiency*, human interaction is perpetually “invited.” Individuals choose to what degree they utilize information and communication technologies to use less energy while accomplishing the same goals.

EVOLUTION OF INTELLIGENT EFFICIENCY

Intelligent efficiency is a new recognition of the importance of holistic, system-based energy efficiency to meet our future energy needs. Many of the enabling technologies for *intelligent efficiency*—e.g., sensors and controls—are not new, nor is the concept of a systems approach to efficiency; however, the recognition of interactions between technology and human behavior is a new way of prioritizing our future energy efficiency potential.

Research has identified systems approaches to energy efficiency improvements for decades. For example, ACEEE has explored emerging technologies and systems efficiency and found that the opportunities from optimization of systems far exceed the savings opportunities from device-level efficiency (see Elliott et al. 2000; Elliott and Shipley 2006). The Electric Power Research Institute (EPRI) did work on intelligent controls in the 1980s and 1990s, and national labs such as Lawrence Berkeley National Laboratory have been exploring Internet-based controls for buildings.

Elements that contribute to *intelligent efficiency* can contribute to energy efficiency in their own right. Clearly improvements in energy using technologies have been a major contributor to energy efficiency. Similarly, ICT has been shown to improve energy efficiency. Past research has assessed this link between ICT and energy productivity gains including ACEEE own (Laitner et al. 2009). These past studies have suggested that 12-22% energy savings could be achieve from ICT-enabled energy efficiency.

The integration of ICT-enabled efficiency with human behavior offers the potential to go beyond the savings from either approach alone, represent if opportunity available from intelligent efficiency.

OPPORTUNITIES FROM A SHIFT TO SYSTEMS-BASED EFFICIENCY

Future significant gains in energy efficiency require a move away from the focus on device-level efficiency and toward understanding how these devices interact to form systems, and then how systems can interact to form even more complex systems. Over the past three decades, appliance and equipment standards have been among the most successful sources of energy efficiency resources (Lowengerger et al. 2012). Today, equipment, like refrigerators, electric motors, cars and light bulbs all use significantly less energy than they did three decades ago. As these products have become more efficient, the potential savings from incremental increases decreases as we approach physical and economic limits to the efficiency of these devices.

Indeed, we already see that the focus on device-level efficiency is beginning to have diminishing returns. Because higher efficiency requires intimate knowledge of the device design it was an important initial approach. However, the singular focus on devices has its limitations. There is a growing awareness among the energy efficiency research and policy communities that the larger opportunity for energy efficiency lies in full system optimization. A great deal of the efficiency of a system lies not in the efficiency of the individual component devices, but rather arises from how devices interact and how the user interacts with the system overall.

A number of levels of systems exist, with opportunities for *intelligent efficiency* to benefit all:

- A process-level system such as a pump or heating system that includes devices such as motors, pumps, piping, boiler, heat exchangers, fans and controls
- A whole-building or manufacturing-plant system incorporating numerous process-level systems
- A large-scale, complex system, such as a transportation network, manufacturing supply chain, and a city with its infrastructure for transportation, buildings, services, etc.

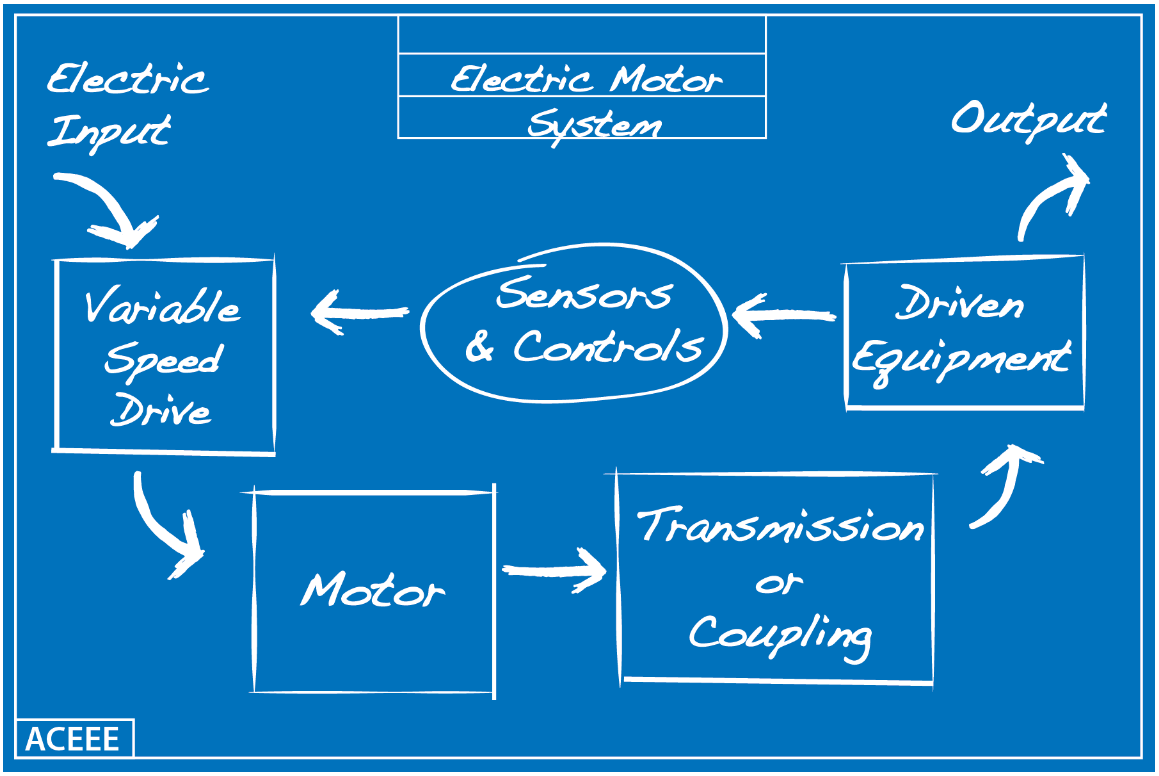
Currently, we see most examples of *intelligent efficiency* emerging at the process level and whole-building or manufacturing-plant system level, and these are the focus of our case studies presented later in this report. At this point in time, the application of *intelligent efficiency* to large-scale systems remains largely conceptual, though we present one case study that begins to address this level of system.

Motor-Driven Equipment as Systems

In many process systems a large part of energy waste is due to the design, construction, installation, and operation of the entire system rather than inefficiency in any component device. This is especially evident in motor systems. Motor systems consume over half of the electricity produced in the United States (Nadel et al. 2002). In 1992, the federal government defined minimum energy performance standards for electric motors, and raised the efficiency levels in 2007. These standards caused typical motors to increase their efficiency from 80-90% to 90-95%. While it is technically possible to still modestly increase motor efficiency further, the returns get smaller and smaller while the costs increase rapidly.

Motors are always part of a system (Figure 1), and each element from electric supply to the actual use of the driven equipment represents opportunities for efficiency improvements. A shift in focus to the entire motor system can yield much higher savings at much lower cost. While savings from more efficient motors are usually 1-3%, savings from optimizing the system frequently exceed 20%. In fact, in some cases, installing even an efficient motor in the wrong application can lead to increased energy use.

Figure 1. Elements of an Electric Motor System



Buildings as Systems

There are times when optimizing each individual device does not lead to the best full-system design due to the complex interaction of devices within a system. In the heating, cooling, and ventilation systems in large buildings, for example, there are multiple zones (usually one room or office suite) each controlled by its own temperature sensor. These sensors tell a controller to change the amount of cooling and outdoor air provided to the space. However, this method of controlling each part of the system separately does not take into account the interaction among these various demands on system, which can actually increase energy use while reducing occupant comfort. As equipment is cycled to respond to coincident demands, it can easily overshoot target temperatures when adjacent areas call for heating and cooling concurrently. A more intelligent approach integrates the data gathered in each zone along with power consumed by the central chiller and distribution fans, and then directs the system to deliver the required cooling and air quality to each zone (Hartman 2006).

Manufacturing Supply Chains as Systems

The production of manufactured goods normally involves multiple facilities operating in sequence, often owned by different companies. These complex interactions lead to inefficiencies through both business transactions and logistics. For example, lack of coordination with a facility's suppliers or customers can result in long lead times for goods, and shipping those goods across the country (or the globe) takes considerable energy and can cause disruptions if something is delayed or damaged in shipment. Some thought leaders in the manufacturing sector are exploring how these multi-facility systems can be optimized for energy efficiency using information exchange, simulation, and feedback among the elements of the supply chain (SMLC 2011), and are exploring symbioses among the facilities, for example, ways they might share infrastructure and waste streams.

Barriers to Intelligent Efficiency

The benefits of *intelligent efficiency* are large; however, as with any new idea it faces numerous barriers to its full implementation in the marketplace. We group these barriers into three broad categories: social, financial, and structural. The **social barriers** reflect the lack of awareness of this new concept among consumers and people in the manufacturing, transportation, and buildings sectors, combined with inherent resistance to new and potentially risky ideas that are complex. . **Financial barriers** encompass the upfront costs of implementing these new technologies, combined with the split-incentive problem[1] that frequently bedevils other kinds of efficiency efforts. Whereas landlords of multi-family buildings or commercial office buildings bear the cost of installing new equipment, the tenants are often the ones who accrue the financial benefits of the energy savings. The landlords in this case have limited incentive to make energy efficiency upgrades. The **structural barriers** are also critical to dissolve. First, there is a lack of a skilled workforce to manage energy usage using *intelligent efficiency* applications. Second, we have a shortage of data on measurable benefits of these applications. Third, there are important privacy issues to resolve. *Intelligent efficiency* systems in homes or businesses, such as smart meters with two-way communication, must be guaranteed not to allow open access to energy usage data.

Organization of the Report

This report characterizes the spectrum of opportunities for *intelligent efficiency* throughout our economy that can dramatically scale up efficiency, identifies barriers to more widespread adoption, and begins to map out policy solutions that can enable *intelligent efficiency* to propel businesses, communities, and households to new levels of energy efficiency, boost economic productivity and create jobs, and enhance the nation's energy security.

This report is organized in the following sections:

- Types of *intelligent efficiency*. We offer a new definition and taxonomy of the types of *intelligent efficiency* in all sectors of our economy, discussing how these approaches have evolved over the past several decades.
- Barriers to widespread adoption. What barriers currently prevent *intelligent efficiency* from being more prevalent?
- The benefits of *intelligent efficiency* in terms of energy savings, productivity, jobs, and independence from the electrical grid.
- Case studies of ten *intelligent efficiency* examples in U.S. buildings, manufacturing, institutions, communities, and transportation.

[1] A market barrier to an innovation, in which higher capital costs of an innovation are borne by one market participant while its operating savings benefit another. The financial incentive to adopt the technology is split from the participant responsible for putting it in place (Green Playbook 2012).

- Discussion of policies that would help overcome the barriers and tap into the potential economy-wide benefits of *intelligent efficiency*.

Understanding Intelligent Efficiency

Intelligent efficiency is manifested in different, sometimes overlapping forms in the economy, and elements of it have begun to emerge in the marketplace over the past few decades. In this section we explore the types of *intelligent efficiency* and how they are manifested in the marketplace. We also explore the historical patterns of technology adoption from which *intelligent efficiency* has emerged, discuss how those have evolved up until today, and present a vision for how *intelligent efficiency*, as a more systematic and comprehensive concept, may evolve into the future.

TYPES OF INTELLIGENT EFFICIENCY

We have developed a framework for defining and characterizing *intelligent efficiency* (Figure 2) based on the approach to achieving energy savings rather than by the sector of the economy. In fact, each type of *intelligent efficiency* spans all sectors of the economy, including our homes, buildings, factories, transportation, institutions, and the electric power grid, and across all types of energy, including electricity, natural gas, and oil. We group *intelligent efficiency* into three broad (frequently overlapping) categories:

1. People-Centered Efficiency (Real-Time Feedback)
2. Technology-Centered Efficiency (Automation and Optimization)
3. Service-Based Efficiency (Dematerialization or Substitution)

Communication and energy infrastructure, such as a campus of buildings, an entire city, or the electric power grid, allow a scaling up of intelligent efficiency, amplifying the benefits by coordinating all systems.

Figure 2. Framework for Intelligent Efficiency

Types of Intelligent Efficiency

People-Centered Efficiency (Real-Time Feedback): Providing real-time information and management tools that enable consumers, building operators, manufacturers, and other users to lower energy consumption in response to changing information.

Examples:

- Building energy use displays and comparisons
- Real-time pricing and smart meters
- Instantaneous fuel economy display
- Energy Management Standards
- Real-time bus arrival apps
- Priority highway lane systems with dynamic pricing and messaging
- Vehicle fleet management through GPS-enabled smart logistics

Technology-Centered Efficiency (Automation and Optimization): Using sensors, controls, and computer software to automate business processes or building or vehicle operations to optimize energy use. This bypasses much of the need for people to respond.

Examples:

- Building sensor and control systems that optimize energy use, i.e. AC and lighting systems, for occupancy
- Plant-wide automation to optimize production for multiple processes
- Sensors and controls in smart power grids and communications networks
- Vehicle electronic systems that improve fuel economy

Substitution with Energy-Saving Information and Communications Services (Dematerialization): Shifting behaviors, services and structure of the economy in ways that displace more energy-intensive activities in ways that reduce energy usage.

Examples:

- Video conferencing instead of traveling for in-person meeting
- Telecommuting
- E-books instead of printing books
- Online shopping and banking instead of driving to stores/banks
- Digital music and movies
- Car and bike sharing programs
- Business-to-business E-commerce

Crosscutting Intelligent Infrastructure

Together, all types of IE enable more integrated, smarter and more reliable infrastructure, including smart power grids, smart cities, integrated transportation systems including electric vehicles, and communications networks.

Through intelligent efficiency, smart grids, cities, transportation systems, and communications networks can become the new normal across the United States and will undergird national and regional economies that, even in the face of increasingly scarce resources, grow and thrive.

1. People-Centered Efficiency (Real-Time Feedback)

People-centered efficiency adds sources of real-time feedback—making energy use visible—in order to invite more human decision making into the quest for energy efficiency. When consumers—whether home owners, building or facility operators, or vehicle drivers—have access to clear and relevant real-time (or near real-time)[2] information, they can modify their behaviors in ways that save energy while accomplishing the task just as well, or better. Examples of enhanced, real-time feedback include smart meters with display capability, in-home energy displays, lobby displays in large buildings, smart phone applications for home energy management, and fuel-economy displays in vehicles.

Much recent research has looked at the energy savings possible through access real-time feedback. A 2010 report by ACEEE documents numerous programs that use behavioral feedback mechanisms to achieve energy savings that hold up to rigorous evaluation, measurement, and verification (EM&V) standards (see Friedrich et al. 2010). One common type of feedback program is the distribution of home energy comparison reports, which compare a consumer's energy bills to those of a neighbor, and taps into "social norms behavior." Research shows that this method of delivering monthly comparison reports consistently results in savings of about 2% per year (EDF 2011). And an ACEEE meta-review of dozens of residential feedback studies across three continents found that, on average, residents saved 4-12% on monthly electricity usage when given access to energy consumption information through technologies such as smart meters and in-home energy displays (Ehrhardt-Martinez et al. 2010).

While the most visible implementations of buildings-oriented people-centered efficiency have focused on residential users, we are beginning to see similar program emerge in large buildings, and even integrated across cities (e.g., the Envision Charlotte program profiled in the case studies.).

In the transportation sector, technologies such as "smart" global positioning systems (GPS) that propose alternative routes and instantaneous dashboard displays showing real-time miles-per-gallon readings help drivers save fuel by maintaining efficient speeds and avoiding traffic congestion. Similarly, network-connected GPS navigation systems can give instructions to a delivery truck driver on the shortest route to cover all of his deliveries. Public transit users benefit from real-time information on bus and train arrivals, for example, via smart phone applications that allow users to optimize their transportation routes and thus save time and remove a barrier to choosing a more efficient mode of transportation.

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[2] We use the term "real-time feedback" as a lay term. We understand that dealing with real-time feedback brings in issues of instrumentation and perceptional delays but we use the term here in the broad sense of "timely information."

2. Technology-Centered Efficiency (Automation and Optimization)

Activities in this category require human intervention at the design stage, with the day-to-day operation of the systems being coordinated nearly exclusively by carefully designed groups of technologies, for example, sensors, controls, computer simulation, and communications networks. Here, "smart" technologies remove much of the need for direct human intervention and finely orchestrate the operation of the systems' components to achieve efficiencies impossible to come by through human oversight alone.

BUILDINGS Building automation and control technologies have been around for decades—the thermostat, a simple example of closed-loop feedback control, was invented in the late 1800s to control furnace use based on a temperature set point—yet great potential remains for greater energy savings and increased comfort and control for building occupants through advanced intelligent technologies.

Today, "intelligent" control systems not only turn lights and heating, cooling, and ventilation systems on or off when needed, but can actively optimize those systems to provide lighting, air quality, and a set temperature with the lowest possible energy use depending on factors such as occupancy of the building or an individual room, variations in natural day lighting, and outside weather. Sensors and controls can also be used as diagnostic tools that measure systems and equipment to evaluate functionality, detect subpar performance, and correct it without human intervention. Many types of sensors are available to monitor and control building energy systems, including those that monitor occupancy, temperature, humidity, and carbon dioxide.

A 2005 analysis for the Department of Energy found that lighting occupancy sensors are in use in about 10% of commercial building floor space and that energy management systems serve about 33% of commercial building floor space (PNNL 2005). Although by 2012 these technologies have no doubt become more widespread, there remains great untapped potential. Recent research by the California Energy Commission on "adaptive corridors" found that hallway lights in commercial buildings are on 24 hours a day for safety purposes, but the hallways are vacant about 50% of the time. An occupancy-based, adaptive lighting system would improve efficiency dramatically. Such a system would include occupancy sensors, dimmable ballasts and sources, and a communication platform for the system components, and would deliver average energy savings of 73% (CEC 2011).

Building systems can also go beyond these levels of "intelligence" toward predictive management by taking advantage of real-time simulations that factor in weather forecasts and occupancy and can adjust building temperatures and lighting to anticipate changing demands throughout the day. For example, by monitoring security badge access information for a building as a proxy for the number of employees present, a heating, cooling, and ventilation system could be automatically adjusted to account for increased or decreased cooling/heating requirements.

MANUFACTURING In today's manufacturing sector, *intelligent efficiency* means integration. Process automation, enterprise resource planning, and energy management standards each represent a consolidation of information and practices that that allow more "intelligence" and control in industry. But more importantly, these trends are beginning to converge, pushing *intelligent efficiency* in manufacturing to new frontiers.

The manufacturing sector has been on the path of technology-centered *intelligent efficiency* for decades, dating back to the first widespread use of sensors and controls technologies in the 1980s. The technology gradually became less expensive and more sophisticated, allowing for increasingly complex automated feedback loops. In the 2000s, closed loop controls for support equipment such as boilers became common, allowing systems to optimize themselves as their environments changed, with little human interaction.

As experience with these controls increases, this technology will be further applied to manufacturing processes. While these processes, such as melting, machining and refining, are responsible for a large portion of energy consumption in industry, manufacturers are very risk averse when considering changes because these systems are directly responsible for the quality of the final product. In 2000, ACEEE released a report on emerging technologies in the industrial sector, and found that process sensors and controls could realize energy savings of 4-17% in certain applications (Elliott et al. 2000). Using those sensors and controls along with closed-loop feedback would increase their savings potential much more. Increased feedback and controls could also mean systems that can sense anomalies in a process, determine the source of the issue, and automatically correct it without intervention. This allows businesses to not only reduce energy use, but also increase product quality and plant safety.

Parallel to the development of sensors and controls, large companies began to use corporate data networks to manage the business side of their operations. In the 2000s, these data networks evolved into enterprise resource planning (ERP) systems, continuing a trend of tracking and internalizing more and more information about their businesses. ERP systems are used by companies to integrate key decision making criteria across multiple aspects of a business, including accounting and finance, human resources, and supply chain management, and energy costs. In the last few years, ERP systems have begun to incorporate more detailed energy usage information, allowing corporate managers greater insight into a cost (and opportunity) that often gets goes unnoticed.

Even more comprehensively, business management standards such as the ISO 9000 quality management standard began to take root in the 1990s, giving companies a rigorous method for tracking and improving product quality, safety, and environmental compliance in their own facilities and across supply chains. In 2011, the International Organization for Standardization (ISO) published ISO 50001, the first facility-level energy management standard. The emergence of energy tracking in enterprise resource planning systems will likely support the adoption of the ISO 50001 energy management standard, giving companies the systems and methods to both track energy performance and ensure continuous improvement in energy efficiency. This will eventually tie in with process systems inside the plant and supply chains outside the plant. "Intelligent" systems can help optimize the supply chain, bringing in raw materials on time and at the lowest cost, and organizing shipments to customers.

TRANSPORTATION In the transportation sector, there are two main types of technology-centered efficiency: within a vehicle's system, and between vehicles or between a vehicle and its surroundings. Within a vehicle, sensors and controls can enable higher fuel efficiency. For example, the recently proposed Corporate Average Fuel Economy (CAFÉ) rule includes several measures to achieve improved vehicle efficiency through electronic controls and system integration (Federal Register 2011). These include measures like variable valve timing, which alters the timing of valves to reduce pumping losses, and shift optimization, whereby the engine and/or transmission controls emulate a continuously variable transmission by continuously evaluating all possible gear options and thus let the engine run most efficiently.

Regarding communication between vehicles and their surroundings, there has been increasing research on "intelligent" transportation systems—the application of information and communication technologies and synergistic systems to transportation infrastructure and vehicles, with the goal of improving safety, efficiency, and reliability. Central to these transportation systems are global positioning systems, wireless communications between vehicles and receiving real-time traffic information, and traffic sensors. In the future cars may communicate both with roadside communication infrastructure as well as with each other. "Vehicle platooning," for example, is an innovative concept that would improve the safety, efficiency, mileage, and time of travel of vehicles.[3] Platooning makes use of information and communication technologies such as radio communication systems, radar, and magnets to automatically control the speed and distance between vehicles. The system makes it possible for a group of vehicles, such as military vehicle platoons, to travel together closely—with 21 feet of separation. Platooning, which is still in the research phase, may enable energy savings for fleets such as military vehicle platoons by optimizing the flow of traffic, improving fuel economy due to reduced air resistance, and decreasing traffic congestion.

ELECTRIC POWER Our electric power system has evolved for well over a century, with electric generators connected to a transmission and distribution system that delivers electricity to consumers. As these electricity networks have become more complex, they have become more difficult to manage (as evidenced by power outages, for example), and our planning has been limited by our ability to collect data on an ever-changing system and respond to unanticipated events that can destabilize it. At the same time, the demands of consumers have intensified, with new consumer electronics and equipment placing rapidly changing demands on systems in ways that could not have been envisioned when the network was designed. In addition, we now are seeking to make our electricity network a two-way street, with increasing deployment of distributed generation technologies on customer sites that connect to the system, such as solar and wind installations.

In response to these changing demands, the utility industry has embarked upon a modernization effort, usually referred to as the "smart grid" that makes use of an array of advanced electronic metering, communications, and control technologies. The goal of the modernized grid is to provide detailed information on electricity flow and system status to system operators, and ultimately to customers, that allows for precise control of the energy flow in the grid and the ability to deliver highly reliable electricity of a high quality to their customers. For example, because of increasing speed with which the grid conditions change and the treat of rapid propagation of instability, the hope is that sensors and controls will automatically isolate problems in the grid and trigger a localized solution with minimal human intervention, before the problem cascades into a system-wide power outage.

[3] For more information, see http://www.tech-faq.com/vehicle-platooning.html and http://www.sartre-project.eu/en/about/Sidor/default.aspx

3. Service-Oriented Efficiency (Dematerialization)

Service-oriented efficiency covers structural changes in our economy that cause shifts from material goods or services toward digital solutions and services. This is often referred to as dematerialization because the substitution leads to less material use. We have already experienced many examples of this in our economy, such as telecommuting, e-commerce, and digital entertainment. A large body of literature exists on these topics, and energy savings varies depending on the area. Generally, substitution with digitally enabled goods and services leads to net improvements in energy efficiency over traditional methods. In some cases, however, significant uncertainty exists around the potential improvements when the substitution uses varying (and sometimes increasing) amounts of energy itself.

TELECOMMUTING AND TELECONFERENCING Telecommuting, also known as teleworking or work shifting, has reduced vehicle miles traveled in the U.S., thereby saving energy and helping to alleviate traffic congestion during peak periods (see for example, Choo and Mokhtarian 2005). States and local governments can encourage telecommuting by creating incentives for employees to pursue alternatives to driving. For example, in Washington State, the Commute Trip Reduction law resulted in new employer incentive programs at more than 1,000 places of work statewide and in 2009 removed 28,000 vehicles from the road each workday morning (WSDOT 2011). Teleconferencing—or video conferencing—can create further savings by enabling colleagues to conduct business meetings from the other side of a city, state, or country, or even from other continents, replacing the need for fuel-intensive travel.

E-COMMERCE Purchasing goods through the Internet—or e-commerce—could lead to energy savings by reducing customer miles traveled to and from stores and by reducing warehouse energy needs. While some recent analyses have demonstrated the real potential for energy savings through e-commerce in specific and limited examples, further research is still needed to understand the net benefit of e-commerce on energy consumption.

As an example, a lifecycle analysis of purchasing flash drives on Buy.com versus traditional retail stores finds that e-commerce has a net energy reduction (35%) over the traditional retail store model; however, significant uncertainty exists in many parameters of the analysis (Weber et al. 2008). The analysis found that customer transportation energy use to a retail store is the highest energy share (65%) for the traditional retail store category. This implies that in some cases location efficiency—consumers living closer to various destinations including shopping—could offset the marginal benefits of e-commerce. The highest categories of energy usage for the e-commerce option were from last-mile delivery to customer homes (32%), wholesale warehousing (31%), and cardboard individual packaging (22%).

In another example, the e-commerce alternative for a DVD purchase consumed 33% less energy and emitted 40% less CO2 than the traditional option of driving to a video store (Sivaraman et al. 2007). The packaging was responsible for 67% of the difference in total energy consumption of the two alternatives, and the mode of transportation used by the consumer significantly affected energy consumption.

DIGITAL ENTERTAINMENT The substitution of material-based entertainment (e.g., CDs, DVDs, and print books) with digital forms (e.g., digital music, movies, and e-books) has become very common in recent years. In these cases, the potential energy savings stem from the substitution toward "moving bits instead of atoms."

Although streaming digital music or purchasing it digitally from the Internet uses more energy than does the purchase of a CD, purchasing a music album digitally generally reduces the energy use and CO2 emissions 40-80% compared to buying a CD, depending on whether or not the person burns the digital files to CD (Weber, Koomey, and Matthews 2009). The main sources of energy savings comes from the elimination of the CD itself and CD packaging and the avoided energy use associated with delivering the CD to the home. Although there are scenarios in which the acquisition of digital music used more energy than traditional delivery methods, for example, when a customer walks to the store, in general digital music use requires less energy than in-store CD purchases.

CAR- AND BIKE-SHARE PROGRAMS Car- and bike-sharing programs are examples of both service-based and people-centered *intelligent efficiency*. Consumers can shift from owning vehicles to sharing a vehicle—or bike—to provide their transportation needs. And, real-time smart phone applications inform consumers about where and when the cars and bikes are available, allowing people to plan their trips to minimize travel time and avoid system disruptions. Other features such as instant reservations dramatically increase appeal of these programs for large numbers of people. In car-sharing, potential energy savings come from reduced car ownership, as consumers choose to replace the fixed costs of owning a car with the variable costs of participating in the program. Car sharing has grown considerably during the past ten years, and a recent survey of active users found that average vehicles per household decreased from 0.47 to 0.24 after signing up for car sharing (Martin, Shaheen, and Lidicker 2010). Most of this shift occurs because of one-car households becoming no-car households. Car sharing helps people to drive only when needed, and to use alternative transportation such as mass transit, biking, carpooling, or walking more than they would if they owned a car.

Scaling Up Intelligent and the Network Effect

Together, all types of *intelligent efficiency* enable more integrated, smarter, and more reliable infrastructure, such as smart power grids, smart cities, intelligent transportation systems, and smart communications networks. For example as buildings become increasingly networked and grid-connected, they play a crucial role in the development of "smart" cities that integrate resource management and information technology at the community level. The Envision Charlotte case study is an example of how this concept is beginning to emerge at the community level. As the types of *intelligent efficiency* become more integrated across our infrastructure, the potential savings become much greater than the sum of the individual parts.

While *intelligent efficiency* has already begun to yield significant energy savings benefits as demonstrated in the case studies in this report, the full impact has yet to be realized. Solutions have typically been adopted in discrete areas or sectors rather than throughout the economy as whole. An integrated, cross-cutting system, however, can scale up intelligent efficiency and yield much greater savings than can incremental measures in discrete sectors. This phenomenon is the "network effect."

In economics, the network effect occurs when the value of a good or service is dependent on the number of users of that good or service, i.e., consumer find it more attractive to use the product because the fact of the other users use of the good or services make it more functional (see Katz and Shapiro 1985 & 1994). Telephones and online social networks are classic examples of the network effect, because the more people using these products, the greater the benefits. Negative effects can also emerge from the network effect, such as greater demand resulting in traffic congestion.

Many types of *intelligent efficiency* will benefit from the network effect. For example, smart phone "energy apps" could benefit from the network effect, as could car-sharing programs. Similarly, looking at a building or a plant as a system creates opportunities for co-optimization that exceed the sum of the savings from the optimization of the component systems. Many of these implementations of "intelligence" are not solely focused on energy, and they manage systems to optimize them for an array of benefits. IBM's project to bring city-wide control of energy consumption to Rio de Janeiro is an example of where we could go, with the system enabling optimization of energy use in buildings (Singer 2012). As we expand our system perspective, we expand our opportunities for greater network effect from *intelligent efficiency*.

EVOLUTION OF EFFICIENCY TOWARD GREATER "INTELLIGENCE"

Below we present a time line to demonstrate historical patterns of adoption of intelligence, and how those have evolved up until today, and present a vision for future opportunities. We examine examples: enabling infrastructure, transportation, industry, buildings, appliances (specifically refrigerators), and electricity generation and highlight major milestones. In the buildings example, the time line starts at the early 1900s, when thermostats were first used as closed-loop controllers, and indicates how in the 1980s energy management systems began to use direct digital controls to automatically manage heating, cooling, and lighting systems. Over the past 15 years, energy management systems have become common in large commercial buildings. Today, wireless sensors are being deployed, and over the next 5-10 years we expect to see more tenant energy management systems and greater usage of predictive analysis to anticipate occupancy or weather and controlling building energy systems based on those analyses.

Barriers to Widespread Adoption of Intelligent Efficiency

While examples of *intelligent efficiency* technologies and applications can already be found, particularly in certain sectors of the economy, we are far from widespread adoption and integration. Many barriers have prevented or may prevent future widespread adoption, with different barriers existing for or being perceived by different end users, providers, and institutions. Several common barriers are:

Table 1. Evolution of Efficiency towards Greater Intelligence: Examples by Sector

Sector	Earlier	Past 10 – 15 years (2000s)	Current (2012)	Near Term(~2015)	Long Term (~2020)
Enabling	1990s: Internet	High-speed internet	~50% of homes on high speed internet		>90% of homes on high speed internet
Transportation		• First hybrid sales in U.S. (1999), with regen braking, optimized engine, real-time fuel economy read-out; • Sensors to monitor traffic flow	• New electric vehicles (EVs) (Volt, Leaf); • Charging during off-peak times	• Smart charging when there's excess due to wind and renewables; • Grid regulation with plugged-in cars as spinning reserve	• EVs reach 3%; • Car batteries as grid storage
Industry	• 1980s: Sensors & controls offer basic feedback • 1990s: Company-wide data networks	• Process simulation, limited closed-loop control • Enterprise Resource Planning (ERP) starts to include energy management	• ERP begins to integrate process energy & simulations • Early supply chain energy management	• Energy fully integrated into ERP • Process-wide closed loop control	• Extension of energy ERP integration through supply chain
Buildings	• Early 1900s: Thermostats used as closed-loop controller • 1980s: Energy management systems (EMS) using direct digital controls (DDC)	• EMS are common in large commercial buildings (~33% of floor space); • Lighting occupancy sensors serve ~10% of building floor space; • Still a lot of master metered buildings	• Wireless sensors start to be deployed; • modulating control equipment going mainstream	• Owners see and report energy use, i.e. tenant energy management systems; • shift from central air systems to more efficient hydronic and VRF systems	• Most new, large commercial buildings "smart" • Predictive analytics
Appliances (Refrigerator example)	• More/better insulation • Better compressors • Improved door gaskets	• Continued insulation and compressor improvements • Adaptive defrost controls	• Variable speed compressors and fans • Electronic expansion valves • Variable anti-sweat heaters	• "Smart" appliances (connect to the grid and home information systems)	• Advanced "smart" features
Electricity Generation	• Regional power grid integration with economic dispatch • Regulatory changes allow "non-utility generation"		• Smart grid pilot projects • Demand response programs	• Smart meters ~ 50% deployment • Demand response 2.0 • Weather response systems	• More small generating plants, on-site renewable energy and CHP; • Widespread smart meter deployment

Social

- *Awareness.* Consumers and businesses are often unaware of *intelligent efficiency* opportunities and their energy-savings benefits.
- *Uneasiness with new technologies.* Consumers face learning curves to become proficient with new *intelligent efficiency* systems.
- *Complexity*. Applying a systems approach to energy savings through *intelligent efficiency* can be complex and challenging. There is a great need for "plug and play" tools that are easy to use.
- *Risk aversion*. End users, as a group, are risk averse, and often prefer the status quo to investments that are perceived as uncertain.
- *Values.* Consumers and businesses do not yet have a strong value proposition either in cost, lifestyle, or business benefits from *intelligent efficiency*.

Financial

- *Upfront costs.* While *intelligent efficiency* can offer long-term benefits in lower energy consumption and savings on energy bills, consumers and businesses generally have to make upfront investments to generate those savings.
- *Split incentives*. Whereas landlords of multi-family buildings or commercial office buildings bear the cost of installing new equipment, generally the tenants accrue the financial benefits of energy savings. The owners in this case have limited incentives to make energy efficiency upgrades.

Structural

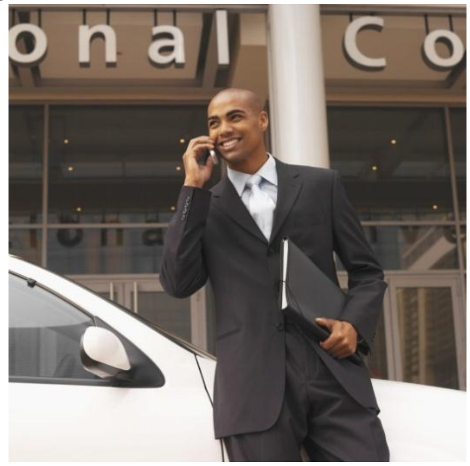
- *Lack of skilled workforce to manage energy.* In manufacturing facilities and building operations, the current workforce often is not equipped with skills to manage energy usage using *intelligent efficiency* applications.
- *Lack of Informational Tools.* Available data often is not organized in a way that translates easily to a user in a way that facilitates behavior change.
- *Shortage of data on measurable benefits*. Consumers and program implementers are concerned about the ability to validate the results and benefits of these complex systems
- *Privacy.* Some consumers have concern that *intelligent efficiency* systems in their home or business, such as smart meters with two-way communication, can provide open access to their energy usage or other sensitive data.

Barriers by Stakeholder

Different stakeholders face different barriers when it comes to understanding, advocating for, feeling safe with, designing, and implementing *intelligent efficiency* measures. Likewise, different stakeholders stand to benefit in distinct ways.

Stakeholder: Owen, Senior Manager with Commercial Building Owner/Investment Firm

Owen oversees a team of building managers for several commercial properties, most of which are over 20 years old, in a large metropolitan area. His salary and bonus are tied to increasing the net operating income from the buildings, as well as retaining tenants. He is also evaluated on occupancy rates and how quickly he can attract new tenants to unoccupied space. The standard leases do not cover utilities, and several of his tenants have recently moved to newer, competing buildings where utilities are paid, in part to reduce their utility expenses and in part for the marketing clout they obtain from working in "green" buildings. Recently, the international conglomerate for which he works has made a public commitment to monitor and report carbon emissions for their buildings.



Barriers

1. **Split Incentives**. While Owen's firm will bear the cost of installing new equipment, his tenants will accrue the majority of the financial savings.
2. **Costly Retrofits.** It is much more difficult and costly to install sensors, networks, dashboards, and other technologies in older buildings.
3. **Staff Training.** The dozens of maintenance staff and building managers will need to be retrained to maintain tenant comfort with the new systems.
4. **Tenant Disruptions**. Owen's tenants include physicians, financial services firms, and others with a low tolerance for service disruptions of any kind or frequency.
5. **Existing Leases.** Existing leases have standard, approved language and were written prior to the introduction of ICT-enabled technologies. They will have to be reworked to account for the benefits and risks inherent in such technologies.

Benefits[4]

1. **Lower Utility Bills.** Utility expenses will be considerably lower because of greater efficiencies in energy and water usage.
2. **Lower Operating Costs.** Building operations budgets will also decrease, as a result of lower maintenance and repair costs because smart system anticipate maintenance problems and allow them to be repair before they fail.
3. **Higher Rental Income.** Increased rent and higher occupancy due to the enhanced value that tenants place on updated services.
4. **Higher Revenue from New Services Offered.** Owen's company will see additional income from new tenant service offerings, such as chilled water and emergency power.
5. **New Benefits.** The upgrades will provide an opportunity to renegotiation of existing lease terms before they expire.

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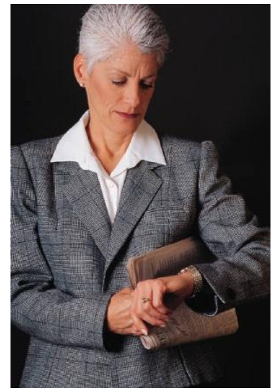
[4] Benefits 1-4 quoted from (Jones Lang LaSalle 20XX) case study "A landmark sustainability program for the Empire State Building", p. 3.

Stakeholder: Nancy, National Government Official



Nancy is an appointed official for a federal agency. As a law school graduate, she is very comfortable with complex technical topics. However, she has limited time and numerous responsibilities, so she cannot devote exclusive attention to any one area. She is frequently visited by lobbyists from the utility industry and spends part of each week defending her job, and her team, from political interference. She is measured primarily on her ability to keep the status quo humming along smoothly, though she is keenly interested in helping to set the stage for the future. She would like to differentiate herself from her predecessors and establish a vision for the next decade and beyond.

Barriers

1. **Clarity of Authority and Scope**. Given that *intelligent efficiency* technologies for energy efficiency touch communications, information, interstate commerce, energy, workforce development, and many other topics, Nancy is not sure that her agency has a clear mandate to take action.
2. **Lack of Data**. Nancy needs to justify any decisions that she makes, and she has not seen any research with clear "calls to action" for *intelligent efficiency* policies.
3. **Lack of a "Burning Platform."** Nancy has seen no clear messaging or positioning document that will help persuade her or her colleagues that this is an issue calling for high prioritization.
4. **Lack of a Price on Carbon.** Nancy is convinced that if her constituents had to pay for the true costs of fossil fuels, including but not limited to carbon emissions, that the business case for *intelligent efficiency* approaches would be much stronger. However, previous efforts at putting a price on carbon have failed.
5. **Spending Freezes.** Nancy's colleagues perceive that any support of *intelligent efficiency* will require additional funding, which will not be forthcoming for several years.

Benefits

1. **Bipartisan.** Nancy believes that, if positioned properly, *intelligent efficiency* can be an issue that receives support from both major parties.
2. **Jobs Potential.** Nancy is very familiar with how the Internet boom created new types of employment that had not existed before. She believes that a wave of development in information and communication technologies could bring similar jobs benefits, though she does not have hard data to support this.
3. **Global Competitiveness.** Nancy is aware that competing countries have invested heavily in such technologies, and she believes that if the United States demonstrates a similar commitment, it can maintain its competitive edge on the world stage
4. **Reliability and Security.** Full and effective use of information and communication technologies for energy efficiency has the potential to solve several related concerns of interest to Nancy—supply, reliability, security, and rate payer equity.

Stakeholder: Ed, Electric Utility Executive

Ed worked his way into his executive role as an engineer. He is very technically focused and enjoys working on new construction projects. He is risk averse, and his annual performance rating and bonus are aligned to bringing new capacity online while minimizing downtime; he is driven to ensure that power generation is very reliable. He is accustomed to rapid demand growth and is used to being rewarded for building things that respond to that growth. Ed views energy-efficiency programs primarily as a customer service initiative, though he is very concerned about the utility's need to minimize peak demand times. He has followed with interest the developments in "Critical Infrastructure Protection" standards from the North American Electric Reliability Corporation, as several conferences that he's attended had case studies regarding hackers and vulnerabilities in utility infrastructure.

Barriers

1. **Uncertainty in Profit.** Ed is concerned about potential for return on investment in *intelligent efficiency* initiatives traditional capital investments. He does not see the potential for profit through such programs.
2. **Security Concerns.** As Ed's facility becomes more and more automated, the potential for an outside person to intentionally or accidentally interrupt the operation increases.
3. **Deficient Staff Skill Sets.** Previously, Ed's success was based on expertise with legacy equipment and mechanical components. Increasingly, his success will be determined through skills with software and electrical engineering, and he will have to change his hiring practices to help manage this trend.
4. **Threat of Lost Revenue.** Ed perceives a threat of lost revenue if energy efficiency programs reduce overall electricity use.
5. **Validation of Results.** Ed is concerned about the ability to validate the real savings that are promised with these complex systems.

Benefits

1. **Reliability.** There is a serious need to reduce and smooth peak demand. *Intelligent efficiency* technologies can automate this capability and reduce the management headaches of this previously labor-intensive process.
2. **New Investment Opportunities.** *Intelligent efficiency* programs provide new avenues for investment and development.
3. **Expanded Customer Base.** A fully connected and "intelligent" grid will allow Ed's regional employer to sell energy farther afield, to previously inaccessible markets.
4. **Enhanced Customer Service**. The utility would be able to deliver greater service reliably to customers with increasingly demanding requirements and respond to their evolving needs for electricity that helps the customer thrive.

Stakeholder: Sam, Resident, Single-Family Home

Sam is a retired contractor from the Midwest. He enjoys using his hot tub, watching television, and playing golf. Sam is uncomfortable using computers and goes online only with the help of his grandchildren; he drives approximately four hours each way once a month to visit them. He strongly values his privacy and is suspicious about revealing any personal data on the Web. He is on a "budget billing" program from his utility and is aware of his energy use only in aggregate. Small peaks and valleys of use throughout the year are invisible to him. He lives on a fixed income and spends a lot of time hunting for bargains. Sam is passionately patriotic and moderately politically active, voting regularly in national elections and locally only for "hot button" issues. As a former military man, he is particularly interested in issues of national security.

Barriers

1. **Threats to his Independence.** Sam is concerned that the utility will take control over his lifestyle decisions, such as when or if he can use his hot tub or even wash his clothes.
2. **Upfront Costs.** Sam has heard that these new meters cost several hundred dollars each, and they'll be paid for out of his electric bill.
3. **Privacy Concerns.** Sam has heard about "smart meters" and is concerned that they can be used to track what he is watching on television, what he is doing, or when he is at home or away.
4. **Discomfort with New Technologies.** Whether Sam's use of *intelligent efficiency* includes "smart" transportation systems, transportation substitution such as video conferences or energy dashboards for his home, Sam faces a learning curve in becoming proficient with the new technologies.

Benefits

1. **Independence.** Effective use of information and communication technologies to reduce overall energy use in Sam's community can reduce dependence on non-domestic fossil fuels.
2. **Lower Utility Bills and Greater Financial Security.** By minimizing energy use in both his home and transportation decisions, Sam's dollars can stretch farther and enhance his financial security.
3. **Strong and Safer Community.** The same technologies that monitor his energy use can alert family members, or other individuals that Sam selects, to unusual patterns. For example, if his hot tub is drawing power while he is out of town, his son can be alerted and know to check on the property.

Stakeholder: Paul, Plant Manager

Paul manages and oversees the plant operations for a pharmaceutical factory, including finance, manufacturing, manufacturing engineering, materials, quality assurance/control, human resources, and information systems. He expects his staff to make recommendations to improve productivity, quality, and efficiency. Paul has a bachelor's degree in chemical engineering and three decades of experience in the field. He reports to the corporate headquarters in another state, and his performance is judged primarily by his ability to meet production schedules within budget while simultaneously controlling risks such as safety concerns within the pharmaceutical plant. He will lose his bonus if production goes down for more than 12 hours in any given quarter. Any capital equipment investments that he requests must have a return on investment of two years or less.

Barriers

1. **Security and Safety Concerns.** Paul is held responsible for the safety and quality of the pharmaceuticals leaving his facility. Changes in condition, including heat, light, or temperature, can change the drug quality. He is very nervous about installing an interconnected system that might open his production to previously unknown variables.
2. **Insufficient Infrastructure.** Most of the equipment in Paul's plant is more than 15 years old. He has no meters or any other devices to measure system energy use, and he has no ability to track where energy is used. This makes it difficult for him to identify and justify projects, even if they will likely save energy.
3. **Upfront Costs.** He does not have access to sufficient capital. Though Paul's local government has a revolving loan program to help him buy energy-efficient equipment, the firm's outstanding loans and the administrative complexity preclude him from taking advantage of these incentives.
4. **Lack of a Skilled Workforce.** Paul's engineers were hired because they were good at managing processes, or packaging lines, or logistics. None of them has received any training in energy management.

Benefits

1. **Early Detection of Malfunctions.** The same technologies that permit real-time energy management can alert operators to impending problems or process abnormalities that could interfere with production time tables.
2. **Lower Maintenance Costs.** Improved maintenance of plant assets result in reduced maintenance costs and lower total cost of ownership for equipment.
3. **Higher Profits.** Advanced control systems can tightly control Paul's energy use and also better control his production. He is pleased to learn that others in his line of business have realized greater yields and improved product quality through the application of such systems.

The Benefits of Intelligent Efficiency

Intelligent efficiency is an enormously beneficial strategy for saving energy and maintaining a strong economy into a future constrained by scarce and uncertain resources. The benefits fall into categories: direct benefits from the avoidance of energy use due to greater efficiency; the non-energy benefits that stem from system optimization, including better services; and the economic benefits of more effectively using money that would otherwise go to energy bills.

DIRECT ENERGY SAVINGS

Recent long-term studies have suggested major energy savings potential in the U.S. from efficiency, on the order of 40-60% reductions in total energy use by 2050 (Laitner et al. 2012 and RMI 2011). *Intelligent efficiency* is a critical tool in enabling this large savings potential. Overall, energy efficiency has been shown to be among the lowest energy resource costs available in the marketplace (Friedrich et al. 2009). Below we review several recent studies that attempt to quantify energy savings potential from specific elements of intelligent efficiency. Also, the case studies included in this report provide a glimpse into the potential energy savings from specific types of intelligent efficiency measures.

Meta-Review of Studies

Intelligent efficiency is a new way to characterize a systems-based approach to energy efficiency, and therefore no recent analyses have addressed potential energy savings from *intelligent efficiency* in its totality directly. *Intelligent efficiency,* however, relies on a range of technologies, many of them information and communication technologies, that have been examined from many different directions, including energy savings, carbon emissions reductions, and economic productivity. Among these technologies that enable *intelligent efficiency* are: semiconductors, sensors, controls, information and communications technologies, software, and computer simulations. To provide a sense of the potential energy savings available from *intelligent efficiency*, we looked at projections of the energy savings resulting from these enabling technologies.

Advances in semiconductor devices[5], which are a basic component of many of the technologies that enable *intelligent efficiency,* enable other technologies to operate more efficiently and perform energy-savings tasks. Increases in semiconductor efficiency, along with the technologies they enable (such as variable-speed motors, GPS routing, and a "smart" electric grid) could save the United States 650 billion kWh by 2020 (ACEEE 2009). That 17% reduction from the baseline electricity use in 2020 could increase to 27% by 2030.

Beyond semiconductors, information and communications technologies have been widely promoted as an energy saver. Studies looking at information and communication technologies are very broad, and include both enabling technologies, such as high-speed Internet, and *intelligent efficiency* solutions, such as advanced manufacturing processes. Several studies examine the potential energy savings and policy

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[5] Semiconductor devices, also known as solid-state devices are the technologies that enable modern electronic devices from computers to televisions to many industrial processes.

recommendations for ICT-enabled energy efficiency. A World Wildlife Fund (WWF 2008) report collected data from numerous other studies, breaking the savings down by sector (Table 1), with an estimated total energy savings of about 12% by 2030.

Table 1: Information and Communication Technology Savings Potential for Selected End Uses (WWF 2008)

Sector/End Use	Savings Potential
Existing Buildings	6%
New Buildings	15%
Urban Planning	5%
Telecommuting	15%
Virtual Meetings	20%
Vehicle Technologies	15%
Transportation Mode Switching	18%
Freight Management	30%
E-Commerce	10%
Product De-Materialization	30%
Production/Process De-Materialization	5%
Industrial/Manufacturing	10%
Total:	**12%**

A 2007 report by American Consumer Institute Center for Citizen Research found that widespread adoption of high-speed Internet and related services could reduce greenhouse gas emissions by 1 billion tons over ten years (similar to the above 2008 WWF report), the equivalent of nearly 1.5 million barrels of oil per day.

The Global e-Sustainability Initiative's (GeSI) 2008 report found that solutions based on information and communication technologies could reduce greenhouse gas emissions by 13-22% from business-as-usual projections by 2020, including energy and fuel savings of $140-240 billion dollars.

The Carbon Disclosure Project's 2011 study on cloud computing estimates energy savings of $12.3 billion by 2020, representing roughly 0.3% of estimated 2020 electricity consumption.

One of the most widely cited and influential studies discussing the energy efficiency of the U.S. economy is the 2009 study by McKinsey (McKinsey 2009). While the report doesn't specifically highlight *intelligent efficiency* enabling technologies, it does provide a useful point of reference by offering a context for the energy savings from ICT and *intelligent efficiency*. According to the study, the United States could reduce its non-transportation energy by 23% by 2020, saving $1.2 trillion dollars in the process.

Looking at individual sectors, an ACEEE study on industrial emerging technologies (Elliott et al. 2000) projected that one suite of enabling technologies, process sensors and controls could save 4-17% of the energy in industrial processes. Looking at the residential sector, another ACEEE study (Ehrhardt-Martinez, Donnelly and Laitner 2010) found that advanced electric metering and feedback systems have the potential reduce individual household electricity consumption by 4-12%.

The enabling resources for intelligent efficiency, such as information and communications technologies (ICT) have been demonstrated to have significant net benefit. An ACEEE report determined that for every kilowatt-hour consumed by ICT systems, a savings of 10 kilowatt-hours were enabled elsewhere in the economy (Laitner 2008). Similarly, another study (GeSI 2008) estimates that in a business-as-usual scenario ICT will enable over *five times* the emissions reductions 2002 to 2020 of any emissions increase resulting from ICT.

These studies show the great potential for information and communication technologies, as well as other factors that enable *intelligent efficiency*. Just by taking advantage of the currently available technologies outlined in the above examples, the United States could reduce its energy use by 12-22% and realize tens if not hundreds of billions of dollars in energy savings and productivity gains. These consumption and demand reductions also offer the prospect of reducing future energy prices for all consumers by avoiding the need for future energy infrastructure investments (Elliott, Gold and Hayes 2011). Also, an *intelligent efficiency* approach will include even greater savings by using a wider array of new technologies and employing a system-wide optimization approach to maximize the savings. These individual saving will likely be amplified through the network effects discussed earlier in the report. *Intelligent efficiency* could thus likely increase the total energy savings potential of the United States significantly beyond what is possible just through the enabling technologies listed above alone.

The Energy Used by Information and Communication Technologies

The savings potential from *intelligent efficiency* is significant, but it is also important to recognize that the enabling resources for intelligent efficiency, such as information and communications technologies (ICT), also directly use energy. While direct energy usage by the ICT sector may appear to run somewhat counter to the goals of efficiency, the amount of direct energy usage is minimal compared to the large-scale energy savings gains. A 2008 report estimates that in a business-as-usual scenario the information and communications sector will triple its carbon footprint from 2002 to 2020, but that increase in deployment will enable over *five times* that in emissions reductions (GeSI 2008). Further, an ACEEE report determined that for every kilowatt-hour consumed by ICT systems, a savings of ten kilowatt-hours are enabled elsewhere (Laitner 2008). So while tracking the energy consumption of new technologies is important to get a full view of the net energy saved, evidence suggests that the energy savings will greatly offset the energy required by these technologies.

NON-ENERGY BENEFITS FROM SYSTEM OPTIMIZATION

The benefits of energy savings from *intelligent efficiency* include direct reductions in energy bills for consumers complemented by other non-energy "co-benefits" such as increased comfort, quality of life, productivity, and product quality. Technologies that enable energy savings will also enable more efficient use of raw materials, people's time, and capital assets. They often make existing tasks easier and open up possibilities to provide new services.

Industry

In industry, where wasted energy can make a job unpleasant or even dangerous, less waste heat in a manufacturing process can mean a more comfortable and safer work environment. Intelligent process management systems that control plant utilities, such as compressed air and steam, will not only save energy by operating at lower pressures, but can also make plants safer. An integrated supply chain enabled by real-time communications between company Enterprise Resource Planning (ERP) systems will pull raw materials from mining and agriculture through manufacturing to the retail stores. This coordinated relationship will improve the financial stability of each organization and ultimately result in a better value for the consumer.

Transportation

While many delivery companies already save fuel by efficiently routing their vehicles, the next step of integrating information on route congestion will help drivers to avoid traffic jams and to become even more time efficient, i.e. productive. It is reasonable to expect that this will result in less stress for drivers, fewer accidents, and even lower staff turnover. Transportation freight companies will be able to increase asset utilization by more effectively finding customers on both ends of a round trip to thereby more fully load containers. Better asset utilization will result in fewer trucks on the road, boxcars on the rails, and containers on ships.

For personal transportation, driving will also be safer as cars will be able to monitor the driving of all the surrounding cars, be aware of any congestion or hazardous driving conditions ahead, and use this information to alert drivers to unseen dangers and congestion. Information tools could also guide drivers to the nearest parking space. These tools can mean less time on the road and result in major productivity gains.

Buildings

In the commercial and institutional sectors, buildings will function better and be more comfortable for occupants. Anyone who has worked in a large office environment or attended events in a conference facility is keenly aware of the inability of most current HVAC systems to maintain a stable temperature. Some areas are too hot while others are too cold, or they fluctuate between the two extremes. The problem is that current systems are reactive and thus unable to keep up with changing conditions. They do not, without human intervention, make the adjustments necessary to keep occupants comfortable. New, intelligent, systems can operate and anticipate as if controlled by a person with full knowledge of all variables including the weather, room occupancy, amount of heat given off by office equipment, and even whether doors will be kept open or closed.

Intelligent buildings mean that occupants will not have to wear layers of clothes to a conference, place a space heater under a desk, or put obstacles in front of blowers because the HVAC system overcompensates. Buildings will instead automatically respond to the dynamic conditions and occupants, and even anticipate upcoming conditions, rather than adjust periodically to arbitrary set points made by the person with command of the thermostat. Similarly in the residential sector, homeowners and apartment renters won't have to readjust their programmable thermostat if they come home early or leave the house early because the intelligent system will know when they are home and adjust the temperature accordingly.

ECONOMIC BENEFITS

The benefits of *intelligent efficiency* go far beyond direct, user savings. The expanded deployment of *intelligent efficiency* will also increase economic productivity and job creation. These economic benefits transcend the amount of money saved through lower energy usage, and rest on how the money saved is ultimately spent. Money saved through energy efficiency moves consumer spending from the energy utility sector to other sectors of the economy that are much more labor intensive. For example, whereas $1 million spent on energy bills supports about ten jobs, if that money were spread throughout the economy it could support more than 17 jobs[6] (ACEEE 2011). Because savings from energy efficiency tend to last for a long time (often more than a decade) with new savings every year, the trend of increased jobs tends to be sustained. Because of this, jobs induced through energy efficiency tend to dwarf any changes in net jobs due to an initial investment.

An initial investment can sometimes have a large impact on employment, however. For example, a 2009 research report estimates that by investing in information network infrastructure, the United States could create over half a million jobs (ITIF 2009). The $30 billion investment would improve broadband access, expand healthcare information technology, and increase the volume of information that can travel over the electrical grid. The study focused on the direct job impacts of investments, but these efforts would continue to sustain jobs through energy savings, and as an added benefit would generate better services to consumers.

When looked at through a narrow lens, productivity benefits that accompany information and communication technologies and *intelligent efficiency* may sometimes appear to lead to a decrease in number of total jobs. But this accounting is mistaken. While it is sometimes the case that easier, technology-assisted access to information can lead to the elimination of certain jobs in some sectors of the economy, this access to information is often accompanied by greater overall economic activity, which leads to more jobs being created (MGI 2011a). Not only would rising productivity coincide with increased employment, but productivity would actually be a primary driver for the increased economic activity responsible for new employment. For every job directly lost, research suggests that the Internet is responsible for creating 2.6 jobs (MGI 2011b).

Case Studies of Intelligent Efficiency

Intelligent efficiency can seem abstract. We provide ten case studies of how *intelligent efficiency* is emerging in different sectors of the economy and is being implemented at different system levels, from the smartening of residential appliances to the plant-wide optimization and urban sustainability cases that hint at the impacts that *intelligent efficiency* will have once it is brought to scale at the broadest level.

[6] This is a simple explanation of how energy efficiency creates jobs. For more detail, please see http://www.aceee.org/files/pdf/fact-sheet/ee-job-creation.pdf

Residential Refrigerator Case Study: Smart Controls, Links to Electric Grid

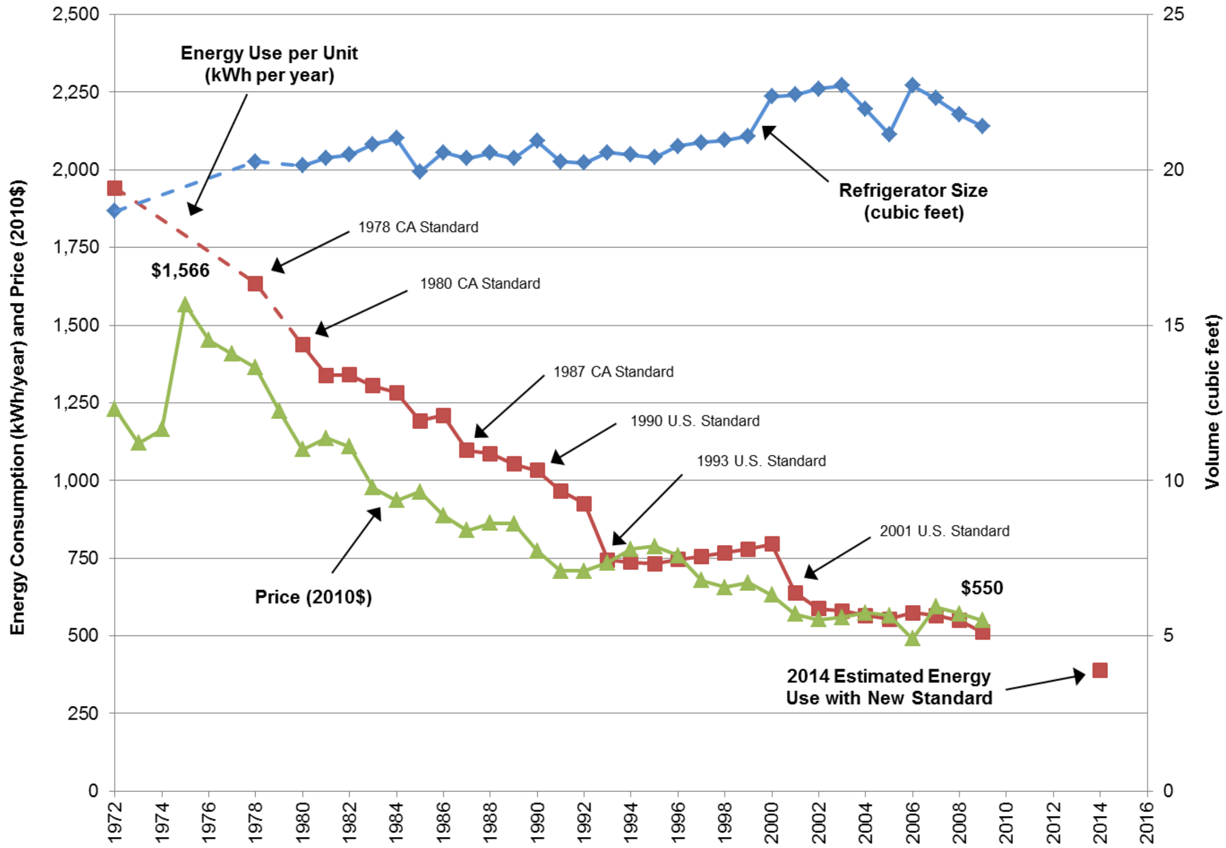
Home appliances are increasingly making use of *intelligent efficiency* to improve efficiency levels, for example, through smart controls and communication technologies. In this case, to meet upcoming federal efficiency standards for residential refrigerators, some products are making use of technologies such as variable-speed compressors and fans using sensors and controls to optimize operation. And looking forward, so called smart appliances that include communications connections with the grid will enable refrigerators to receive an external signal such as upcoming electricity prices and adjust operations in response. These technologies will open expansive opportunities for energy savings.

Residential refrigerator energy use peaked in 1975 (Geller and Goldstein 1998) and has been declining steadily since then, as shown in the chart below. These efficiency increases have been driven by progressively stronger state and federal minimum efficiency programs, energy efficiency programs such as Energy Star and utility incentives, and higher energy prices for consumers. From a technical point of view, early efficiency gains were largely driven by a shift from fiberglass to foam insulation, improved foam insulation formulations, improved door gaskets, and better compressors.

To meet the 2001 federal efficiency standard, manufacturers began to employ "adaptive defrost," a system in which sensors detect the build-up of frost and operate the defrost cycle when frost reaches a level that impacts efficiency. Prior to adaptive defrost, most defrost cycles worked on a time clock, typically cycling on every 24 hours. According to a U.S. Department of Energy (DOE) analysis, "adaptive defrost" typically reduces refrigerator energy use by 3-4% (DOE 2011). In August, 2011, DOE issued a new federal refrigerator efficiency standard that will take effect in 2014. For the most popular product classes (units with a top-mount freezer or side-by-side configuration), the new standard reduces energy use by about 25% relative to the 2001 federal standard. To meet these efficiency levels, some refrigerators will use smarter technologies such as variable-speed compressors, variable-speed fans, electronically controlled refrigerant expansion values, and variable anti-sweat heaters, technologies that use sensors to adjust speed or other parameters in order to optimize energy-efficient operation (DOE 2011).

Looking forward, there is growing interest in these smart appliances, units that receive an external signal the utility and adjust operations in response to that signal (e.g., temporarily turn off certain components in response to peak demand signals from a utility) and that can transmit information from the appliance to users or other applications such as smart phones. For example, Pacific Northwest National Laboratory examined some of the benefits of "smart" refrigerators and determined that across different electricity grids, electricity savings are greater than the costs required to implement capability (Sastry et al. 2010). And in November 2011, the U.S. Environmental Protection Agency (EPA) proposed to provide a 5% energy use credit in its new Energy Star specification for "connected" refrigerators, in order to help jump start the market for smart appliances. "Connected" includes communication connections to the grid as well as information flowing from the appliance to the consumer without need for a grid connection (EPA 2011).

Figure 3. Average Household Refrigerator Energy Use, Price and Volume over Time



Source: Lowenberger et al. 2012

EXISTING BUILDING CASE STUDY: TENANT ENERGY MANAGEMENT SYSTEM BY JOHNSON CONTROLS[7]

The tenant energy management system, which is being used for the first time in the Empire State Building, was developed by Johnson Controls, provides tenants with an online micro-website and dashboard dedicated to helping them track and manage their energy use. This system includes information collected from on-site electricity meters and sensor in the office space. This information is used to calculate and display key performance indicators and metrics for tenants, such as energy consumption per square foot and energy consumed per occupied hour. Eventually, tenants will be able to visualize and track their energy use and will be able to compare energy consumption and demand on an hourly, daily, weekly, monthly, and yearly basis.

This system supports benchmarking of energy performance to inform and encourage energy-saving behavior from tenants. The benchmarking program allows tenants to opt into a group of similar tenants (e.g., accounting firms) so that they can compare their percentile efficiency ranking within the group. Tenants can challenge their employees to improve their efficiency and improve their efficiency ranking.

[7] Conversation with Clay Nesler, Johnson Controls. 6 May 2011.

The portal website provides guidance on reducing energy use, and tenants can submit questions online to building management staff for advice and assistance. The lease structure was changed to encourage tenants to reduce their energy use by offering incentives for meeting or exceeding energy efficiency targets.

This energy management system has already been deployed for some of the tenants in this building. As leases expire and new tenants move in, a top-to-bottom renovation of the space will take place and the tenant energy management system will be installed. Johnson Controls estimates that most of the tenant changeover will occur within the next three years. As the system has only been installed a few months at the time of this writing, the return on investment is unknown. The Tenant Energy Management System, along with “intelligent” building management capabilities such as active daylighting control, occupancy-based control of temperature and plug-loads, demand-controlled ventilation, wireless sensing, and continuous fault detection, results in significant additional energy savings over spaces designed and built only to minimum code requirements.

In the future, this system will be a platform for automating the energy conservation actions of the tenants. The tenant energy management system is capable of responding to internal information from sensors in individual suites as well as external information such as from utilities and weather forecasts. In the future, for example, the system may allow tenants to dim lights or adjust temperatures in response to changes in per-hour energy pricing or other demand-response signals. Over the next five years, Johnson Controls anticipates incorporating information from other sensors, systems, and the tenants themselves to further reduce energy use while maintaining and improving comfort, safety and productivity.

INSTITUTION CASE STUDY: PRINCETON UNIVERSITY

Recently Princeton University brought together its energy sustainability commitments under a comprehensive “Sustainability Plan” to reduce emissions to 1990 levels by 2020, even while the University plans to expand building square footage.[8] To reach this target the University is using a comprehensive set of approaches throughout the campus, including green buildings, sustainable transportation, and an on-site energy production facility. Several examples of *intelligent efficiency* applications figure among these approaches.

Princeton University’s Frick Chemistry Laboratory

[8] http://www.princeton.edu/reports/2010/sustainability/greenhouse/campus-energy/

GREEN BUILDINGS The new Frick Chemistry Laboratory features an estimated 30% energy savings relative to a comparable building.[9] The building incorporates many systems-based *intelligent efficiency* approaches to reduce energy use, including integrated mechanical systems that enable optimal transfer of cooled and heated air from offices through the atrium and into the laboratories, which reduces the amount of outside air that must be conditioned to meet ventilation demands for the labs. In the atrium the building also features one of the University's first public electronic dashboards tracking building performance. Several devices in the building optimize lighting and increase daylighting while limiting heat gain, including external cast-aluminum louver sun shades, glass fitted with small ceramic dots to control heat gain, and high-efficiency exterior glazing, as well as an auto-dimming lighting system.

CAMPUS ENERGY PRODUCTION The Princeton Energy Plant[10] is a district energy facility that provides electricity, steam, and chilled water to meet the energy needs of the Princeton University campus. The electric generator is a combined heat and power facility powered by a gas turbine (that also can operate on bio-diesel), which can generate up to 15 MW of electricity. Recovered heat is then used to make steam or chilled water to heat or cool buildings on the campus. The system can operate up to 80% efficiency and typically operates above 70%, compared to 25%-45% efficiency for a typical electric generator run by a utility. The state-of-the-art "intelligent" aspect of the plant is the use of an economic dispatch simulation to monitor various factors in real time, including electricity and fuel prices, biodiesel "renewable energy credit" values, the campus CO2 value, and current campus demand, to determine whether to import electricity from the grid or generate electricity on campus.

<u>Future plans</u>: The University has several near-term plans for applications of *intelligent efficiency*, including: (1) installing optimization software to monitor building energy performance, and 150 new meters for building energy monitoring; (2) replacing hundreds of steam traps to improve efficiency—some of the 10,000 devices in the University's distribution system that hold steam vapor in the pipe while letting water drain out; and (3) installing advanced sensor technologies to reduce the number of air changes in two major molecular biology laboratories.

Longer-term plans are to: (1) continue to install motion sensors integrated with lighting and room heating and cooling systems; (2) complete the installation of new energy meters, and accompanying system optimization software for energy controls; and (3) maximize computer management.

INSTITUTION CASE STUDY: DEPARTMENT OF DEFENSE

The benefits of *intelligent efficiency* go beyond private industry and consumers, and extend directly to the heart of national security. In recent years, the Department of Defense (DOD) has identified excessive energy consumption as a key strategic vulnerability and sees energy efficiency as having great potential to free up resources. The DOD has an enormous physical footprint, with over 500 global installations and over 2 billion square feet under management. As of FY2009, DOD was spending $3.8 billion per year to

[9] http://www.princeton.edu/reports/2010/sustainability/greenhouse/green-building/
[10] http://www.princeton.edu/facilities/info/news/archive/?id=975

supply energy—mostly electricity—to these installations, accounting for roughly one quarter of DOD's total energy costs. Reducing energy consumption would free funding to support its core mission and facilitate greater independence from the electric grid. The control, management, monitoring, modeling, and decision making for energy use in buildings are based solidly on both technology-based and information-based *intelligent efficiency*.

Legislation and executive order mandate the Department to reduce the energy intensity (energy use per square foot of facility area) of its installations by 30% by 2015. The Department's efforts are ramping up to meet the challenge, but they are coming from behind; it is requiring a major push to ensure that all buildings are simply metered, let alone equipped with advanced energy management systems. Ultimately, however, implementing smart technology for *intelligent efficiency* will be a key component for meeting its energy goals. DOD officials are aiming much higher, hoping to obtain energy reductions of up to 50% in existing buildings and 70% in new buildings.

There are many DOD projects underway that evaluate emerging technologies in real-world environments, and one of the most intriguing is the Installation Energy Test Bed Initiative, administered by the Department's Environmental Security Technology Certification Program (ESTCP). Since the inception of the Test Bed initiative in 2009 with Recovery Act funding, it has pursued several projects and is making advances in building control and retrofit, efficiency, renewable energy resources, and microgrids at facilities. Through this initiative, ESTCP identifies facility needs, solicits proposals from industry, government labs, and universities, and performs rigorous testing and evaluation to assess costs and performance of new technologies related to facility energy control, management, monitoring, modeling, and decision making. It also assists with technology transfer upon program completion.

Several Installation Energy Test Bed projects have gotten underway recently that test multiple examples of *intelligent efficiency.* These include advanced energy management software, campus-wide energy monitoring systems, lighting optimization, and microgrid control technology. From 2012 to 2013, ESTCP is testing multiple platforms for *intelligent efficiency*, working with United Technologies Research Center and Naval Station Great Lakes in Illinois. One platform is an advanced energy management software package for buildings, which interfaces directly with the existing Siemens management system to enable visualization, modeling, and fault diagnostics in buildings' heating, cooling, and ventilation systems. Another will demonstrate a prototype monitoring system for building energy performance and optimization over the entire station campus. These technologies would facilitate

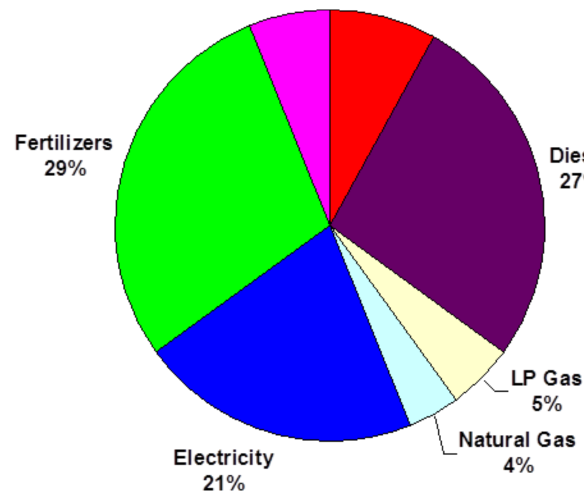
Naval Station in Great Lakes, Illinois more precise real-time control for installation energy managers, and are expected to reduce the energy consumption of the heating, cooling, and ventilation by 20%.

Elsewhere, ESTCP and Philips Research North America are collaborating with Fort Irwin, California, to test three different systems for lighting optimization. The systems operate in single rooms or building-wide, using a mix of wired and wireless sensors and automated controls that may reduce lighting energy use by 50%. A similar project at Fort Sill, Oklahoma, is testing different systems with different levels of functionality for external lighting in streets, parking lots, and maintenance areas. And ESTCP is also pursuing related work in microgrid control technology, to manage small-scale grid systems that integrate "intelligent" buildings and localized energy generation to achieve both efficiency and independence from the civilian grid.

AGRICULTURE CASE STUDY: PRECISION AGRICULTURE

Agriculture is among the most energy intensive sectors of the economy, though most consumers do not realize this fact about the food they consume. Energy is used both directly on the farm for operations such as equipment and irrigation, but also in the form of chemicals used as fertilizers and pesticides. Fertilizers and other chemicals are particularly energy-intensive to produce; fertilizers are the largest single energy input in agriculture, and fertilizers and pesticides combined represent more than a third of the total amount of energy used on a farm.[11] Reducing the chemical inputs used to produce crops can significantly reduce the amount of energy needed to produce our food crops. Energy represents a major cost, so using energy more efficiently could simultaneously increase farmer profits and decrease consumers' food costs.

Figure 4. Direct and Indirect Energy Inputs to Agriculture in 2004



Source: Miranowski (2005)
Note: Total Energy Input = 1.7 Quads

Conventional agricultural methods are based on the presumption that it is most cost-effective to treat each field as a single, homogenous unit since there has been no way to determine if this is true. Each field receives a uniform application of water, seed, fertilizer, and pesticides—often more than is really needed, to ensure that the parts of the field naturally deficient in water or nutrients are able to reach their full capacity. Chemicals and automated machinery have made it possible to operate farms like factories. Today, farms can be tens of thousands of acres in size, and a single field can be hundreds of meters long.

[11] Miranowski, J. 2005. "How Energy Is Used in Agriculture, Why It Is Important, and Where It Is Going." Presentation at the ACEEE Forum on Energy Efficiency in Agriculture on November 15. Ames, Iowa: Iowa State University.

But despite these technological advances, fields are not factories, and variations in land have real impacts on crops. The natural conditions such as soil structure, sun exposure, and fertility can vary across a field, with one corner lush and green, while another section of the same field may be full of stunted, yellowing plants.

Precision agriculture allows farmers to use technology to add the right inputs in the right places at the right time, to ensure the best yields while minimizing the cost from consuming direct and indirect energy. Precision agriculture makes use of multiple aspects of *intelligent efficiency*. It uses remote sensing and on-the-ground observations to detect the variations within a field. Computer simulations can determine the inputs needed for optimal production, combining factors ranging from soil type to the weather forecast. Farmers can use global information system (GIS) software to create a detailed map of their fields that shows which types of inputs are needed where. Machinery, loaded with computers and guided by global positioning systems (GPS), can apply the volumes of water, pesticides, and fertilizer that are optimal for each square meter of field. From the farmers' point of view the benefits are clear: they can maximize yields, and therefore revenues, while spending less money on water and chemicals.

The benefits of precision agriculture go beyond farmers' profits. Additional benefits include minimizing the amount of chemical runoff into nearby bodies of water, improving water quality locally and as far away as the Gulf of Mexico, while decreasing pressure on increasingly constrained local water resources.

The Digital Northern Great Plains (DNGP) project is working to help farmers increase their efficiency through precision agriculture, making this process as easy as possible for farmers. It makes available database multispectral images of the northern Great Plains states taken by several satellites. Farmers can use DNGP's web interface to search for their farms' spatial coordinates, use GIS vector layers, and generate useful information from the satellite images. Since many rural areas lack access to high-speed Internet, data is processed on DNGP's server so that farmers with a low-bandwidth connection can still easily use the program. From the farmers' point of view the benefits are clear: they can maximize yields, and therefore revenues, while spending less money on water and chemicals. One farmer used DNGP to reduce nitrogen fertilizer application by about 60 pounds per acre, or almost 50%, over the course of four years, saving over $51,000. A rancher used DNGP to salvage over 200 acres of grazing land, worth about $40,000 annually, from a weed infestation by using a precision application of pesticides.[12]

There are a number of technical challenges associated with precision agriculture. One problem is the reliance on remote sensing systems that do not yet fulfill all the needs of the farmers. For example, the data in the database is updated infrequently. According to one expert, an ideal system would provide farmers with an overview of their fields twice a week with less frequent in-depth surveys, with a resolution of 2-5 square meters per pixel. Most importantly, farmers would receive this information within 24 hours

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12 Zhang, Xiaodong, Santhosh Seelan, and George Seielstad. "Digital Northern Great Plains: A Web Based System Delivering Near Real Time Remote Sensing Data for Precision Agriculture." Remote Sensing. 2. (2010): 861-873. http://www.mdpi.com/2072-4292/2/3/861/pdf (accessed September 9, 2011).

of its capture so that they can act on the most up-to-date data.[13] Some remote-sensing satellites do not fly over a particular region frequently enough to be useful. Others have spatial resolutions that, even though they can be used to analyze broader regions, are much too imprecise for precision agriculture. And sometimes available data is simply too expensive. Some farmers fill in the gaps with sensors based on airplanes, but this too can be expensive and is not always available. But overall, remote sensing technology has advanced dramatically in recent years and will continue to do so. As more satellites outfitted with the latest technology are launched, more farmers will have access to the detailed data that is essential for precision agriculture.

SMART MANUFACTURING CASE STUDY: MOVING TO CLOSED-LOOP CONTROLS[14]

The manufacturing sector reflects the evolving nature of intelligent efficiency. In many cases, a company will begin to incorporate information feedback and controls technologies to improve the operation of the system, and will continue to add more advanced technology in order to further reap the benefits of *intelligent efficiency*.

This progression can be seen in the Bayport, Texas, facility of steam system Air Liquide. Air Liquide is a global corporation specializing in cryogenic liquids and industrial gases, and their Bayport plant is one of the largest industrial gas suppliers in the world, manufacturing oxygen, nitrogen, and hydrogen for use in other industries. Producing these gases requires a lot of steam heat, which is provided by seven large boilers (four of which are fired by the exhaust of gas turbines used to cogenerate electricity). The facilities boilers are driven by several constraints, such as production volume, reliability, energy cost, and emissions. Prior to implementing closed loop control Air Liquide has been using Visual MESA software to track and optimize against these key indicators, provide open-loop feedback to operators to guide them in optimizing their boiler systems. This use of data tracking and analysis of operations is a best practice in the industry and is an example of one type of *intelligent efficiency*. Operators receive data and analysis results every 15 minutes, running in parallel with pricing changes in the electricity market (although they typically only manually implement these results once or twice a shift). Air Liquide then took optimization

Typical Manufacturing Boiler System, Source: http://www.donahuesteam.com

[13] http://earthobservatory.nasa.gov/Features/PrecisionFarming/precision_farming5.php Viewed Aug. 31, 2011

[14] Conversation with Tyler Reitmeier, Soteica Ideas & Technology LLC, 31 May 2011

to the next level by closing the loop between the data feedback system and the boiler control system. Instead of relying on operators to adjust the system a few times a day, the new system analyzes process variables and adjusts the system immediately, allowing it to update the boiler control settings every 15 to 30 minutes.

Currently, the data feedback system in the open-loop optimization that Air Liquide had been using takes about 10 to 12 months to install. Upgrading to closed-loop control can take another 6 to 12 months, but the energy savings alone are estimated to give the project just a one-year payback. There are also additional sources of savings, such as increased system productivity and the benefits of freeing up operator time for other work.

Experts working on the project estimate that as more closed-loop systems are installed and the savings are properly verified, more companies/plants will choose to install the data feedback systems with closed-loop control at the outset, bypassing open loop entirely. This would allow the entire installation to take about 12 months, and the simple payback based on total cost savings could drop to less than a year.

Smart Manufacturing Case Study: Plant-Wide Optimization

Manufacturing facilities are full of complex systems, and managing energy consumption requires not only understanding how these systems interact, but possessing real-time information about what the systems are doing at any given moment. Fortunately, smart sensing and control technology is improving this task. Automation companies have been exploring how new information technologies and advanced controls can improve system efficiencies and integrate controls across multiple systems. Both Schneider Electric™ and Rockwell Automation offer unique services to improve plant-wide optimization and significantly increase both energy efficiency and productivity.

Schneider Electric Company[15]

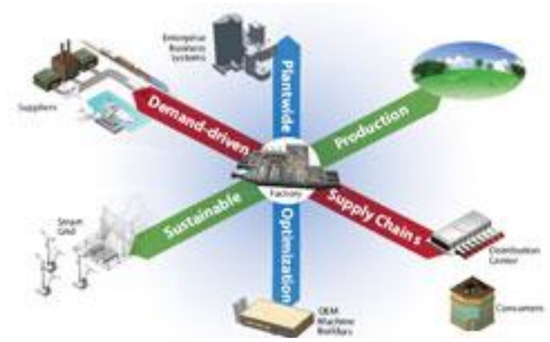
Schneider Electric's new Production Energy Optimization (PEO) concept includes a broad array of data sensors and allows extensive energy analytics to be run on various production indicators. The PEO system enables manufacturing and mining operations to track energy use per unit of product and to identify potential issues by comparing real-time data to a baseline. The PEO system also helps locate where in the process the problem occurred, so it can be fixed quickly.

One example of the PEO system can be seen at a new steel mill in Alabama, where Schneider Electric designed and installed sensors and variable-speed motors in each of the facility's 65 cranes. The cranes transport materials in the plant. Sensors detect the load on the chain, along with any skew or sway the load is experiencing, and interact with the crane's motor to adjust the hoisting speed to the fastest safe speed while using the least amount of energy. A three-dimensional positioning system helps the crane operator guide the load to its destination. When the load gets close, the automated system takes over and

[15] Conversation with Rusty Steele, Schneider Electric Company, 11 July 2011

adjusts the speed to reduce the sway. This process lets the load be lowered more quickly and has reduced the time to transport material by 15 to 20%.

Schneider Electric is currently implementing other aspects of Production Energy Optimization with a number of manufacturing and mining companies to help them identify, gather, and analyze energy usage and production data and optimize their time, costs, and energy savings. In many cases, these energy and production savings have made it possible for the system to pay for itself in just over a year.



Source: Rockwell Automation

Rockwell Automation[16]

Rockwell Automation has worked with an automaker to design a new facility which incorporates smart manufacturing technologies at every turn, enabling the company to accept custom orders from dealers and adapt—on the spot—to customers' preferences. Those same technologies will allow the company to track every auto part to its source, quickly identifying and addressing any quality or safety problems that may arise. The control system predicts bottlenecks and breakdowns on the factory floor before they happen. It also has the capacity to seamlessly order parts from its suppliers the instant it receives a custom new car order from a dealer. The factory will minimize energy use, water use, and emissions while increasing economic performance, worker safety, and environmental sustainability. The reductions in oil and gas use and electricity use could be as great as 35% and 40%, respectively.

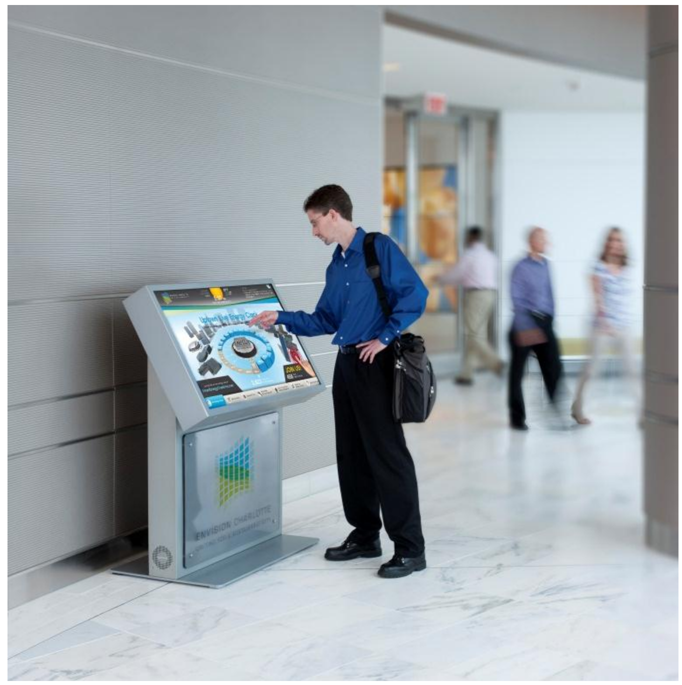
PUBLIC TRANSPORTATION CASE STUDY: DYNAMIC MESSAGING, PRIORITY LANES, AND TELECOMMUTING

To relieve congestion on major highways, the Twin Cities metropolitan area (Minneapolis and St. Paul) is instituting a new effort as part of a Minnesota Urban Partnership Agreement. The effort incorporates several "intelligent" transportation solutions, including using tolls on highways, strengthening public transit, and encouraging telecommuting.

First is a priority-lanes toll system with differential pricing to help clear an interstate during high traffic hours and encourage use of

[16] Case study supplied by Rockwell Automation, January 2012

public transportation. This system converts existing bus-only and high-occupancy-vehicle lanes to wider toll lanes, with prices based on vehicle occupancy. A portion of the toll revenues from the new lanes are being used to fund fare discounts for public bus riders during peak periods, to improve transit services by increasing the availability of buses and park-and-ride lots, and to fund the creation of a bus rapid transit network. A dynamic message system communicates with drivers in real time. These signs inform travelers about the availability of lanes, toll rates and travel speeds on the priced lanes, and public transit alternatives. Real-time transit information, including next-bus-arrival information, is also provided in downtown Minneapolis and St. Paul and at park-and-ride facilities throughout the metro area.



Telecommuting is also part of this effort. *eWorkPlace*, a state-sponsored program focuses on employers encouraging the use of telework and flexible work arrangements so that employees can work from home on occasion and help relieve traffic congestion while also reducing energy consumption. Between March 2009 and March 2010, 30 employers and more than 3,000 employees in the Twin Cities were participating in *eWorkPlace* (DOT 2011).

Urban Sustainability Case Study: Envision Charlotte[17]

Envision Charlotte[18] is a collaborative partnership that aims to make downtown Charlotte, North Carolina, the most sustainable urban core in the United States. Duke Energy, a major U.S. electric utility headquartered in Charlotte, is working with partners Cisco and Verizon in a project to dramatically raise awareness about energy use in Charlotte by providing consumer feedback. An example of information-based *intelligent efficiency,* the initiative calls for video screens installed in the lobbies of downtown office buildings that display, in near-real time, the collective energy used by buildings in the city's core. The interactive displays include suggestions that help individuals take steps to cut their own energy consumption. Social media postings are supplementing information on the screen, along with tales of "energy champions" who create new conservation ideas for their firms.

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[17] This case study is based on an interview with Vincent Davis of Duke Energy, February 16, 2012 conducted by Larry Plumb of Verizon.

[18] See www.envisioncharlotte.com and www.smartenergycharlotte.com

The effort is a first-of-its-kind public-private initiative to address energy efficiency, and ultimately overall sustainability across an urban area. It's also a major jump into the commercial energy-savings market for Duke Energy, Verizon, and the other companies involved, whose energy-efficiency products have typically been focused on the residential market.

Verizon's 4G Long Term Evolution (LTE) wireless network connects the nearly 70 buildings in Charlotte where energy usage data is collected, and it streams the results to the lobby monitors. Duke Energy, the area's electric power supplier, anticipates that actions inspired by the project will produce a 20% drop in power use—approximately 220,000 metric tons of greenhouse gases—by 2016 (Envision Charlotte 2012).

Reduced energy use in downtown Charlotte is one benefit of the collaborative effort. Another expected benefit is enhanced economic vibrancy of the metropolitan area. Envision Charlotte organizers hope that new businesses will be attracted to a city where there's a strategy and the technologies in place to significantly reduce energy costs. The Environmental Protection Agency estimates that the typical commercial building wastes about 30% of the energy it consumes.

The companies involved in project believe it may open similar opportunities in other cities, as the advantages yielded by Envision Charlotte become more widely known. Organizers of the effort describe it as creating a "Prius effect," a model that creates a high regard for going green. That effect seems to be taking hold: the initiative earned a utility industry award for Best Energy Efficiency/Demand Response Project for 2012 (Downey 2012).

Envision Charlotte uses the latest 4G LTE technology in a manner that could never have been imagined before the early 21st century. The technology offers an effective way to give people the information they need to become responsible stewards of energy use.

CLOUD COMPUTING CASE STUDY

For most businesses and organizations, traditional practice is to support employees' personal computers through a dedicated, local computer network. A growing alternative is to provide many services through "cloud computing," meaning large servers, typically in data centers, that provide the computing, storage, and software services connected to the user via the Internet. Two different approaches to cloud computing are (1) a "private cloud," where IT resources are shared among different business units in the same organization, and (2) a "public cloud," where IT resources are delivered to different corporations through specialist providers.

The cloud platform achieves these savings by enabling higher utilization of servers, more efficient matching of server capacity to server demand, and "multitenancy" to serve thousands of organizations with one set of shared infrastructure. When not all servers are needed, some can be turned off entirely, and loads can be rerouted to other servers. In addition, advanced techniques can be used to lower operating expenses, such as DC virtualization and statistical multiplexing (Holler 2010). The savings can be significant. The cloud platform provided by Salesforce.com, which is a public cloud option, enables greater efficiency over both a dedicated, on-premises network and a private cloud option (WSP Environment and Energy 2011). When a user switches from a private cloud to Salesforce.com's public cloud platform, the carbon savings are estimated to be 80% of per-user carbon emissions; when users switch from an on-premises option to Salesforce.com, they see an 86% decrease in carbon emissions. .

In another example, Google (2011) has estimated the relative energy use per user for e-mail, comparing small, medium, and large businesses with their own servers (with 50, 500, and 10,000 users, respectively) to using cloud-based e-mail (e.g., Gmail). Google's estimates are provided in Table 3 below. They estimate that energy savings can be over 50% for large users and well over 95% for small users. Some of the gains are from more efficient equipment (shown in the second column) but much of the gain is from improved power use effectiveness (PUE) (shown in the third column), which means less energy spent to house and cool the computers inside a building.

Table 3. Relative Energy Use for E-Mail for Different Size Businesses

Business Type	IT Power per User	PUE	Total Power per User	Annual Energy Use per User
Small	8 W	2.5	20 W	175 kWh
Medium	1.8 W	1.8	3.2 W	28.4 kWh
Large	0.54 W	1.6	0.9 W	7.6 kWh
Gmail	<0.22 W	1.16	<0.25 W	<2.2 kWh

Source: Google 2011

It must be noted that in some situations, cloud computing uses more energy than do traditional, on-site servers—specifically, in situations involving computationally intensive tasks that require a great deal of data transport. In these cases, the energy consumption for data transport can cancel out the energy savings that would accrue if the company used its own highly efficient on-site servers (Baliga et al. 2011). But for the vast majority of companies, with more typical data handling needs, cloud computing represents a very significant, largely untapped source of energy savings.

On a national and global scale, if cloud computing were to be widely adopted by large corporations, the energy savings would be enormous. Large U.S. companies that adopt cloud computing could reduce their IT-related CO2 emissions by an estimated 50% by 2020, compared to their emissions while using dedicated IT networks (Carbon Disclosure Project 2011). For example, a typical food and beverage firm transitioning its human resources application from a dedicated IT to a public cloud can achieve a net present value (NPV) of $10.1 million, CO2 emissions reductions of 30,000 metric tons over five years, and a payback of one year. Adopting a private (internal) cloud could achieve an NPV of $4.4 million, CO2 emissions reductions of 25,000 metric tons over five years, and a two-year payback.

The example of energy savings from cloud computing reflects the promise of *intelligent efficiency*. We have the opportunity to achieve greater levels of efficiency by rethinking the system we use to meet the needs we have from the buildings we live and work in to how we make the products we use and how we move those products and ourselves.

Policies to Tap Into the Potential for Intelligent Efficiency

We have outlined a broad array of *intelligent efficiency* approaches, including (1) people-centered efficiency; (2) technology-centered efficiency; and (3) service-oriented efficiency, and we discussed how these three approaches, together, can enable a "network effect" for larger opportunities of system-wide, infrastructure benefits. We have also identified the pervasive barriers that have prevented more rapid adoption *intelligent efficiency* in the marketplace, including social barriers (awareness, complexity, and risk aversion), financial barriers (upfront costs and split incentives), and structural barriers (lack of skilled workforce, lack of measurable data, and privacy issues). Public and private sector decision makers can, by embracing policies and programs that address these barriers, play an important role in ensuring that *intelligent* efficiency realizes its full potential for energy savings and economic benefit.

AWARENESS, RECOGNITION, AND LEADERSHIP

Policy leaders must recognize *intelligent efficiency* solutions as an integral part of a national energy efficiency strategy, and raise awareness among their colleagues and constituents. Policymakers have the ability to raise awareness through "lead by example" policies in federal and state governments by enacting *intelligent efficiency* practices in their own buildings and facilities. By capturing data and experiences, these projects can serve to educate the public about the energy and economic benefits of *intelligent efficiency* and can be models for other jurisdictions and for the private sector.

Leaders in the private sector also have an opportunity and obligation to lead by using *intelligent efficiency* in their own operations, and promoting their example in business-to-business commerce. The firm has a self interest in promoting *intelligent efficiency* because if offer the promise of greater competitiveness and efficiency in their own operations. The benefits also extend to their business partners, because if they adopt intelligent systems, all parties stand to benefit from network effects discussed earlier.

INFORMATION INFRASTRUCTURE

The public sector has a key role to play in promoting *intelligent efficiency* by installing the infrastructure needed for *intelligent efficiency* to realize the full extent of its benefits. Information about energy use is critical to the success of *intelligent efficiency*; therefore, policies need to be designed so that key energy information is available, that the infrastructure to store and access this data is in place, and that the human capital needed to grow *intelligent efficiency* is developed.

Access to Energy Information

Good energy efficiency policies and decisions, like good energy management, require timely, accurate, and meaningful data. On national and regional levels, we need to collect information about emerging energy use trends, such as the growth of energy consumption from plug loads in buildings. These new loads related to information technologies represent an increasing share of the energy use in buildings, particularly as device-level efficiency measures reduce other energy uses. *Intelligent efficiency* has the potential to counteract the growth in these loads. Similarly, the private sector needs access to this type of information to enable the potential benefits from *intelligent efficiency.* Better data and better informational tools, which put the data into a meaningful form, also enables comparative benchmarking to measure the results of complex systems.

Unfortunately, the government's primary source of energy information, the Energy Information Administration (EIA), has seen its budget cut by nearly 50% relative to the budget in the early 1980s (Gold and Elliott 2010), even as policymakers and business strategists need new and even more timely data to use as they formulate strategies that encourage the adoption of *intelligent efficiency* technologies. It is critical to increase funding for data-gathering agencies to ensure that reliable data on major energy uses and trends is publicly available.

Consumers also need ready access to accurate information about their own energy usage data in order to identify and track energy savings opportunities. Visible and meaningful feedback motivates consumers to reduce energy usage or shift certain activities to off-peak periods of demand. The *Electric Consumer Right to Know Act* or "E-Know" bill represents an example of the kind of policy that would address this barrier by ensuring that home owners have easy and regular access to their electricity usage information. Consumers would also be allowed to give third parties of their choosing, such as their home retrofit contractor, access to their energy usage data in order to monitor energy savings information following the implementation of new efficiency measures.

Widespread Access and Use of High-Speed Internet

As demand for information to enable *intelligent efficiency* increases, it is critical that the capacity to deliver this information be in place. In 2010, 98% of Americans had access to fixed-line or mobile broadband communications, but only two-thirds (68%) of all U.S. households subscribed to high-speed Internet access powerful enough to support many of the technologies associated with *intelligent efficiency* (NTIA 2011).[19] Accelerated deployment of applications that enable people to better manage their households and to save money by being more energy efficient represents a possible path to both increase broadband penetration and to leverage America's broadband infrastructure to achieve more *intelligent efficiency*. There is a need for much more widespread adoption of high-speed Internet access, coming from two complementary directions. Full adoption of high-speed Internet access will both allow consumers to take advantage of current *intelligent efficiency* technologies and support the continued development and expansion of these technologies themselves.

OR

The development and expansion of *intelligent efficiency* technologies both encourages and benefits from more widespread adoption of high-speed Internet access.

Rapid Knowledge-Based Innovation in Energy Efficiency

Innovation and large, exponential energy efficiency improvements are intricately linked. Efforts to drive innovation in the United States, however, often treat energy efficiency as marginal. While the United

[19] *See* U.S. Federal Communications Commission (FCC), Internet Access Services: Status as of June 30, 2010 (rel. Mar. 2011) ("477 Report"), available at: transition.fcc.gov/Daily_Releases/Daily_Business/2011/db0520/DOC-305296A1.pdf; NTIA Digital Nation: Expanding Internet Usage (Feb. 2011), at 5, using October 2010 U.S. Census Bureau Population Survey data, available at: www.ntia.doc.gov/reports/2011/NTIA_Internet_use_Report_February_2011.pdf

States still places in the top 5 in the overall innovation rankings (4th in 2011), which are based on indicators such as number of scientists and engineers, corporate and government research and development spending, and venture capital spending, we have fallen from the number one position in 2000 and have made little or no progress since then. For example, the United States ranks second-to-last among a group of about 40 countries on *progress* over the past decade toward a "knowledge-based" innovation economy (Atkinson and Andes 2011). These challenges suggest the need for a call to action by policy leaders for government to enact a proactive innovation and competitiveness strategy in the United States

REGULATORY BUSINESS MODELS

Regulations govern how businesses plan and operate, whether they are public entities such as utilities or private sector businesses such as builders. Our framework of desirable regulations outlined below would send a powerful signal to public and private entities about their operational models and influence their plans to realize opportunities for market success. By including *intelligent efficiency* in the consideration of government regulatory frameworks, we have the opportunity to exert a strong influence over the directions for these entities, speeding the adoption of *intelligent efficiency* in the marketplace.

Performance-Based Efficiency Codes, Standards, and Programs

Current building energy codes, energy performance metrics and labeling, and equipment standards are based on a component-focused approach—a prescriptive or "checklist" approach. In this approach, only the savings possible through optimizing individual components, each in isolation, is possible. Codes, metrics, and standards will largely have to shift to a systems-focused (performance) approach. The shift from a component-focused to a systems approach will open vast new opportunities for efficiency gains.

Our current device-focused approaches to building energy codes often fail to account for how the use of the building evolves (e.g., building occupancy patterns, age, how equipment operates, patterns of vacancy in the spaces, and addition of energy-intensive equipment) over the short- and long-term. A performance-based building code, in contrast, combined with efficiency incentives, can overcome this challenge by focusing on the overall energy efficiency of the building system rather than the performance of the devices.

Performance-based building codes could, for example, encourage the use of sensors, controls, and sub-metering in ways that identify problem areas in a building's energy systems and that could better optimize energy usage to save energy. For example, in a large commercial building, control systems would allow monitoring the performance of devices such as chillers and boilers that allow for problems to be detected quickly and addressed before they result in disruptions or costs. Sub-metering of energy use can help to monitor and track energy usage, providing feedback to managers and occupants on their energy performance.

Similarly in the residential sector, a prescriptive approach would focus on predicted efficiencies of individual components and equipment. A shift to performance-based efficiency codes and incentives would ensure that new homes or retrofit projects meet actual performance criteria, i.e., lower energy usage than the baseline energy usage. Under a performance-based approach, the performance level—in energy savings—would be assessed for the entire home after the project is completed.

This shift to performance-based regulations and programs will encourage a shift in the marketplace in the direction of practices and businesses that seek to exploit the system-efficiency available through *intelligent efficiency*.

Utility Regulatory Policies that Encourage Greater Intelligent Efficiency

The utility sector business model, perhaps more than that of many other industries, is powerfully influenced by its regulatory framework. The United States has been seeking a new utility business model for many years as a result of an increasing focus on electric and natural gas as commodities and technology changes that are making the traditional utility model less viable (York and Kushler 2011). Throughout the 20th and 21st centuries, energy demand has grown exponentially. Historically, state regulations and policies have encouraged the utility sector to meet the rising energy needs through growth in supply, i.e., by building new power plants and transmission infrastructure. The traditional regulatory model for determining utility revenues emphasizes *growth* in utility assets and the volume of energy sales.

Given that endless growth in supply as the primary response to growth in demand is not viable, and that current policies primarily reward only growth in supply, a new regulatory framework is called for that reduces the growth in demand through the most inexpensive solution, energy efficiency. Widespread energy efficiency measures allow us to defer or even remove the need to build new power plants, and demand-side energy-efficiency measures are the cornerstone of this strategy. For example, efficiency programs can save energy at a cost of about 3 cents per kilowatt-hour (kWh), while building new power plants typically deliver energy at a cost of about 7 cents per kWh (Fredrick et al. 2009). Formulating policies that simultaneously reward utilities and strongly encourage energy-efficiency programs is critical for building an energy infrastructure capable of meeting the demands of the coming century.

ACEEE has researched policy opportunities in the utility sector extensively, including energy efficiency resource standards (EERS), which require utilities or other third-party program administrators to achieve specific energy savings targets. Currently about 25 states in the United States have adopted an energy efficiency resource standard (Sciortino et al. 2011). To achieve these targets, utilities have developed and are delivering comprehensive sets of energy efficiency programs for their residential and business customers. As efficiency targets ramp up to higher levels in many of these states, utilities and other program administrators will be looking for new ways to achieve energy savings from their customers. *Intelligent efficiency* technologies and the system-focused, performance-based approaches they enable offer attractive new opportunities for the next generation of utility energy efficiency programs.

The new regulatory framework must ensure that utilities' financial motivations are well aligned with achieving improvements in energy efficiency. Utilities need a new business model for the 21st century that supports greater levels of efficiency. ACEEE has examined regulatory changes which could help create this new business model for utilities (York and Kushler 2011; Hayes 2011). Three elements of the new model include: (1) ensuring that utilities can recover the costs of efficiency programs; (2) changing the price structure that rewards utilities for increasing sales; and (3) establishing performance incentives that provide a return on efficiency investments. With a new business, forward-thinking utilities would have a financially viable route forward, leading the implementation of *intelligent efficiency*.

Evaluation, Measurement, and Verification (EM&V)

To realize the potential benefits of efficiency it will be important to ensure that the savings are real. This requires robust and continual evaluation of the energy savings and costs of *intelligent efficiency* strategies so energy efficiency program administrators and regulators are confident that these efficiency resources can be counted on to deliver the energy required to meet customer demands, just as a power plant is expected to deliver. Evaluation, measurement, and verification (EM&V) demonstrates the value of energy efficiency by providing accurate, transparent, and consistent assessments of their methods and performances. Data gathered by EM&V must be standardized if it is to be comparable. While EM&V efforts have largely varied by state, a recent regional effort by the Northeast Energy Efficiency Partnership has made significant progress toward standardized EM&V methods.

Intelligent efficiency approaches, by their very nature, support EM&V efforts better than do conventional energy efficiency programs that have focused on component efficiency. The optimization of systems that is enabled by real-time information offers the potential to improve tracking of energy savings in ways that can support EM&V protocols. At the same time, *intelligent efficiency* approaches require EM&V approaches different from those currently implemented. Correctly designed, the evaluations will encourage *intelligent efficiency* by capturing the full range of savings and benefits offered by the systems approach.

SOCIETAL VALUES

Many of our current societal norms were shaped before the "information age." We have not had sufficient time to adapt to the rapid changes seen over the past few decades. Changes carried on the wave of the information age have been of many stripes, from riveting, game-changing technologies (as well as simply riveting games) and easily adoptable time- and labor-saving tools, to the more complicated technologies that photograph us or detect our presence in public throughout our day. Societal norms color how we perceive and accept *intelligent efficiency*, much as fear and excitement about technological change have inhibited and spurred new advances in the past. Individuals' concerns and perceptions about technology are critical to take into account, and policymakers must respond with regulations and market structures that address the public's concerns.

Tension between Privacy and Open Access to Information

Intelligent efficiency depends upon access to data. Energy-usage data can provide insights into how people can conserve energy, and it can be used to optimize the operation and energy use of machines such as vehicles and air conditioners. Energy-use data enables the creation of new services that can lead consumers to become more actively engaged in their energy use.

At the same time, data that reveals details about personal behavior is sensitive, and its release can be perceived as a violation of privacy. Protecting the privacy of energy-usage information is critical to consumer protection and acceptance of these new technologies and of the new services they will enable. The challenges are similar to those of Internet banking and shopping: just as it is important to protect the privacy of online banking information and online shopping transactions, privacy protection practices must be applied to personally identifiable energy-usage data.

Balancing the need for access with a need for privacy is critical for the success of *intelligent efficiency*. Fair information practice principles recommended by the U.S. Federal Trade Commission and applied by responsible service providers to all forms of online commerce should be extended to energy-usage data.[20] These principles include the idea that consumers should be informed of what data will be collected (transparency) and should have some choice of whether the allow collection and whether such data is collected anonymously *before* data is collected and used (other than for the operational purposes cited above), no matter which technology or what company is collecting the data. Policymakers dealing proactively with these conflicting needs will thus ensure that *intelligent efficiency* will deliver on its promises.

Next Steps for Intelligent Efficiency

This report provides an initial foundation for *intelligent efficiency* upon which to build future research, policy ideas, and recommendations. Perhaps the most important contribution of this report has been to build a consensus among some thought leaders from across the market spectrum on what is *intelligent efficiency.* Having a definition allows researchers to identify examples and to begin to appreciate the evolution of this concept in the marketplace, and identify the policy needs that would speed its adoption.

ACEEE intends to continue our research, preparing a report in 2012 identifying specific technology and/or behavioral "measures" from *intelligent efficiency* with specific estimates of energy savings and costs from these measures. We feel that utilities represent a key market player moving forward, first, because of the rapid expansion of energy efficiency program spending, and, second, because of the search for new energy efficiency opportunities needed to respond to regulatory mandates such as energy efficiency resource standards that are now in place in 25 states. It will be necessary to move to define the role that *intelligent efficiency* can play in meeting these goals through concrete program measures and the associated evaluation methodologies. Such program measures and evaluations will provide policymakers and utility planners with the confidence that the energy resource offered by *intelligent efficiency* can be relied upon to meet customer energy needs in the future.

ACEEE also intends to continue to track the evolving business models that incorporate *intelligent efficiency* in other sectors of the economy and to explore the regulatory and market barriers that emerge to these business opportunities. We will seek to respond to these barriers with suggested policy responses that would remove the impediments to the expanded implementation of *intelligent efficiency*. In some cases these impediments may be in the interrelation between different entities in the marketplace, such as between energy utilities and telecommunications companies. ACEEE will continue to convene thought leaders from a diverse set of communities to explore opportunities for market synergy that creates new business opportunities while advancing the implementation of systems that make use of *intelligent efficiency.*

[20] For information on fair information practice principles, see http://www.ftc.gov/reports/privacy3/fairinfo.shtm

Conclusions

The promise of *intelligent efficiency* is great, offering a path to achieving major, long-term energy reductions, increased productivity, and job creation in every region of the country. Just as we have achieved energy efficiency over the last 30 years from devices, we need to expand now to energy efficiency gains that are systems-based and performance-focused. "Intelligence" in the energy-using systems in our homes, buildings, factories, and farms optimize these systems, allowing us to achieve the promise that energy efficiency holds for our future. *Intelligent efficiency* rests on carefully considered combinations of relying on technologies (not humans) where that maximizes efficiency, and inviting human interaction where that is optimal. In this systems-based approach, energy usage is made visible (to people) or invisible (automated by technology) according to the need. *Intelligent efficiency* represents a pivotal opportunity in a time of constrained resources to step up our energy efficiency game, and to lay the foundation of a thriving U.S. economy.

While the term *intelligent* efficiency is new, the elements have been evolving in the marketplace for the past three decades and are now converging to create new opportunities. We present a new framework for characterizing and analyzing *intelligent efficiency,* identifying three broad (frequently overlapping) categories:

1. **People-Centered Efficiency** (Real-Time Feedback)
2. **Technology-Centered Efficiency** (Automation and Optimization)
3. **Service-Oriented Efficiency** (Dematerialization or Substitution)

In addition, we identify a fourth, cross-cutting category that reflects the **infrastructures** through which *intelligent efficiency* can function as an integrated approach. Together, all types of *intelligent efficiency* enable more integrated, smarter, and more reliable infrastructure, such as smart power grids, smart cities, transportation systems, and communications networks.

Intelligent efficiency exists along a continuum where technology and human behavior intersect. At one end of the spectrum are measures where consumer decisions play the dominant role in determining efficiency. On the other end of the continuum, you might have a fully automated system controlling end-use devices, where human input, other than programming and commissioning the system, is not needed—or even desired. Thus, *intelligent efficiency* "invites" individuals' engagement with a system when this improves efficiency and "disinvites" engagement when it does not.

Intelligent efficiency offers both the direct benefits of energy savings and the indirect, but very real, benefits of economic productivity and job creation. These economic benefits are not simply a matter of how much money is saved through lower energy usage, but rather how the money saved is ultimately spent. As is common when new paradigms emerge, *intelligent efficiency* promises to bring us essential benefits that an economy that thrives into the future will require, and at the same time it faces several types of barriers. While some examples of *intelligent efficiency* have already been deployed in the United States, as the case studies presented in this report reflect, much more potential remains. Here we have documented the barriers to greater adoption, and we suggest several areas where policy and policymakers can respond to these barriers to facilitate greater adoption and development of systems built around *intelligent efficiency*. These policy actions fall into three categories:

1. Expanding **awareness, recognition, and leadership** by policymakers to educate and lead by example on the implementation of *intelligent efficiency*
2. Enhancing **information infrastructure** including energy data, communications systems required to allow access to this information, and the human capital required for continued innovation
3. Redefining **regulatory business models** under which public and private entities such as utilities and businesses operate to encourage models that promote energy efficiency through greater system efficiencies

The promise of *intelligent efficiency* is great, offering a path to achieving the major, long-term energy reductions suggested in recent ACEEE (Laitner et al. 2012) and Rocky Mountain Institute (Lovins 2011) research reports. The immediate opportunity is for increasing "intelligence" in the energy-using systems in our homes, buildings, farms, and factories. However, even greater opportunities exist through *integrated* and *crosscutting intelligent efficiency* in our infrastructure, such as smart cities, transportation networks, and power grids. This expanded vision for *intelligent efficiency* offers the potential to exponentially expand the benefits beyond the opportunities in individual systems. Future work will further identify and quantify the benefits of *intelligent efficiency* and will expand the range of policy responses that will enable *intelligent efficiency* to realize its full potential. With the groundwork laid for *intelligent efficiency* to spread throughout the economy in a resource-constrained future, our economy will have its best chance to grow and thrive.

References

[AAP] American Association of Publishers. 2011. "AAP Publishers Report Strong Growth in Year-to-Year, Year-End Book Sales." February 16th Press Release. http://www.publishers.org/press/24/

[ACEEE} American Council for an Energy-Efficient Economy. 2011. *How Does Energy Efficiency Create Jobs?* Washington, D.C.: American Council for an Energy-Efficient Economy. http://www.aceee.org/files/pdf/fact-sheet/ee-job-creation.pdf

Atkinson, R. and Andes, S. 2011. *The Atlantic Century II: Benchmarking EU & U.S. Innovation and Competitiveness.* Washington, D.C.: The Information Technology and Innovation Foundation.

Baliga, Jayant, Robert Ayre, Kerry Hinton and Rodney Tucker. 2011. "Green Cloud Computing: Balancing Energy in Processing, Storage and Transport." Proceedings of the IEEE (99)1, January, pp. 149-167.

Carbon Disclosure Project. 2011. Cloud Computing – The IT Solution for the 21st Century. Prepared by Verdantix. London, United Kingdom: Carbon Disclosure Project.

[CEC] California Energy Commission. 2011. "Adaptive Corridors" University of California, Davis. http://cltc.ucdavis.edu/images/documents/case_studies/pier_adaptive_corridors_ucd.pdf

DOE. 2011. Final Technical Support Document for Minimum Efficiency Standards for Refrigerators, Refrigerator-Freezers and Freezers. Washington, DC: U.S. Department of Energy. http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/refrig_finalrule_tsd.pdf .

Downey, J. 2012. "Duke Energy wins award for its part in Envision: Charlotte," Charlotte Business Journal, January 24, http://www.bizjournals.com/charlotte/blog/power_city/2012/01/duke-energy-wins-award-for-its-part-in.html.

Ehrhardt-Martinez, K., K. Donnelly, and S. Laitner. 2010. *Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities.* Washington, D.C.: American Council for an Energy-Efficient Economy.

[EDF] Environmental Defense Fund. 2011. http://opower.com/uploads/library/file/5/edf_behavior_and_energysavings.pdf New York, NY. Environmental Defense Fund.

Elliott, N., J. Amann, A. Shipley (ACEEE), Martin, N., E. Worrell, M. Ruth and L. Price (LBNL). 2000. *Emerging Energy-Efficient Industrial Technologies.* http://aceee.org/research-report/ie003 Washington, D.C.: American Council for an Energy-Efficient Economy.

Elliott, N., R. Gold, S. Hayes. 2011. *Avoiding a Train Wreck: Replacing Old Coal Plants with Energy Efficiency*. Washington, D.C.: American Council for an Energy-Efficient Economy (ACEEE).

Envision Charlotte. 2012. Envision Charlotte website accessed February 16th. http://www.envisioncharlotte.com/energy-program/.

EPA. 2011. "Energy Star Program Requirements Product Specification for Residential Refrigerators and Freezers, Eligibility Criteria, Draft 1 Version 5.0." Washington, DC: U.S. Environmental Protection Agency. http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/refrig/ENERGY_STAR_Draft_1_Version_5.0_Residential_Refrigerator_and_Freezer_Specification.pdf

Federal Register. 2011. Vol. 76, No. 231. Proposed Rules 74923. December 1st.

Friedrich, K., J. Amann and S. Vaidyanathan and N. Elliott. 2010. *Visible and Concrete Savings: Case Studies of Effective Behavioral Approaches to Improving Customer Energy Efficiency.* Washington, D.C.: American Council for an Energy-Efficient Economy (ACEEE).

Friedrich, K., M. Eldridge, D. York, P. Witte, and M. Kushler. 2009. *Saving Energy Cost-Effectively: A National Review of the Cost of Energy Saved Through Utility-Sector Energy Efficiency Programs.* Washington, D.C.: American Council for an Energy-Efficient Economy (ACEEE).

Geller, H. and D. Goldstein. 1998. "Equipment Efficiency Standards: Mitigating Global Climate Change at a Profit." (Szilard Lecture). College Park, MD: American Physical Society.

[Green Playbook] Playbook for Green Building + Neighborhoods. 2012. Glossary, http://www.greenplaybook.org/resources/glossary.htm, accessed February 27.

Gold, R. and N. Elliott. 2010. *Where Have All the Data Gone? The Crisis of Missing Energy Efficiency Data.* Washington, D.C.: American Council for an Energy-Efficient Economy (ACEEE).

Google. 2011. "Google's Green Computing: Efficiency at Scale. http://static.googleusercontent.com/external_content/untrusted_dlcp/www.google.com/en/us/green/pdfs/google-green-computing.pdf

Hartman, Thomas B, 2006. "New Vistas with Relational Control," *AutomatedBuildings.com*. http://www.automatedbuildings.com/news/apr06/articles/hrtmn/060327030702hrtmn.htm

Hayes, S., S. Nadel, M. Kushler, and D. York. 2011. *Balancing Interests: A Review of Lost Revenue Adjustment Mechanisms for Utility Energy Efficiency Programs.* Washington, D.C.: American Council for an Energy Efficient Economy.

Holler, Anne. 2010. "The Green Cloud: How Cloud Computing Can Reduce Datacenter Power Consumption." Presentation at SustainIT10, Feb. 22, 2010, San Jose, CA. http://www.usenix.org/event/sustainit10/tech/slides/holler.pdf .

[ITIF] The Information Technology & Innovation Foundation. 2009. *The Digital Road to Recovery: A Stimulus Plan to Create Jobs, Boost Productivity and Revitalize America.* Washington, DC. http://www.itif.org/files/roadtorecovery.pdf

Katz, Michael and Charles Shapiro. 1985. "Network Externalities, Competition, and Compatibility." *The American Economic Review.* Vol. 75, No. 3, pp. 424-440.

———. 1994. "Systems Competition and Network Effects." *Journal of Economic Perspectives.* Vol. 8, No. 2. pp. 93-115. http://socrates.berkeley.edu/~scotch/katz_shapiro.pdf

Kalundborg. 2011. Web site for "Kalundborg Symbiosis," accessed Oct 31. http://www.symbiosis.dk/en.

Laitner, John A. "Skip". 2010. "Energy and the Economic Imperative: The Role of Efficiency in Creating a Robust Economy" (Preliminary Observations in Anticipation of an ACEEE 30th Anniversary Symposium). Washington, DC: American Council for an Energy-Efficient Economy.

———. 2011. "The Link Between Energy Efficiency, Useful Work, and a Robust Economy: An ACEEE Working Paper." American Council for an Energy-Efficient Economy. Washington, D.C

Laitner, S., C. Knight, V. McKinney and K. Ehrhardt-Martinez. 2009. *Semiconductor Technologies: The Potential to Revolutionize U.S. Energy Productivity.* Washington, D.C.: American Council for an Energy-Efficient Economy (ACEEE).

Laitner, S., S. Nadel, N. Elliott, H. Sachs, and S. Khan. 2012.. *Long Term Energy Efficiency Potential.* Washington, D.C.: American Council for an Energy-Efficient Economy.

Lister, K. and T. Harnish. 2011. *The State of Telework in the U.S.: How Individuals, Business, and Government Benefit.* Telework Research Network.

Lovins, A. and Rocky Mountain Institute. 2011. *Reinventing Fire: Bold Business Solutions for the New Energy Era*. White River Jct., Vt.: Chelsea Green Publishing.

Lowenberger, A., J. Mauer, A. deLaski, M. DiMascio, J. Amann and S. Nadel. 2012. *The Efficiency Boom: Cashing In on the Savings from Appliance Standards*, Washington, D.C.: American Council for an Energy-Efficient Economy (ACEEE).

Martin, E., S. Shaheen, and J. Lidicker. 2010. *Carsharing's Impact on Household Vehicle Holdings: Results from a North American Shared-Use Vehicle Survey.* University of California, Berkeley, Transportation Sustainability Research Center.

[MGI] McKinsey Global Institute. 2011a. Growth and renewal in the United States: Retooling America's *Economic Engine*. Feb 2011. http://www.mckinsey.com/Insights/MGI/Research/Productivity_Competitiveness_and_Growth/Growth_and_renewal_in_the_US

———. 2011b. *The Great Transformer: The impact of the Internet on Economic Growth and Prosperity*. Oct 2011. http://www.mckinsey.com/Insights/MGI/Research/Technology_and_Innovation/The_great_transforme

MNDOT. Minnesota Department of Transportation. 2011. *Minnesota: Innovative Choices for Congestion Relief.* http://www.upa.dot.gov/docs/fhwajpo11039/arminn1.pdf

Nadel, S., R.N. Elliott, M. Shepard, S. Greenberg, G. Katz and A.T. de Almeida. 2002. *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, 2nd ed. ACEEE, Washington DC

OECD. 2011. OECD Broadband Portal. Accessed December 2011. http://www.oecd.org/document/54/0,3746,en_2649_34225_38690102_1_1_1_1,00.html#Penetration

Pew. 2010. http://www.pewinternet.org/Reports/2010/Home-Broadband-2010.aspx

[PNNL] Pacific Northwest National Laboratory. 2005. *Advanced Sensors and Controls for Building Applications: Market Assessment and Potential R&D Pathways.* http://www.pnl.gov/main/publications/external/technical_reports/pnnl-15149.pdf

Sangho Choo & Patricia L. Mokhtarian & Ilan Salomon, 2005. "Does Telecommuting Reduce Vehicle-miles Traveled? An Aggregate Time Series Analysis for the U. S," *Econometrics* 0505001, EconWPA.

Sastry, C., R. Pratt, V. Srivastava and S. Li. 2010. *Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves, Cost/Benefit Analysis*. PNNL-19083. Richland, WA: Pacific Northwest National Laboratory.

Shipley, A. and N. Elliott. 2006. *Ripe for the Picking: Have We Exhausted the Low-Hanging Fruit in the Industrial Sector?* http://aceee.org/research-report/ie061 Washington, D.C.: American Council for an Energy-Efficient Economy.

Singer, N. 2012. "Mission Control, Built for Cities," *New York Times*, March 3, http://www.nytimes.com/2012/03/04/business/ibm-takes-smarter-cities-concept-to-rio-de-janeiro.html?emc=eta1.

Sivaraman, Deepak. 2007. Comparative Energy, Environmental, and Economic Analysis of Traditional and E-commerce DVD Rental Networks. *Journal of Industrial Ecology, Vol. 11, No. 3, pp. 77-91.*

[SMLC] Smart Manufacturing Leadership Coalition. 2011. *Implementing 21st Century Smart Manufacturing.* https://smart-process-manufacturing.ucla.edu/about/news/Smart%20 Manufacturing%206_24_11.pdf. June 24. Los Angles, Calif.: University of California Los Angles.

York, D. and M. Kushler. 2011. *The Old Model Isn't Working: Creating the Energy Utility for the 21st Century.* http://aceee.org/white-paper/the-old-model-isnt-working

Weber, C., C. Hendrickson, P. Jaramillo, S. Matthews, A. Nagengast, and R. Nealer. 2008. *Life Cycle Comparisons of Traditional Retail and E-commerce Logistics for Electronic Products: A Case Study of buy.com.* Carnegie Mellon University, Green Design Institute.

Weber, C., J. Koomey, and H.S. Matthews. 2009. *The Energy and Climate Change Impacts of Different Music Delivery Methods.* Analytics Press.

WSDOT. 2011. Washington State Department of Transportation. "Commute Trip Reduction Overview." http://www.wsdot.wa.gov/Transit/CTR/overview.htm Accessed December 2011.

WSP Environment & Energy. "Salesforce.com and the Environment: Reducing Carbon Emissions in the Cloud."

[WWF] World Wildlife Foundation. 2008. The Potential Global CO_2 Reductions from ICT Use: Identifying and Assessing the Opportunities to Reduce the First Billion Tonnes of CO_2. Sweden: WWF (May)