# How Smart Manufacturing Saves Money

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**ABSTRACT**

Smart manufacturing is a broad, complex, and often confusing subject. It has many parts and many connections with other technologies. Simply put, it is the integration of all facets of manufacturing through the use of information and communications technologies (ICT). It seeks to integrate all aspects of manufacturing, regardless of level of automation, and all the individual units of an organization in order to achieve superior control and productivity. It can give everyone in the organization the actionable information they need, when they need it, so that each person can contribute to the optimal operation of the enterprise through informed, data-driven decision making.

With smart manufacturing, energy can be saved at each level of automation. Starting at the device level, replacing an inefficient device such as a motor with a more efficient one will save energy. However additional energy can be saved as a system is made more efficient, and then again as a process is operated more efficiently. Ultimately the entire manufacturing facility operates more efficiently, and the entire manufacturing supply chain produces only the particular items requested by customers.

This paper will examine how smart manufacturing saves energy. It will provide a basic understanding of the layers of smart manufacturing and how they all contribute to a superior ability to manage energy use and document energy savings.

## Introduction

Smart manufacturing is many things. It is the sensors and devices that are embedded with software and that can communicate with one another and with other systems through networks. It is automated control, integrated manufacturing, and networked companies improving productivity through information sharing and informed decision making. It is improved measurement, evaluation, and validation via cloud-based data analytics. It is the harvesting of big data to analyze operations, identify faults in systems, understand customer interests, and inform operators. It is the combining of enterprise resource planning (ERP) and production management systems, and the connection of both with product design systems that take into consideration environmental issues throughout a product's life cycle. It is the networking of an entire supply chain, from mine to manufacturing to merchandise on a retail shelf, from farm to factory to table. It is the capability, it is the stuff, it is the phenomenon that is transforming manufacturing.

Smart manufacturing has been enabled by the ability to connect just about any device to any other object or person. It is set to transform the industrial sector and its use of energy, raw materials, and labor over the next couple of decades. Savings opportunities encompass electricity, natural gas, transportation fuels, and other fuels as well as chemical feedstocks. This paper explains how smart manufacturing can address all of these opportunities in a holistic way and help stakeholders meet their respective goals more effectively.

Given its potential to impact the nation's energy use, smart manufacturing is worth the attention of a diverse set of stakeholders. Understanding smart manufacturing and how it can transform energy management is obviously important to end users, but it is also relevant to energy efficiency and economic development professionals and to environmental advocates. The information in this paper is intended to facilitate more informed energy efficiency decision making in the manufacturing sector, program development in the efficiency program sector, and policy discussions in the utility and public sectors.

## Smart Manufacturing Technologies and Energy Savings

Smart manufacturing is enabled by conventional automation and by ICT. The building blocks of automation are devices, sensors, systems, processes, and controls. The building blocks of ICT are hardware, software, communication protocols, networks, and interfaces. Many of today's devices are sold embedded with software (called firmware) that enables connection with other devices. Combining devices with other equipment and sensors forms systems; combining multiple systems forms processes. Multiple processes comprise a manufacturing facility and such facilities are key components of a supply chain that also includes conversion of raw materials, transportation segments, and receipt by customers.

At each level of a production process, additional energy can be saved. Starting at the machine level, replacing an inefficient device such as a pump with a more efficient one will save energy. A control loop at the process level will save additional energy and tying that control loop into the production line control system will produce another increment of savings. . Ultimately, connected control systems for the entire manufacturing facility and its suppliers and customers will minimize energy usage as only items requested by customers will be produced.

System optimization becomes more challenging at each level. However it is now possible to identify the optimal operating conditions of complex systems by inexpensively collecting and analyzing large quantities of performance data, often remotely in the cloud. System optimization maximizes productivity and minimizes costs. Energy is one of the key manufacturing costs that is minimized.

With the ability to measure and track energy usage comes the ability to report the performance of energy efficiency investments in real time. This capability will be valuable to energy efficiency program administrators that must prove the cost effectiveness of their programs and financial institutions that create investment instruments backed by investments in energy efficiency. For the former, it yields higher quality and more timely performance data. For the latter, it provides an inexpensive way of analyzing risk and reporting asset performance. But before the manifestation of efficiencies in a supply chain can be explained it is first necessary to explain the fundamental difference between smart manufacturing and conventional automation.

### Hierarchy of Control Technologies and Associated Energy Savings

To differentiate between conventional energy measures and intelligent energy measures, it may be helpful to revisit a methodology discussed in *Intelligent Efficiency: Opportunities, Barriers and Solutions* (Rogers et al. 2013). The same concepts apply to automated manufacturing and smart manufacturing.

We will illustrate the difference using the example of a pumping system that pulls water from the city water supply and moves it to a water tank several hundred feet away.[1] The water tank supplies various processes throughout the factory, so water is drawn out at varying rates

[1] This example is a friction-dominated system so that we can demonstrate how affinity laws can result in energy savings.

throughout the day. The goal is to use as little electricity to supply water to the plant as is needed to keep up with the pace of customer demand for product.[2]

The methodology establishes a hierarchy of technologies ranging from the most basic to intelligent efficiency measures with adaptive, anticipatory, and network capabilities. Table 1 shows the hierarchy. The levels connote complexity rather than additional energy savings, although energy savings generally increase as we move toward level 4.

Table 1. Hierarchy of control technologies

| Level | Technology |
|---|---|
| **Level 0** | Manual on/off |
| **Level 1** | Reactive on/off |
| **Level 2** | Programmable on/off |
| **Level 3** | Variable response |
| **Level 4** | Intelligent controls |

The pump in the water system is driven by an electric motor. The most basic way of controlling the speed of the motor is by using a simple manual on/off switch. Since there is no automation at this baseline level, we are calling it level 0. Whether the pump is on or off has an obvious impact on the energy use of the system, but other components—the pump, valves, and piping—also contribute to the pumping system's energy use over time. The amount of energy consumed by the motor is related to the features of the pump and friction within the piping and valves.

The next level (1) is a reactive control, such as a level sensor that turns the pump motor on and off automatically. A common system would be a pump that fills the tank until it is full, at which time a float trips the off switch and the pump is turned off. When the tank gets too low, another mechanical device turns the pump on. This process continues without human intervention day in and out. This is a rudimentary example of a closed-loop system.

The next level (2) is programmability. Instructions in the water pump's programming determine the conditions (e.g., time, tank level, production scheduling) under which the pump is turned on or off.

This system seems efficient enough; however, in this and the preceding scenarios, the pump operates at full speed each time it runs. Running the pump at a lower speed can save energy. Cutting the speed in half reduces energy consumption for a given amount of time by seven-eighths, so even though it will take twice as long to fill the tank, it will take a fourth as

[2] In a conventional push system, a company estimates its sales volume, orders the appropriate materials, and "pushes" them through the production line toward the customer. In a pull system, the customer "pulls" a product from the end of the production line, which triggers the manufacture of a replacement product. That in turn pulls intermediate and raw materials from suppliers.

much energy.[3] However, if it is run too slowly, it may not be able to keep up with demand for water by production.

Level 3 incorporates variable response. The pump motor is connected to a variable-speed drive (VSD) that speeds up or slows down the pump in response to an instruction. That instruction could be in response to data from a sensor or from a predetermined program. For example, the pump speeds up the lower the tank gets and slows down the closer to full it gets. The VSD adjusts the speed of the pump, and with each second that the pump operates at less than full speed, energy is saved.[4] We can call this system-level savings due to automation.

There is still some waste left to be eliminated: the difference between what this automated system uses to fill the water tank and the least amount needed to satisfy production. Prior to new smart technologies, it would have been very difficult and expensive to capture this comparatively small amount of additional savings. What smart technologies give is the ability for the production line to tell a central control how much water it needs now, five, fifteen, and sixty minutes from now. The pump can use this information to fill the water tank to the exact level needed to ensure it maintains pressure and volume for the production line.

Level 4 is the full integration of all of these enabling technologies with an additional software component that analyzes past performance and adjusts system outputs in anticipation of future performance. At this level, additional savings are possible because the process control is proactive and not just reactive. It has the ability to take past performance into consideration in determining future operating set points. This may be called system-level savings due to smart manufacturing.

Conventional production automation allows the pumping system to be integrated into the production process, which is essentially just a larger and more complex system. Processes have the same levels of control as a system, including on/off (level 0), reactive (level 1), automated (level 2), and automated and adjustable (level 3), all these to be integrated with the rest of the plant and programmed with adaptive and predictive decision making (level 4). These same levels of control are possible for facilities, for entire companies, and even throughout the manufacturing supply chain.

In this hierarchy of control technologies, it is important to keep in mind that they connote increasing level of complexity and not higher levels energy savings. For example, a reactive control for warehouse lighting will save as much or even more energy than a programmable system. Nevertheless, in a cost–benefit analysis, these levels are useful for determining the portion of overall energy savings attributable to the intelligent or smart aspect of a system. For example, they can help determine incremental savings due to an enabling technology such as a variable speed drive (VSD), as well as the additional savings that are possible when that drive is networked with an intelligent plant production management system.

## Savings by the Level

A more efficient motor is a more efficient device. Device efficiency is tied to the innate ability of the device to convert one form of energy into another. For the motor, it is electricity into mechanical motion. For the pump, it is mechanical motion into hydraulic energy. The motor,

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[3] Flow is proportional to shaft speed, while the amount of power use by a pump is proportional to the cube of the shaft speed ($P_1/P_2 = (N_1/N_2)^3$).

[4] This is not an absolute. There are many common situations in which a VSD does not guarantee energy savings.

its electrical drive, the pump and associated pipes and valves, and the control mechanism and its sensors (if any) all comprise a system. Using more efficient devices or, as was just described, operating in an optimal way, can improve system efficiency. This and the other ways smart manufacturing saves energy are listed in figure 1.

(Efficient device) − (Inefficient device) = Savings

(Device operating only as needed to meet demands) − (Device operating in on/off mode) = Savings

(Process operating only as needed to meet production target) − (Process operating in on/off mode) = Savings

(Past performance instructing current performance) − (Best guess at optimal settings) = Savings

(Smart design[5]) − (Conventional design process) = Savings

(Connected systems and business units) − (Conventional isolated systems and business units) = Savings

Figure 1. Energy savings from smart manufacturing

## Process-Level Energy Savings

The water-pumping system described above is part of a larger manufacturing process. The same network that enables the pump to schedule its load for the day also allows each system in the production line to optimize its use of energy. The system may do this automatically or it may present options to the production manager. The manager can accept its recommendations or adjust them when aware of important information of which the production automation system is not. As each of these systems communicates with other systems, an improved optimal operating scenario can be discovered. This process-level efficiency adds to the savings that are possible at the systems level. The analysis that optimizes the process may be centralized or it may be dispersed throughout the network.

## Facility-Level Energy Savings

At the facility level, smart manufacturing integrates both vertically (within a production process) and horizontally (across systems). For example, many companies now have separate business and production management systems. The first system takes care of accounting and perhaps payroll, and the second manages the machinery in the plant.

The next level of integration is for the production process to communicate with the business management systems, such as accounting, payroll, and ERP. This will simplify the transfer and analysis of information, such as raw-material delivery times and labor hours per product shipped. When connected with suppliers, these systems can communicate to production the quality of the raw materials so that any changes to the amount of processing required can be anticipated. For example, a high-quality, albeit more expensive, raw material might require less milling than a lower-quality, less expensive raw material (Koc and Lee 2002). The business automation system can take all of these variables into consideration and recommend options that reduce energy use and overall costs.

[5] Smart design, often referred to as “design for the environment” or DfE, is not covered in this paper, but is well established field of work. For more information: EPA “Design for the Environment”: http://www.epa.gov/dfe/pubs.about/index.htm.

## Enterprise-Level Energy Savings

Integration of multiple production facilities makes asset and resource utilization visible to corporate management. Determining the optimal production levels for a mix of product across a fleet of manufacturing facilities is no longer a forecasting process but a dynamic one that integrates customer demand, supplier realities, and facility capabilities. Factories are most efficient when operating at capacity, so integration that improves decision making about how to best allocate resources will result in less waste.

## Energy Savings throughout the Supply Chain

After achieving success through integrating business asset management and production automation systems, the next step is to integrate management systems that organize a company's customer relationship management (CRM) and procurement and supplier relations, known as supply-chain management (SCM). Customer order processing and client-management software programs can be integrated to inform the production system of existing and pending orders. Once they are integrated, customer demand, production, and supplier data are more accessible, better contextualized, and available more quickly. The ability to make better decisions leads to the possibility of operating more efficiently. When the supply chain operates more efficiently, less waste is generated and, by extension, energy is saved.

## Smart Manufacturing Software Platform

For a network to function, it needs a software platform to manage the exchange and processing of information and interface with operators. Software's first step is to turn data from a sensor or meter into information. The next step is to turn that information into knowledge. The last step is to turn the knowledge into wisdom that enables the cost-efficient management of the organization (SMLC 2011).

A simple example of a platform is the software that enables a cell phone to send and receive phone calls. A smart platform, like a smart phone, enables other software programs (applications) to make phone calls, texts, video, and many other types of transactions. Most smart phones come with built-in applications and the ability to add more to meet a user's needs. Smart manufacturing platforms will come with built-in applications, such as data translators and workflow modeling tools, and have the ability to support other applications to meet facility and enterprise needs. A platform may be vendor-specific, requiring all applications to come from a single vendor, or it may use open standard, in which case multiple vendors can provide applications so long as they are compatible with established standards. Some platform products are commercial off-the-shelf (COTS), while others are purpose-built to fulfill a customer's specific process-control needs.

A smart manufacturing platform will provide a foundation for unified communications, network enablement tools, system virtualization (modeling and simulation) technologies, and the software infrastructure for interactive applications (SMLC 2011). The benefit will be improved production control and simpler worker experience and interaction (Harbor Research 2011). Figure 2 illustrates the role of software in a smart manufacturing platform.

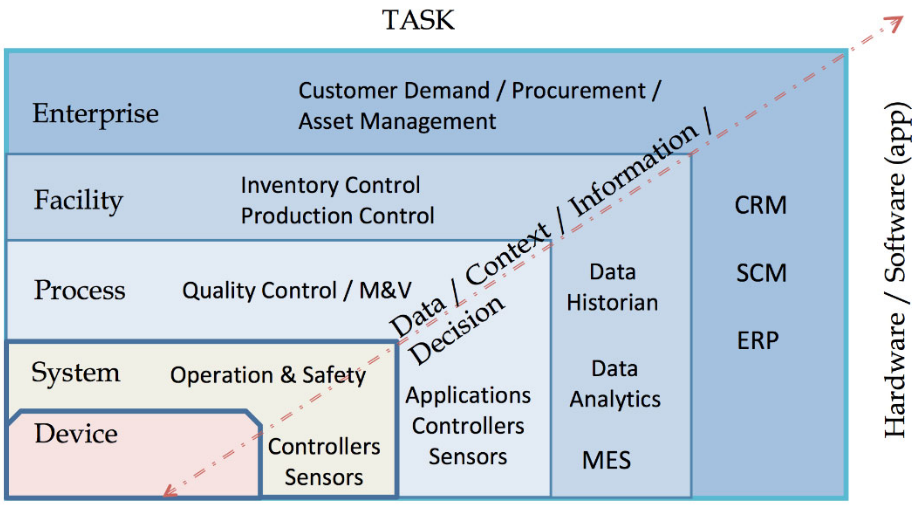


Figure 2. Software purposes and locations within an organization

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### Case Study: Valero Energy Corporation

Valero used computer modeling to determine the most efficient loading of individual pieces of equipment and to optimize energy usage at one of its refineries. The model took into consideration the purchase price and the supply and use of fuel, steam, and power at the facility. It ran simulations based on process unit energy demands and system constraints caused by equipment or environmental regulations. With this information it determined the optimal operating conditions. (OEERE 2005)

### Integrating Management Systems

ERP systems have been the business-operating backbone of many corporations dating back to the 1980s (Koc and Lee 2002). However, until recently, it was not possible to integrate resource planning and manufacturing execution systems (MES) that control systems on the factory floor. Information coming from and flowing to the plant floor, important details, such as maintenance schedules, unpredicted downtime, and variability and reliability of raw materials, were not factored into the information these systems provide to high-level decision makers. With new smart manufacturing software platforms, this will be possible.

Currently, for most facilities, production information flows between production and management, and ERP systems share information between business operations and supply chain. What they cannot do is have production information influence interactions with the supply chain and have supply-chain information influence production decision making (Koc and Lee 2002). The ultimate goal of smart manufacturing is to handle information only once, enabling the optimization of assets, synchronization of enterprise assets with supply-chain resources, and automation of business processes in response to customer demands (Koc et al. 2005).

As the name implies, an ERP system is an enterprise-level resource and asset-management system. The more it can reach down into the day-to-day operations and collect data, the more informed decisions management can make. This extends beyond collecting production and energy information. Though beyond the scope of this paper, the ultimate goal is the integration of all methods of monitoring, reporting, and managing organizational tasks: environmental monitoring and compliance systems, customer relationship software systems, purchasing, financial, payroll, and even worker training. Where energy use is influenced by these control practices, time-value information from energy suppliers via the smart grid can be used to minimize costs and improve profitability. Figure 3 shows the interrelated functions of a smart manufacturing ERP system.

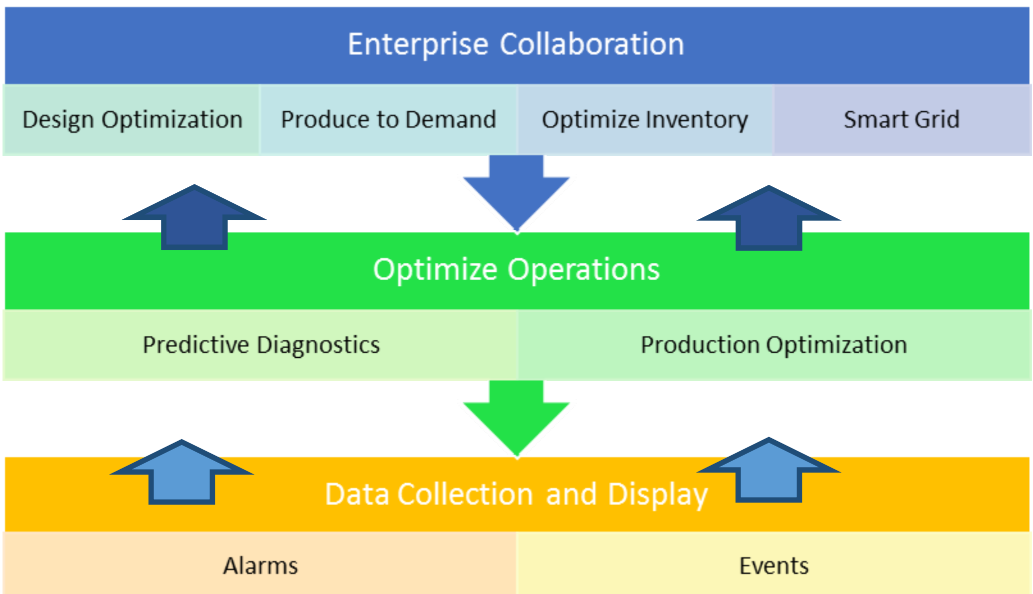


Figure 3. Software roles and relationships. *Source:* Sujeet Chand, Rockwell Automation (Chand 2011).

There are management systems for functions at all levels of an organization. Some of them (such as an ERP system) involve software, while others (such as an ISO 50001 system for energy management) may not. A smart manufacturing platform can collect and integrate the information from both and simplify organizational management. This is often done through interfaces that provide information as knowledge and that enable wisdom.

### User Interfaces

Most manufacturers have collected data from machines on their factory floor for many years and have linked the equipment together for greater efficiency with a process control system. This is the current baseline for manufacturing (Warren 2011).

More advanced companies are investing in new data analytical capabilities that can be stored remotely and have user interfaces that convert the data into actionable information that enables real-time problem solving (Selko 2013). They provide the right information at the right time to users in a context that is clear and simple to understand. They translate information into knowledge that facilitates wise decision making.

This is significantly different than automation that operates without human intervention. There are points in all complex manufacturing processes at which decisions must be made by people because the data needed or the logic required are not available within the existing automation system, or because it would not be appropriate for a machine to make the decision. It is at these intersections that the inorganic communicates to the organic, i.e., machine to human.

In response to the need for these interactions, a whole industry has developed around creating dashboards, i.e., interfaces that present system performance in a meaningful and actionable way to operators. Since many people are visual learners, comparative charts and graphs and simple color scales are the modes of choice to communicate system performance. Many of these products leverage smartphones, tablets, and social media applications (Herbert 2014). They commonly are used at three levels: machine control, operation, and enterprise. For example, a service technician could have the ability to securely and remotely chat with a device to check status and run diagnostic routines. The technician could post notes for other technicians, customers, or managers on the device's Facebook-style wall (Harbor Research 2011). At a higher level, these interfaces can put customer demand, production, and supplier data in context at a rate that is faster and more accessible, enabling companies to make quicker decisions and improve efficiency (Selko 2013).

Some dashboards are created specifically to manage energy. In others, there may be only a page or graphic on a page that reports energy use and trends (Tyler Reitmeir, Sotecia, pers. comm., November 21, 2013). At an advanced level, a dashboard is an energy visualization system that correlates energy and process data to provide operators with energy measurements in the context of production outputs or inputs that resemble other production metrics such as kWh per widget or Btu per million gallons. This contextual energy is then tracked, trended, and analyzed to support continuous improvement initiatives (Dussault 2013).

**Summary of Energy Savings**

Smart manufacturing brings about savings at all levels of a process and an organization. It has the potential to make each piece of something and every collection of pieces more efficiently. The leading motivation to invest in automation is to improve productivity. Most energy savings are ancillary benefits to other higher-priority performance metrics for manufacturers. If one measures productivity as the ratio of throughput to the value of capital equipment and operating costs, then improvements in productivity can come from greater output, lower value of equipment, or lower operating costs. Since energy is a variable cost of production, it is important to companies as a component of this larger metric. When an investment improves the productivity of a process, workforce, facility, or company, it also tends to save energy.

Smart manufacturing has the potential to bring about a step change in manufacturing efficiency and ability to fulfill customer demand. In the process, it will reduce the energy intensity of manufactured products. At the most basic level, energy intensity is the amount of energy used by a facility divided by production volume. It is an average amount of energy used per unit of production and an important metric to keep in mind when discussing industrial energy efficiency, because most facilities increase in size and capacity over time. Productivity improves, consolidation happens, and new product lines are added. Therefore the amount of energy consumed by a facility may go up even as its overall efficiency improves. Energy intensity, also referred to in the inverse as energy productivity (the amount of product for a given amount of energy), is a better method of gauging the use of energy at a facility.

Many investments in smart manufacturing will directly yield significant energy savings, while others will produce only marginal and inconsistent savings. It is the collective impact that is noteworthy. In aggregate, they will have a profound effect on consumption; it is this potential that will be important to organizational management and may be of interest to other stakeholders such as local utilities and energy efficiency resource acquisition programs. Regardless of a facility's size or energy intensity, pursuit of these potential savings will be a necessity. To be competitive in the 21st century, manufacturers must manage all of their costs.

### Additional Benefit of Smart Manufacturing's Energy Management Capabilities

Energy is usually a variable cost of production, and as such, it should be measured, monitored, and managed. Fortunately, the technologies that comprise smart manufacturing make these tasks easier. The same data collection abilities that enable system optimization also can be used to report performance in real time to management and other stakeholders such as a utility energy efficiency program administrators or financial institutions.

## Concluding Thoughts

As we look to the future, it is obvious that the ubiquity of energy performance data and the ability to analyze it will transform the manufacturing sector. Companies will be able to compete on energy efficiency, environmental, safety, and sustainability performance metrics. Customers, efficiency programs, and investors will have access to the information and will incorporate it into their own decision making.

Smart manufacturing will transform the manufacturing environment. It will enable mass customization, reduce waste, and document energy, water, and material savings with accuracy and speed. That information will be shared throughout the organization and its supply chain in an actionable format that facilitates decision making and the management of the entire manufacturing process.

Smart manufacturing will become an economic engine of growth in the industrial sector. Innovation will respond to customer demand to develop better and more-targeted products. Design, development, and delivery to market will be quicker and at a lower cost.

Aided by government involvement and technical resources, precompetitive collaboration within the vendor and manufacturing communities will bring about common protocols and standards. The interoperability of systems will grow the market to the benefit of customers and vendors alike.

Development of an open-access smart manufacturing platforms will create an entirely new business sector. While existing proprietary systems will be displaced in the short term, the much larger market for an open-access product and ancillary services will more than compensate. With the development of standard communication, security, and data-integrity protocols, the creation of open-access platforms, and the education of companies about their value, vendors will spend less of their sales cycle talking about technology and more about solutions. This approach will speed up innovation, increase customer adoption, and reduce costs.

Energy intensity, that is, the amount of energy embedded in a unit of production, will continue to decrease in individual facilities and all across the industrial sector. No overwhelming market conditions will prevent or complicate this evolution. It is part of the normal progress of manufacturing technology. It will happen because it helps manufacturers save money. Some of that money will be in the form of energy not purchased.

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