Increasing Energy Efficiency in Industry through Emerging Electrotechnologies

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ABSTRACT

Industrial activities continue to be a vital element of the United States economy, while facing mounting challenges from global competitors as well as ever increasing pressures to ameliorate environmental impacts. Extremely diverse, the industrial economy encompasses agriculture and food processing, mining, construction, manufacturing, transportation, and others. At the same time, the U.S. industrial sector consumes nearly 40 percent of primary energy resources. This energy demand must accommodate a dizzying variety of processes, physical plant requirements, and time-of-use needs. No other economic sector demonstrates this diversity of energy needs or the opportunity to realize the breadth of benefits available by utilizing electricity to a greater extent.

Tapping the energy-saving potential of electricity is an opportunity custom-made for today, as the issues of a sustainable energy future and a clean and safe environment become more urgent. In addition to addressing these needs, electrotechnologies offer a host of non-energy benefits, including improved manufacturing precision and control, enhanced product quality, increased worker productivity, and reduced environmental impacts. While efficient electrotechnologies are used throughout industry today, the potential for broader application remains, as does the potential for greater energy-efficient processes.

Introduction

Industry in the United States remains a vital element of the American economy, providing 27 million full-time and part-time jobs and contributing nearly one-quarter of the total value of the U.S. GDP (Martin, Worrell et. al. 2000). Yet it faces growing challenges. In the face of continuing global competition, this sector must grapple with increasingly stringent environmental regulatory requirements for waste disposal and cleaner processes. Furthermore, energy costs continue to rise, as does energy demand, adding to the challenge. In 2002, U.S. industry consumed nearly 23 trillion BTUs, with 832,061 million kWh of electricity consumed (Manufacturing Energy Consumption Survey (MECS), Energy Information Administration 2002). U.S. industrial energy use accounts for nearly 40% of the total national annual energy consumption. More significantly, a handful of sectors, including paper; chemicals; petroleum and stone, clay, and glass products; primary metals; and food and kindred products, use the lion's share of this vital resource, accounting for 80% of the total energy consumed by all industrial sectors (Martin, Worrell et. al. 2000). While other sectors of the U.S. economy have led the way in adopting energy efficient technologies, industry lags behind. This is due in part to the diverse energy needs of this sector in such a vast range of applications. Unlike commercial settings, which exhibit more similarities than differences, industrial applications cover a wide range of processes, physical plant requirements, and time-of-use needs.

Yet, this diversity of applications means that electrotechnologies are an ideal solution, for like no other energy source, electricity exhibits unique attributes that can accommodate this diversity. Electricity as an energy source is readily available, from the electric utility provider or through onsite generation, to meet load requirements at the point of use. It can be more easily *controlled* than thermal energy sources. As well, electricity can be delivered with great *precision* as to quantity and power quality. Electricity's versatility, precision, and ease of use have given rise to a remarkable range of new applications. Whether energizing the beam of an industrial laser, or powering the microsecond-by-microsecond opening and closing of computer circuits, electricity can do more things faster, more easily, and more precisely than any other energy form. For these reasons, it has become the energy standard for virtually all new technologies across the residential, commercial, and industrial sectors.

While users have tended to prize the convenience and expanded capabilities electricity offers above other considerations, the same technical attributes electricity exhibits offer users an additional benefit of substantial value in an increasingly energy-constrained environment: energy efficiency. For industry, becoming energy-efficient can also provide a range of non-energy benefits. Electrotechnologies often offer enhanced product quality, shorter production times, increased workplace safety, and reduced environmental impacts.

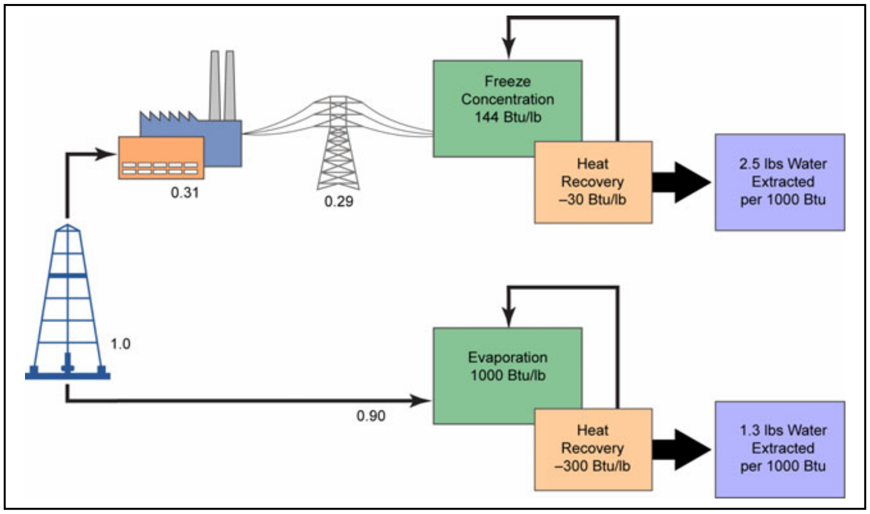
Efficiency of Electricity

Electricity is a uniquely efficient resource at the point of end use. It can be generated from a variety of fuels, such as fossil fuels like coal and natural gas as well as renewable fuel sources such as wind, hydro, and solar. Electricity requires less energy than other fuels to produce equal or greater results. This latter concept is known as the concept of total resource efficiency, and can be illustrated by comparing the net energy result between electricity and other fossil fuel sources after taking into account all losses from conversion and delivery.

For instance, consider a single unit of energy derived from an oil or gas well. In an electrical system, it is converted to electricity at an assumed heat rate of 11,000 Btu/kWh. This conversion results in 0.31 units of electricity from the original 1.0 unit of fossil fuel. (This is a conservative assumption; many fossil power plants are more efficient than this.) Applying a steady-state loss of eight percent in transmission results in a delivery of 0.29 units of energy to the electric end use. By comparison, a typical gas transmission and distribution system loses ten percent of its energy in pumping and leakage, resulting in 0.90 units of energy being delivered to the gas end use from the original 1.0 unit extracted from the well.

On its face, the comparison would seem to point to electricity as being the less efficient energy source. But at the point of end use, electricity ends up being far more efficient than gas in producing greater results from that single unit of energy. Compare the processes of freeze concentration and thermal evaporation. Both processes result in the extraction of water from a substance. However, freeze concentration achieves this extraction with only 14% of the energy required by the evaporation process (144 Btu per pound of evaporated water compared to 1000 Btu per pound of water extracted by direct evaporation). Even after considering the improved heat recovery possible in the evaporation process, the net energy use is twice as high in the natural gas fired evaporation process (see Figure 1). (Other electrotechnologies, such as technologies based on membranes and mechanical vapor recompression can provide excellent efficiency as well.) Electric infrared drying of textiles has replaced fossil fuel (gas and steam) because of significantly higher energy efficiency (2.5 lbs. of water extracted compared with 1.0 lbs. of water extracted).

Figure 1. Comparable Energy Efficiency of Freeze Concentration and Thermal Evaporation Processes



Source: Utility Marketing Strategies: Competition and the Economy, Clark W. Gellings 1994.

The benefits don't stop with energy efficiency, however. Electricity at the point of end use is also frequently the cleanest energy option, with little or no harmful effect on the environment. In addition, users can optimize the "green" effect of electricity usage by selecting renewables as a generation source for some or all of their electricity needs.

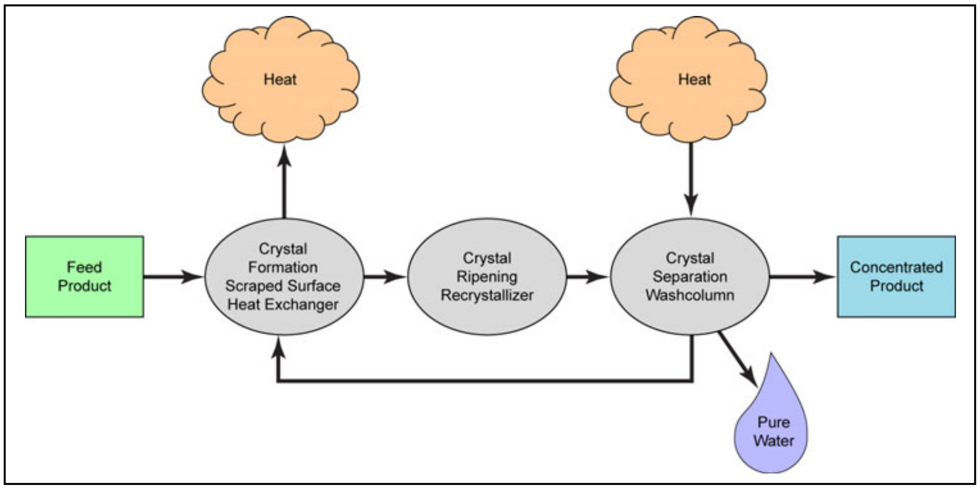
Electrotechnologies with Broad Potential Impacts in Industrial Applications

Given the wide expanse of industrial applications that can benefit from electrotechnologies, it is useful to consider the unique attributes of each specific electrotechnology and how it can be applied in diverse industrial settings. Each specific technology may also offer a host of unique benefits in addition to energy efficiency. For instance, some process heat electrotechnologies may significantly reduce production time as well as require less physical space than thermal counterparts. Or, an electrotechnology may result in improved product quality when compared to a thermal process. Other benefits may include load shifting, enabling a manufacturer to operate electrical equipment such as electric boilers at lower-cost, off-peak times.

Freeze Concentration/Conditioning

As described above, freeze conditioning or concentration uses electrically-based vapor compression to freeze out water from a water and solid mixture. As the system lowers the temperature of the product or solution below the freezing point of water, the water portions crystallize out as ice particles (see Figure 2). As illustrated in Figure 1, freeze conditioning is a highly energy-efficient technology. In fact, some energy providers estimate that freeze concentration processes use only one-eighth the energy needed to evaporate the same quantity of water.

Figure 2. Freeze Concentration Process



Source: Global Energy Partners

The process also offers other unique benefits. Because end products can be concentrated to a fraction of their original volume, they require less storage space, reducing shipping costs. Perhaps most importantly, freeze concentration enhances the end product quality. This makes it an ideal process for agricultural and dairy applications. The low operating temperatures retain natural flavors, nutritional values, and aromas. Shelf life can be extended for some products, such as concentrated milk.

Freeze concentration also shows promise for wastewater treatment applications, necessary in a variety of industrial settings, such as paper processing, food processing, hazardous waster removal, and municipal wastewater plants. In one application in The Netherlands, freeze concentration is being used to treat liquid waste streams to concentrate the hazardous fraction of waste prior to incineration. This process reduces the energy needed for incineration by 75% (Freeze Conditioning Technology, Global Energy Partners 2006). Los Alamos National Laboratory has also explored the use of this process to separate radioactive materials from liquids, slurries, and sludges. Once the components are separated, the water can be recycled for reuse while the concentrated radioactive substances can be disposed of more economically (Freeze Conditioning Technology, Global Energy Partners 2006).

Ozonation

Many industrial applications create waste materials that must be cleaned prior to reuse or disposal. These waste materials may contain harmful bacteria or viruses that pose health risks to humans. The most common conventional process used to eliminate these hazards involves chlorination. This process itself, while cost-effective, has proven ineffective against certain microorganisms, as chlorine is ineffective against certain bacteria. Furthermore, chlorination results in the creation of potentially harmful chlorinated by-products.

Alternatively, ozonation involves the generation of ozone, a powerful oxidizing agent, which is then applied to the product or solution to eliminate the undesirable elements. This process is highly effective in destroying bacteria, fungi, and viruses. In fact, the U.S. Food and Drug Administration (FDA) recognized ozone as an antimicrobial agent suitable for use in food processing in 2001 (Ozonation of Food, Global Energy Partners 2006). The process is increasingly being used in treating wastewater and in the food processing industry for this reason. For instance, Strickland Produce Company in Nashville, Tennessee installed an ozonation system for cleaning and sanitizing its flume water, which is used to wash fresh cut vegetables and lettuce before packaging. With the upgrade, the company realized water savings of 60% while providing superior product quality and longer shelf life ("Ozone Improves Processing," EPRI 2002).

New ceramic-coated metal conductors in ozone generators have lowered energy consumption compared to earlier technologies by as much as 50% (Highly-Efficient Ozone Generator, U.S. Department of Energy 2002). Other industrial applications where ozonation may be beneficial are in the paper and pulp industries, for product bleaching, and in hospitals and other healthcare settings for sterilizing equipment. In addition, emerging uses for ozonation may include treatment of agricultural crop residue to improve its potential for livestock feed, controlling NO_x emissions in stack gases, and treating tire rubber to enhance its performance in asphalt blends (Emerging Environmental Technologies, EPRI 2003).

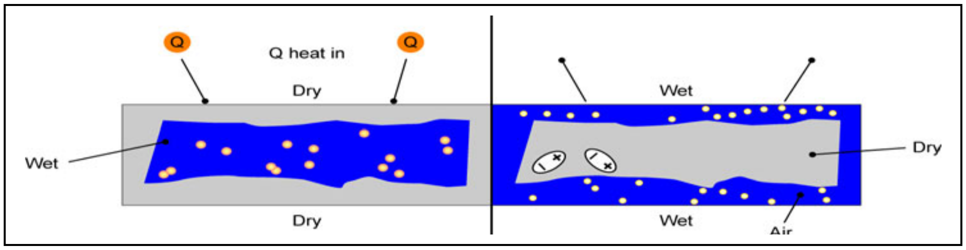
Heat Process Technologies

Electrical heat process technologies, which utilize wavelengths of different frequencies of the electromagnetic spectrum (middle frequency infrared, high frequency radio, and high frequency microwave) offer increased energy efficiency and a host of other benefits. They provide outstanding control of heat output and process temperature, can selectively heat specific areas, and provide high heating efficiencies. In addition, electrical heat process technologies often reduce physical plant space requirements compared to conventional thermal heat process technologies.

Of these, electric infrared (IR) already enjoys widespread use in materials fabrication, aluminum casting, paint and coatings applications, and other curing processes. For instance, Maytag replaced its gas IR oven with an electric IR oven to treat kitchen range control panels as part of the process of applying operation labels. While energy savings will vary from installation to installation, in this case Maytag realized energy cost savings of 33% by switching to an electric IR oven. Furthermore, Maytag reduced floor space requirements by 95% ("Electric IR Oven," EPRI Tech Application 1999). Additional benefits from IR processes include the elimination of combustible materials from the workplace as well as reducing CO_2 and VOC emissions emanating from the facility.

Dielectric processes utilize an alternating electric field of high frequencies (RF or microwave) to generate heat in dielectric (non-conductive) materials at the molecular level. The substance heats from the inside out instead of from the outside in as with conventional heating processes (see Figure 3). Like IR, dielectric methods enable faster heating times and more even heat application. The absence of combustible materials results in fewer environmental and safety issues. And, dielectric methods enable faster shutdown and startups due to their instant on/off operating characteristics.

Figure 3. Comparison of Conventional and Dielectric Heat Processes



Source: PSC

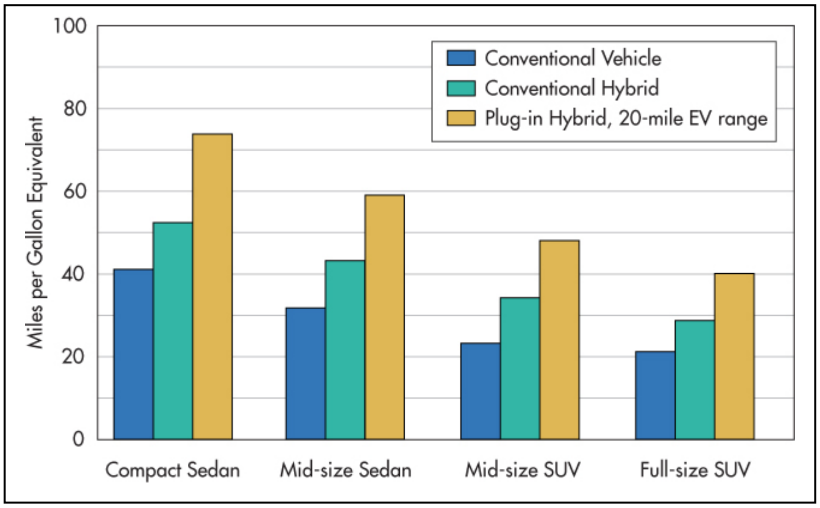
Numerous industrial applications employ RF and microwave heating (e.g., food processing, textiles, paper manufacturing). Some research has explored other applications, such as environmental processing of hazardous wastes and municipal and steel mill sludges. Preliminary results of research on treating oily steel mill sludges via microwave processes suggest this method may be far more efficient at removing greater quantities of oil and grease, with removal rates exceeding 95 percent. With current disposal costs ranging from $20-35 dollars per ton, this method could generate savings of $15-30 dollars per ton of sludge, for total savings industry wide of $6 to $12 million dollars annually (Emerging Environmental Technologies, EPRI 2003).

Electric Transportation

Given the ubiquitous need for materials transportation in industry, electric transportation presents opportunities for energy savings throughout the industrial sector as well as the freight industry. Widespread research and development has resulted in commercial electric vehicles (EVs) gaining acceptance for individual and commercial use. Most EVs feature hybrid gas and electric technology in which the internal combustion engine charges the electric battery system. Plug-in hybrid electric vehicles (PHEVs) feature larger batteries than conventional hybrid vehicles and the capability to recharge batteries by plugging into electrical outlets. PHEVs offer greater fuel economy than either conventional vehicles or conventional hybrid vehicles (see Figure 4).

These vehicles offer additional benefits that are particularly well-suited to industrial applications. Because PHEVs are charged when the vehicle is not in use, some of the electricity required to recharge can be shifted to off-peak times when electricity costs are lower.

Figure 4. Comparative Fuel Economy of Plug-in Hybrid Vehicles versus Conventional and Conventional Hybrid Vehicles



Source: EPRI. 2006

Non-road electric vehicles are widely used as lift trucks, forklifts, and other service vehicles in many manufacturing settings. Most of these vehicles utilize batteries that must be removed, recharged, and replaced in the vehicles. Electrotechnologies such as fast-charging batteries speed this process, which is particularly important in multi-shift manufacturing and distribution operations. For instance, the GM-Spring Hill Manufacturing Operations General Assembly Plant in Spring Hill, Tennessee operates two shifts and changes electric lift truck batteries daily. The company tested the feasibility of fast charging and found that not only did the new technology improve energy efficiency but it significantly improved worker productivity (Fast Charging for Electric Lift Trucks," EPRI 2004).

The ground freight industry offers unique applications for energy-efficient electrotechnologies. Studies have shown that diesel truck engines idle about eight hours per day, since under federal law, drivers must rest eight hours for every ten hours of driving. During these rest times, many drivers idle their engines as a source of power for cab air conditioning or heating as well as on-board appliances that may include microwave ovens, refrigerators, coffee makers, televisions, DVD players, and stereos. Electrically-based systems that can provide a source of power, both on-board and off-board, can save as much as 1800 gallons of diesel fuel (the amount of fuel an average heavy-duty truck uses annually to support idling), five tons of nitrogen oxide, and 21 tons of CO_2 per truck annually (Truck Stop Electrification, California Energy Commission 2007). The U.S. Department of Energy is spearheading efforts to reduce idling through adoption of such technologies, referred to as truck stop electrification (TSE). To date, more than 30 truck stops across the U.S. have idle reduction electrical systems providing shore power for heavy-duty trucks.

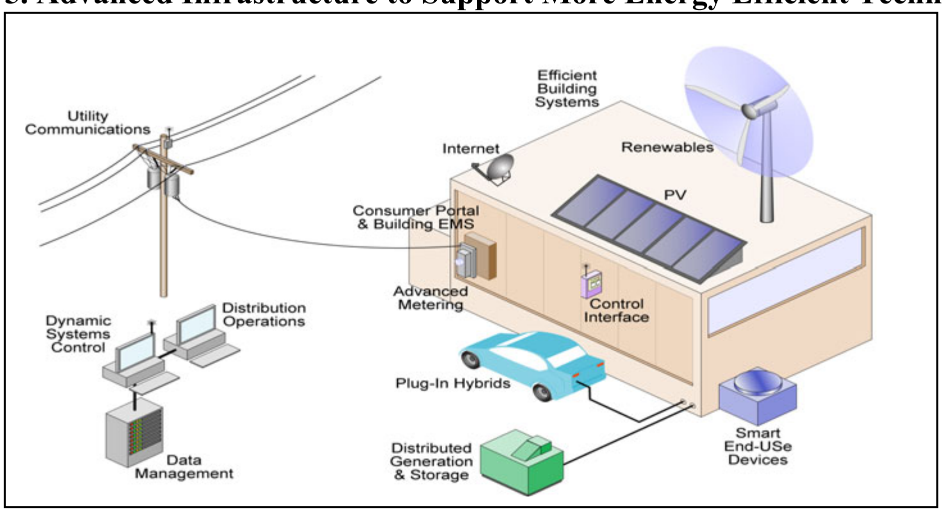
The Challenges Ahead

Arming U.S. industry with the tools it needs to remain competitive in the global marketplace, while also adopting energy-efficient, sustainable processes requires a continuous stream of technology innovations. The success of the electrotechnologies already in use throughout industry only hints at the performance potential of future technologies or enhancements to existing ones. R&D can pinpoint where advances in existing technologies can increase energy efficiency and technical capabilities. Particularly in high energy consuming industrial sectors, such as paper, food processing, chemicals, and petroleum, even modest advances offer significant impacts. Furthermore, continued R&D can help reduce capital costs, increasing adoption of energy-efficient electrotechnologies.

An integrated, coordinated energy efficiency initiative is one such step that can be implemented to ensure that technological innovations continue to enter the marketplace. Through the participation of stakeholders such as energy providers, industry leaders, policy makers, and consumers, such an initiative can help identify technologies that show great promise for energy efficiency and demand response. Some research has already been conducted to identify electrotechnologies with the potential for significant impact in critical industrial and environmental applications. A few of these have been highlighted in this paper, such as freeze concentration, dielectric heating, and ozonation (Emerging Environmental Technologies, EPRI 2003). Already in use in some industrial applications, these technologies could be beneficial in other applications with further technical development. Other research has identified technologies that are still in development or just entering the marketplace (Martin, Worrell, et. al. 2000).

In parallel with this component is the development and deployment of an advanced infrastructure that can enable more energy efficient technologies. Critical elements of this infrastructure include building intelligence into industrial electrotechnologies, so that industrial users and energy providers can exchange energy information. This cannot be achieved, however, without the other critical element, which is an advanced communications and metering system (see Figure 5). Together, these elements enable the two-way exchange of a range of energy-related information—usage data, pricing signals, demand reduction requests—which continuously optimize energy efficiency resources system-wide.

Figure 5. Advanced Infrastructure to Support More Energy Efficient Technologies



Source: EPRI. 2006

Such a dynamic system will also have the capability to integrate one of the most promising technologies—electric transportation. Already in use in many industrial applications, electric vehicles and associated electrotechnologies (e.g., ETS) can be enhanced with embedded intelligence and operate as mobile distributed generation resources within a dynamic system. Containing stored electricity within batteries, electric vehicles can transport production materials throughout manufacturing facilities and plug in to recharge. Via two-way communication at the plug-in station combined with fast-charging technology, industrial users can ensure their fleet of vehicles recharge at the optimal time of day. In addition, PHEVs can provide a distributed energy resource. Utilizing stored battery energy for short-term needs, industrial users can tap into onsite PHEVs for electricity, reducing demands on the grid at peak periods.

A final challenge lies with the industrial sector itself. Facing continuous global pressure to reduce production costs, industrial users who perceive new, more energy-efficient electrotechnologies as carrying a higher initial capital cost than conventional processes, may be averse to investing in these technologies. Technology demonstrations of new processes that show both the greater energy efficiency as well as production benefits can be one means of educating industrial decision makers about the total value electrotechnologies can bring to their company.

Conclusion

American industry is searching for solutions to address rising environmental pressures, fuel prices, and production costs, while remaining competitive in the global marketplace. New or enhanced process technologies that improve overall energy efficiency as well as improve manufacturing precision and control, enhance product quality, increase productivity, and reduce environmental impacts, will go a long way toward ensuring the long-term stability and prosperity of this vital economic sector. An energy efficiency initiative can coordinate multiple development projects that focus on desired enhancements, such as advances in membrane technology for separation and purification of key industrial components, the technologies necessary to integrate PHEVs into the distribution grid, and development of advanced meters and energy services portals to enable two-way data communication. Such an R&D technology initiative would extend beyond energy efficient technologies to address the overlapping areas of demand response and dynamic systems to create a truly dynamic energy infrastructure. From the fields where rice straw is treated with ozone to the steel mills where oily sludges are purified and to the truck stop where haulers plug into shore power for a well-deserved rest, industrial energy users would rely on intelligent processes and devices to optimize electricity use, productivity, and sustainability. In a world where resources are in ever-increasing short supply, this is a picture that makes economic sense.

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