Intelligent Efficiency: the Next Generation of Energy Efficiency[1]

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ABSTRACT

Information and communication technologies (ICT) and their enabling technologies are responsible for a significant portion of energy efficiency improvements in the past decade. Sensors and controls, the internet, and semiconductor technologies have already changed the way we use energy and interact with other people: how we work, shop, and have fun. But that is only the start. As highly efficient technologies begin to interact with each other and respond in real time to their environment, there will be a structural change in how we use energy.

This paper explores the next generation of energy efficiency: what we call *intelligent efficiency*. Building on recent work in this area, this paper will define intelligent efficiency and provide specific case studies to illustrate its impact. This paper will focus on the manufacturing sector, but examples include commercial building energy management, industrial automation, and transportation infrastructure. This paper will discuss how these technologies work together synergistically to reach new levels of efficiency, allowing us to not only save energy, but to improve the economy and create jobs. Finally, the paper will identify barriers and policy solutions to intelligent efficiency achieving even greater savings and economic benefits.

INTRODUCTION

Energy efficiency has been a major contributor to meeting the United States' energy needs for the past four decades, and numerous studies suggest that the potential for new energy efficiency remains enormous (11, 14). A significant portion of our past efficiency gains came from improvements in the individual products, appliances and equipment that use energy, whether the light bulbs that illuminate our world, electric motors that drive our equipment, or the cars and trucks that move us and our things. But we are reaching a point of diminishing returns from focusing on component efficiency. The nature of our future energy efficiency potential will be very different from what we have seen in the past decades. Although discrete, device-level improvements in efficiency will continue to play an important role, they are not sufficient to scale up efficiency dramatically enough to meet the challenges we will confront in future years.

Ultimately, making significant gains in energy efficiency depends less on the devices themselves and more on how we use the things and services we demand. These system efficiencies require a combination of technology and behavioral "intelligence" that interacts dynamically with its surroundings. The efficiency of a system is a function of 1) how its energy use is managed within the technologies and how they interact with one another, and 2) the choices made by the humans involved. Over the past three decades, elements of this dual "intelligence" have been converging to produce something new and unique. We characterize this convergence of technology and behaviors that can form the basis of a thriving economy into our resource-constrained future 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. Opportunities for *intelligent efficiency* exist along a continuum between technology and human behavior. At one end of the spectrum are measures in which consumer decisions play the dominant role in determining efficiency. 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

[1] This paper is drawn from a more comprehensive forthcoming report, tentatively titled *A Defining Framework for Intelligent Efficiency.* ACEEE 2012

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.

Types of Intelligent Efficiency

We have developed a framework for defining and characterizing *intelligent efficiency* (Figure 1) 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 (and frequently overlapping) categories:

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

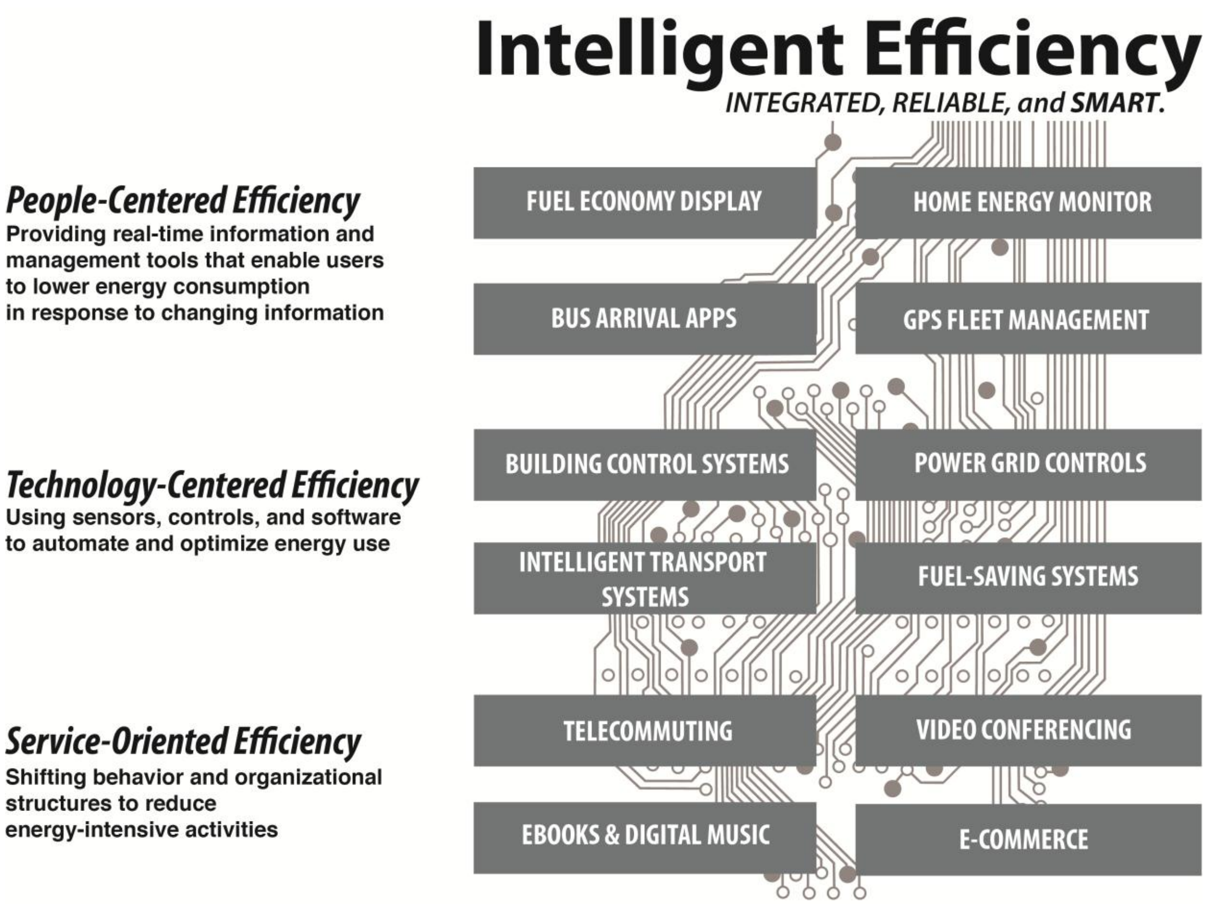

Figure 1: Framework for Intelligent Efficiency

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.

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[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, 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 (4). 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. 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.

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.

Technology-Centered Efficiency in 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 process equipment. While process equipment is 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 (2). Using those sensors and controls along with closed-loop feedback would increase their savings potential much more. Increased feedback and controls could also

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

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 overlooked.

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.

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.

Scaling Up Intelligent Efficiency: the Network Effect

In addition to the three categories detailed above, there is another aspect of *intelligent efficiency* that is the key to realizing its potential: intelligent infrastructure. *Intelligent efficiency* enables more integrated, smarter, and more reliable infrastructure, such as smart power grids, cities, transportation systems, and 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. 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, a concept we refer to as 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., consumers evaluate the attractiveness of a product based on whether others users in the same "network" have adopted the product (8, 9). Telephones and online social networks are classic examples of the network effect, because the more people using these products, the greater the benefits. Negative externalities can also emerge from the network effect, such as 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 to Rio de Janeiro is a good example of the system enabling optimization of energy use in buildings (18). As we expand our system perspective, we expand our opportunities for greater network effect 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. Indeed, we already see that the focus on device-level efficiency is beginning to have diminishing returns. While it was an important initial approach, because higher efficiency requires intimate knowledge of the device design, the singular focus on devices has its limitations. As we push device efficiencies for a sustained period of time, we encounter technical and economic limits that mean that increases in energy savings become smaller and smaller. 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 the full report associated with this paper presents 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 (15). 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 the returns get smaller and smaller while the costs increase rapidly.

Motors are part of a system (Figure 2), 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 actually increase energy use.

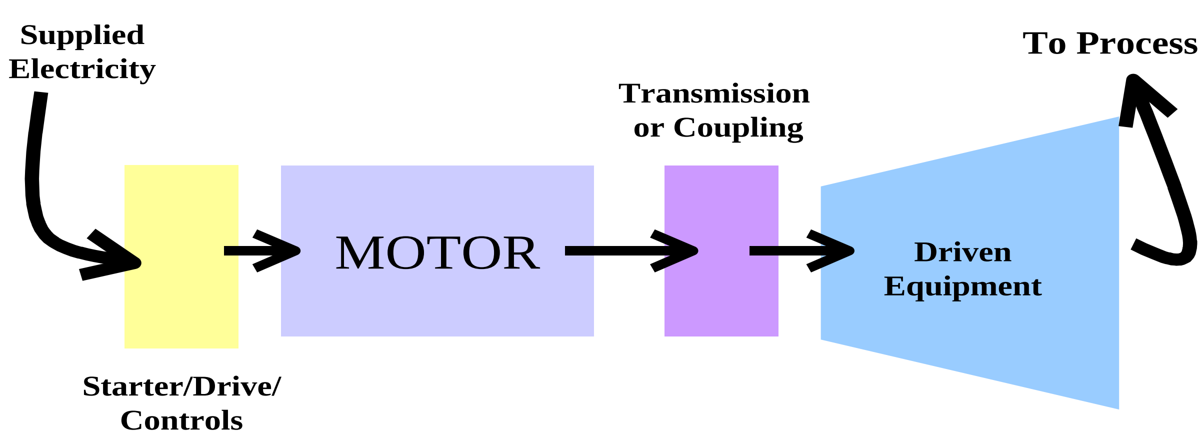

Figure 2: Elements of an Electric Motor System

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 (6). This approach allows the system to deliver the required cooling and air quality to each zone while optimizing the system for energy efficiency.

Manufacturing Supply Chains as Systems.

The production of manufactured goods normally involves multiple facilities, some operating sequentially and other in parallel. These facilities are often owned by different companies producing feedstocks or components that are then used by other manufacturers to produce products that ultimately reach the consumer. 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 (19), and are exploring symbioses among the facilities, for example, ways they might share infrastructure and waste streams. An example of this has already been accomplished over the past three decades in Kalundborg Denmark (7).

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.

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 (11). *Intelligent efficiency* is a critical tool in enabling this large savings potential. The benefits of energy savings from *intelligent efficiency* include reductions in energy bills for consumers and other "co-benefits" such as increased amenity (e.g., comfort, quality of life, productivity, product quality). And overall, energy efficiency has been shown to be among the lowest energy resource costs available in the marketplace (5). 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 (3).

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 recommendations for ICT-enabled energy efficiency. Two of the most comprehensive studies, which themselves contained extensive literature reviews, were a 2008 World Wildlife Fund (21) report and a 2009 ACEEE (10) report. These reports laid out both the potential savings with an array of policy considerations for achieving those savings.

These and other 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 these studies, the United States could reduce its energy use by 12-22% and save tens if not hundreds of billions of dollars in energy savings and productivity gains. However, 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. *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.

Economic Productivity and Jobs

The benefits of *intelligent efficiency* go far beyond energy savings. The expanded deployment of *intelligent efficiency* will also increase economic productivity and job creation. These economic benefits depend 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 (1). 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.

Some applications of information and communication technologies may not appear to have the same benefits on direct job creation. 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 the number of local 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 (12). 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 example, one study shows that for every job directly lost, the Internet is responsible for creating 2.6 jobs (13).

CASE STUDIES OF INTELLIGENT EFFICIENCY

In order to make *intelligent efficiency* seem less abstract, we provide two case studies of how *intelligent efficiency* is emerging and is being implemented in the industrial sector at different system levels.

Smart Manufacturing Case Study: Moving to Closed-Loop Controls

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 steam system of 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 (16). 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). Boiler operation is driven by several constraints, such as production volume, reliability, energy cost, and emissions. In order to track and optimize against these key indicators, Air Liquide has been using Visual MESA software to provide open-loop feedback to operators to guide them in optimizing their boiler systems. Using this method, operators receive data and analysis results every 15 minutes to take advantage of pricing changes in the electricity market, but typically only manually implement these results once or twice a shift. While this use of data tracking and analysis of operations is a best practice in the industry (and is an example of people-centered *intelligent efficiency*), Air Liquide took optimization 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 settings every 15 to 30 minutes.

Currently, the data feedback system in the open-loop optimization that Air Liquide had been using is becoming standard practice, and it 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 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 all the savings are properly verified, more facilities 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.

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 (20). 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. These 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 adjusts the speed to reduce the sway. This process lets the load be lowered more quickly and has reduced the time for each trip 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.

Rockwell Automation.

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 (17). 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 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.

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. Other social barriers include the learning curve with new technologies, the complexity of understanding the sometimes counter-intuitive systems approach, and the general risk aversion of end-users. Financial barriers encompass the upfront costs of implementing these new technologies, combined with the split-incentive problem 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 consumption in *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.

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.

CONCLUSIONS

As we transition from a focus on component or device efficiency to a focus on optimizing energy-using systems, *intelligent efficiency* represents an important framework for creating the policies and programs necessary to achieve the large potential for energy efficiency promised by *intelligent efficiency*. 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.

As is common f new paradigms, *intelligent efficiency* promises to bring us essential benefits required by an economy that will thrive into the future and at the same time it faces various 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.

The promise of *intelligent efficiency* is great, offering a path to achieving the major, long-term energy reductions. 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.

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