

Digitizing the Manufacturing Process Using Industry 4.0 Strategies and Building Systems Optimization in Utility Programs

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ABSTRACT

Our states are confronting climate change with new policies designed to create a cleaner, more reliable, and most importantly, more sustainable energy future. Successfully confronting climate change requires efforts in not only energy efficiency, but also greenhouse gas emission reductions. The manufacturing sector represents a large opportunity for both avenues to meet climate goals. Many manufacturing processes could enhance their energy efficiency by adopting state-of-the-art monitoring and digital control capabilities that exist today. Various companies in the market are beginning to offer services that monitor, assess, and control manufacturing processes. Digitization of building systems is well developed, but optimization of manufacturing processes and building systems through artificial intelligence algorithms and internet of things is just beginning.

This paper will discuss the programmatic implementation barriers to digital tool adoption from the utility perspective including incentive structure and customer engagement and education and assess some methods to overcome these barriers. Adoption challenges will be explored and best practices to overcome them will be defined.

Introduction

Due to global warming and climate change, the global energy trend is shifting towards decarbonization to meet the aggressive greenhouse gas (GHG) emission reduction goals set for the next decade and beyond. To keep the global average temperature from increasing by 1.5°C this century, the world needs to meet ambitious greenhouse gas emission reduction goals [UN emissions gap report 2021]. These goals include reducing global GHG emissions by at least 40% below 1990 levels by 2030 and reaching global net-zero GHG emissions by 2050 [IPCC 2021]. The United States (U.S.) is the second highest emitter of greenhouse gas globally, accounting for 13.53% of the global total¹. The U.S. has set a goal of net-zero GHG emission by no later than 2050 [Pathways to Net-Zero GHG Emissions by 2050 2021]. This requires a huge investment in clean power, electrification of transportation and buildings, industrial transformation, and reduction in methane and other climate pollutants. Most states are therefore adopting goals to reduce greenhouse gas emissions in the next decade, which can be achieved by rapidly deploying new technologies such as electric vehicles, heat pumps, renewable technologies, smart technologies for manufacturing processes and building systems, and cleaner fuels.

Figure 1 below shows the CO₂ emissions from 1990 to 2020 in different sectors. Because of the impact of COVID-19 on economic activities, there was a decline in CO₂ emissions in 2020. Additionally, there was 9% decrease in days cold enough to require building heating in 2020 relative to 2019, which decreased the demand for natural gas in 2020.

¹ This finding (13.53%) is based on the report from Statista, distribution of fossil fuel CO₂ emissions worldwide in 2020. www.statista.com/statistics/271748/the-largest-emitters-of-co2-in-the-world/

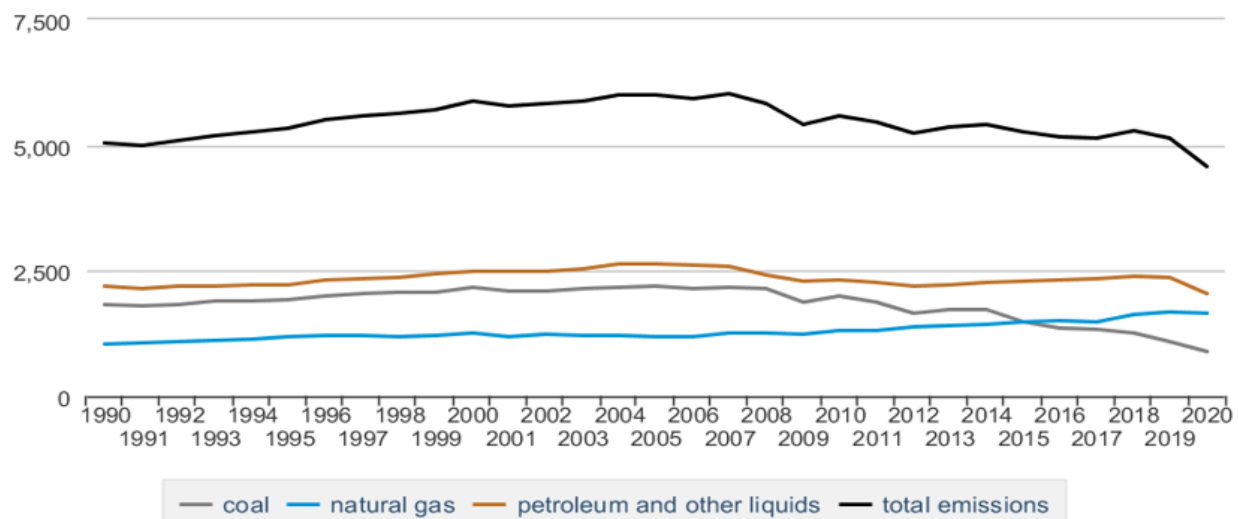


Figure 1. U.S. carbon dioxide emissions by fossil fuel (million metric tons of carbon dioxide). *Source:* EIA October 2021

Figure 2 below shows that the industrial sector accounted for 36% of the total energy consumption by the end use sectors. The figure also shows that renewable energy accounted for only 12% of energy used in the United States, and that 20% of the renewable energy in the US was used by the industrial sector.

U.S. energy consumption by source and sector, 2020

quadrillion British thermal units (Btu)

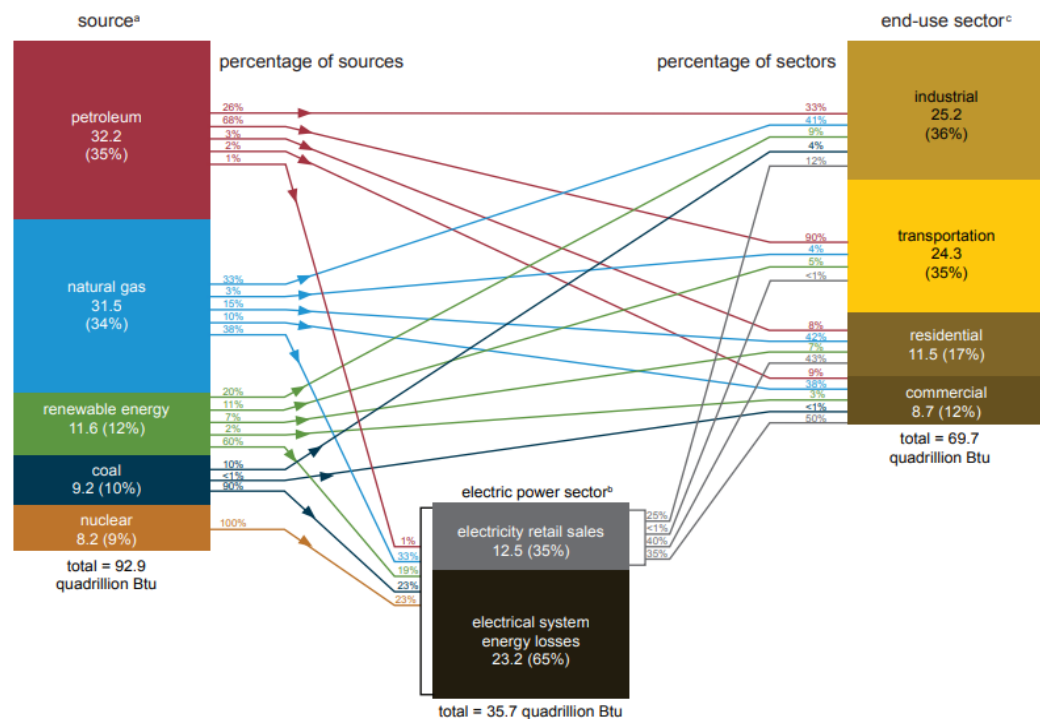


Figure 2: U.S total energy consumption by source and sector. *Source:* EIA April 2021

Within the industrial sector, the manufacturing sub-sector consumed significantly more energy than other sectors such as mining, construction, and agriculture.

Table 1. Top Four Industries Energy Consumption (%)

Industries Type	Energy Consumption (% of total energy consumed by Industrial Sector)
Manufacturing	77%
Mining	12%
Construction	7%
Agriculture	5%

Source: EIA 2020 annual energy outlook reference case for 2020

The major energy sources used in the manufacturing sub-sectors are electricity and non-electric feedstocks such as high carbon gas liquid (HGLs), natural gas, and coal.

In figure 2 above, the commercial sector accounts for 12% of the total energy usage. The major energy sources in commercial buildings are electricity and natural gas. Electricity is used for lighting, refrigeration, ventilation, cooling, plug loads, cooking, domestic water heating, and space heating. Lighting, cooling, refrigeration, ventilation, and office equipment are the largest electricity end uses in commercial buildings. Natural gas is usually used in commercial buildings for building heating, domestic water heating, and cooking purposes. GHG emissions from commercial buildings have declined in 2020 because economic activities decreased due to the COVID-19 pandemic.

Table 2. Top Five Commercial Buildings Energy Consumption

Commercial Building Type	Energy Consumption (% of total energy consumed by commercial buildings)
Mercantile and service	15%
Office	14%
Education	10%
Health care	8%
Lodging	6%

Source: EIA 2018

GHG Emissions Reduction and Energy Efficiency Measures in Manufacturing

There is a direct relationship between reducing GHG emissions and implementing energy efficiency measures (EEMs). Nadel and Ungar (2019) mention that GHG emissions can be reduced by 50% by 2050 using energy efficiency programs alone, which is halfway to the U.S. GHG emissions reduction goal.

The manufacturing sub-sector represents a large opportunity for improving energy efficiency and thereby meeting this goal. Globalization has created a competitive market in the manufacturing sub-sector which has sped up product innovation. Adopting new tools that optimize process efficiencies in the manufacturing sub-sector would enable companies to efficiently meet market demand. While governmental and environmental agencies have been targeting the manufacturing sub-sector for GHG emission reduction goals, in spite of guidelines being available, many medium-to-large manufacturers in the United States set their own corporate sustainability and greenhouse gas emission reduction goals and have included requirements for reporting progress to stakeholders. Using data to optimize building systems is not new in commercial buildings; however, it is new in manufacturing processes. Understanding manufacturing processes, installing smart sensors and actuators, and using data analytics to assess manufacturing process are new ways some manufacturers are approaching efficiency.

The largest energy savings and GHG emission reductions will come from the installation and management of strategic electrification measures such as electric vehicle charging networks and EEMs such as improving industrial efficiency, building zero energy new construction projects, upgrading efficiency in existing buildings, and using new high efficiency equipment. The importance of data increased significantly during the Covid-19 pandemic, as manufacturers are realizing that digitizing the manufacturing process will help industries increase productivity, decrease energy bills, and help achieve corporate sustainability and GHG emission reduction goals. Some of the standard EEMs already adopted by many manufacturing plants include automating manual processes using robotics, installing variable frequency drives (VFDs) in the dust collector exhaust fans, upgrading existing fluorescent lighting to LEDs and installing occupancy sensors, repairing air leaks, repairing steam traps, optimizing compressed air systems, recovering compressed air heat, and replacing old equipment with new high-efficiency products.

The following sections will discuss digitization in the manufacturing sub sector using Industry 4.0 technology and optimization of building systems using monitoring-based commissioning (MBCx) technology. Industry 4.0 and MBCx have many aspects in common. They both involve monitoring of energy using equipment by utilizing sensors, data analytics and reporting to optimize the energy usage and operation (minimizing scrap in manufacturing processes and minimizing maintenance issue in HVAC systems).

Industry 4.0 in Manufacturing Sub-sector

The discussion on digital transformation in the manufacturing sub-sector is growing around the world. Germany was the first country to introduce and promote computerization in industry, which is publicly known as Industry 4.0. The concept of digitization of manufacturing processes has been given different names in different countries such as smart manufacturing, industrial internet manufacturing, smart industry, and smart factory. There are four industrial revolutions that have taken place in terms of technological advancements as shown in figure 3.

The first industrial revolution enabled using water and steam power instead of human and animal power. The second industrial revolution introduced assembly lines and the use of electricity, gas, and oil. Automation started here with the use of these power sources coupled with communication technologies like the telegraph and telephone. The third industrial revolution took place around the middle of the 20th century. It introduced the use of computers, advanced telecommunications, and data analysis in the manufacturing processes. The very popular PLCs (programmable logic controllers) were introduced to automate the manufacturing process. There was also collection and sharing of data. We are now in the fourth industrial revolution, named Industry 4.0.

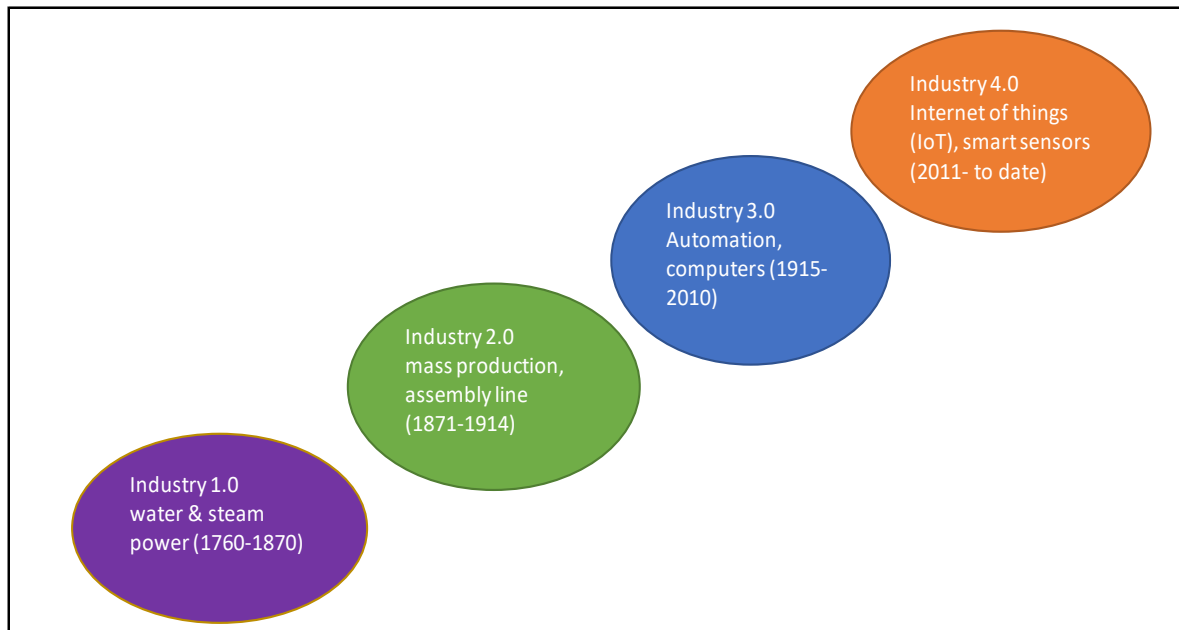


Figure 3: Four Industrial Revolution Steps

Industry 4.0 is revolutionizing the manufacturing process and increasing efficiency and transparency in decision making. Industry 4.0 can be implemented in all types of manufacturing processes. Using Internet of Things (IoT), machine learning, artificial intelligence (AI), data analytics, and cloud computing improve the product manufacturing and distribution processes. These data driven manufacturing processes provide transparency in decision making. The data are collected and analyzed with the help of advanced sensors, robotics, and monitoring software. This process helps streamline the supply chain, customer services, and manufacturing processes. The digitization of manufacturing processes also helps to predict maintenance, optimize the process (which decreases machine downtime), increase product quality, reduce machine errors, increase productivity, and provide real time visibility into the manufacturing process. Technical expertise and customer education are required to handle and analyze the big data collected by the high-tech sensors in a real time fashion. Once enabled with technology and trained, the factory personnel can monitor the manufacturing process virtually from anywhere. These modernized factories are now known as smart factories.

Technologies Used in Industry 4.0

The basic technologies used in Industry 4.0 are listed below:

- Industrial Internet of Things (IoT)
- Cloud computing
- AI and machine learning
- Cyber security
- Edge computing

Industrial internet of things (IoT) is the main component of Industry 4.0. IoT includes process machines equipped with high-tech sensors. These sensors feed controllers that are Internet Protocol (IP) addressable, making them connectable to other web enabled devices. The data collected by the sensors is stored in the cloud and is analyzed using advanced data analytics software which utilizes Artificial Intelligence (AI) and machine learning. The manufacturers can review the data from the machines, suppliers, sales, and warehouse inventories to make key decisions to find efficiencies in the manufacturing process. This advanced data analysis is done in real-time which can help increase the efficiency of the plant as well as maintain the quality of the product.

In addition to IoT, cybersecurity, supply chain management, and edge computing are vital components of Industry 4.0. Cybersecurity protocols protect the big data that these modernized systems rely on, which is paramount to maintaining system health. The use of smart technologies optimally allocates raw materials and distributes the products to end users and sharing data with suppliers helps optimize the distribution process. Edge computing uses high-tech sensors to collect enormous amounts of data and analyze it at multiple levels before applying real-time algorithms to collected data and refining to eliminate errors. Industry 4.0 provides interoperability with different systems and data granularity.

Commercial Building Systems and Monitoring Based Commissioning

Commercial buildings have various systems for maintaining function and occupant comfort. These building systems are mechanical, electrical, plumbing, fire protection, and water/sewer systems. Most of the energy usage in these building systems comes from building heating, cooling, ventilation, lighting, plug loads, and domestic water heating. To meet GHG emission reduction goals, these building systems should use new smart technologies to operate more efficiently and should switch to non-fossil fuel energy sources. This includes converting fossil fuel fired boilers to heat pumps systems and using renewable energy like solar photovoltaics to produce electricity. Digitizing building systems and using smart technologies are effective ways to achieve incremental energy savings and reduce GHG emissions in commercial buildings. The digitization process – converting information into a digital format which can be processed by a computer - includes collecting information from the sensors, storing the data, analyzing the data, and providing the results back to the input loop to make changes in the system or process for optimizing the use of materials and energy.

In commercial buildings, energy usage can be monitored using meters which are installed on the equipment. The data collected over time provides trends which can help to identify actions to reduce or optimize energy use in the buildings. This may lead to incremental energy savings. Commercial buildings utilize building management systems (BMS) and fault detection

diagnostics (FDD) tools to minimize building energy use and increase occupant comfort. The use of FDD and BMS systems is also called monitoring-based commission (MBCx), continuous commissioning, or real-time energy management (RTEM). Control systems that continuously monitor equipment, analyze data, and optimize operations have been defined by Lawrence Berkeley National Laboratory (LBNL) as automated system optimization (ASO) (Kramers, Lin and Curtin, 2020).

The FDD tool consists of software and hardware that pulls data from the base BMS system and analyzes the data to find faults in the systems. There are four functions of the MBCx, which are 1) continuous monitoring of the BMS data, 2) using advanced analytics to diagnose the system, 3) retro commissioning of the system by correcting the faults, and 4) achieving savings based on actual measurements and maintaining proper system operation. The MBCx generates three types of additional savings (Mills and Mathew 2012) which are 1) added MBCx savings from persistence, 2) added MBCx savings for measures identified at the time of initial installation of the FDD tool, 3) added MBCx savings for measures identified by continuous monitoring.

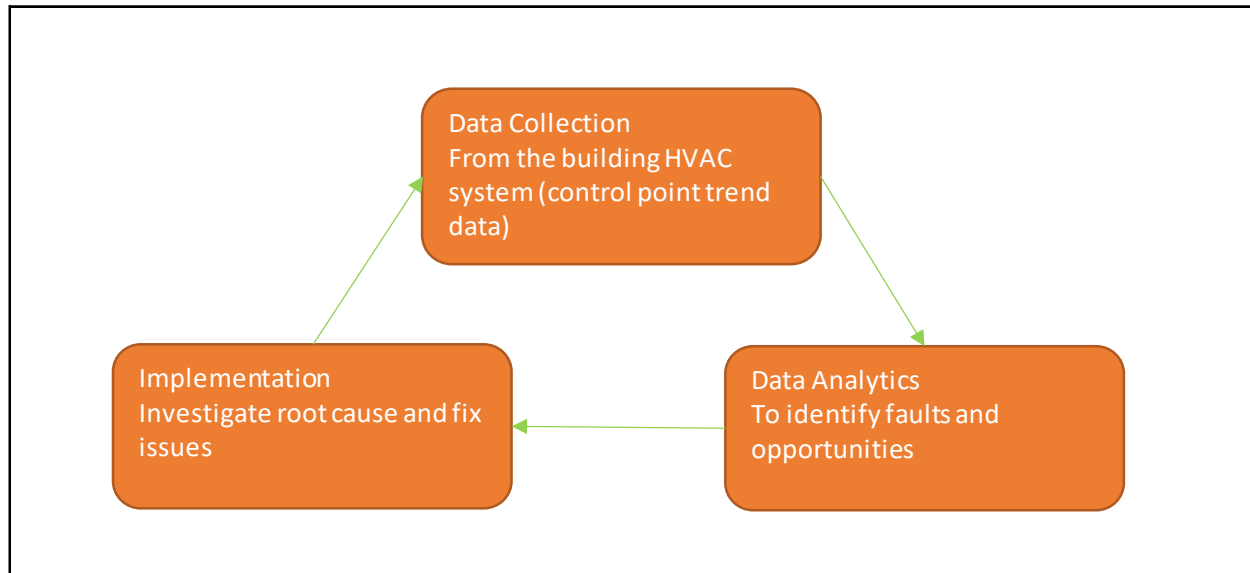


Figure 4: Core elements of MBCx Process. *Source:* Berkley Lab MBCx Factsheet

BMS in commercial buildings are used in several day-to-day applications, such as monitoring and controlling the HVAC system in the building. Typically, the air handling units (AHUs) scheduling, setpoints, and performance can be monitored, and the control parameters can be adjusted from the computer. The BMS system can generate alarms, override reports, trend reports, and help building operators understand HVAC system performance. Additionally, the lighting schedule and power usage can be monitored from the BMS lighting dashboard. The user can easily change the lighting schedule and monitor the energy use. More advanced lighting technologies such as high-end trim controls, adjusting dim levels, daylight harvesting, and network lightings technologies are being rapidly implemented in the commercial buildings. Similarly, plug loads can be monitored and controlled remotely or from the front-end dashboard. The building operator can change the schedule of the plug loads or track energy use. The smart plug load controllers cut the power equipment based on a pre-programmed schedule or motion

sensing. Other building systems such as window shades, domestic water heaters, and utility meters can be mapped into the BMS dashboard to track energy use. Smart window systems allow auto control of the shades to maintain light levels and solar heat gains in the space. The typical BMS system can work as a central tool to monitor and track these different building systems while minimizing energy use in the building by incorporating demand response functionality in the system. The central dashboard provides a picture of the entire building systems connected to the BMS. With the advancement in sensors, communication tools, and data analytics, the data generated by the BMS can be analyzed and shared with advanced digital tools such as FDDs. The data can be analyzed using AI and machine learning and the setpoints and sequence can be corrected based on the output in real-time. There are numerous companies in the market that provide FDD tools and services. BMS trend data, FDD tools, and data analytics identify faults in the system. Usually, the FDD tool vendor also provides technical service to support the use of MBCx. The service includes checking the control system periodically, generating control point health reports, analyzing reports, and identifying corrective actions needed to fix issues. Also, the FDD vendor provides technical services such as quantifying energy savings from the measures identified by the FDD tool along with the measurement and verification services. The building operator does not have to review every unit's trend data and find a way to operate it more efficiently; the FDD tool automatically tracks the units, analyzes the data, and produces a report that shows the health assessment of the entire control points and provides corrective actions as needed.

Utility companies, including Eversource, are developing programs to provide incentives for using these tools in buildings. Some faults that are detectable by FDD tools are sensor errors, economizers and ventilation, simultaneous heating and cooling, equipment cycling, pump and fan systems, lighting energy use, and cooling and heating systems (Lin 2019).

FDD tools typically save 5-10%² of the baseline energy usage, can monitor and assess building systems such as chillers, boilers, AHUs, lighting, furnaces, utility meters, domestic water heaters, variable air volume boxes (VAVs) and heat pumps. The top ten most frequently implemented measures identified by FDD tools are listed in table 4.

² This data (5-10%) is based on the paper published by ACEEE - Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings, page V and table ES.1. Authors: Jennifer King and Christopher Perry. <https://www.aceee.org/sites/default/files/publications/researchreports/a1701.pdf>

Table 4. Top Ten Frequently Implemented Measures Identified Through FDD Technology

Implemented Measures Identified by FDD tool	% of participants implementing measure
Scheduling Equipment Loads	77%
Correction of Control Problems	77%
Economizer/Outside Air Loads	77%
Controls/Setpoint Changes	69%
Controls Reset Schedule addition or modification	54%
Retrofits	46%
Occupant Behavior Modification	31%
Equipment Efficiency Improvements/Load Reductions	15%

Source: L. Guanqing, Lawrence Berkeley National Lab, ACG, MBCx State of the Art Using FDD Tools, April 17, 2019.

Barriers to expand digitization tools in the manufacturing processes and building systems

The upfront capital cost is the main reason that customers are hesitant to invest in smart technologies. Smart technologies are expensive tools to deploy because of the aggregate cost of smart sensor installation, data analytics software, and manpower need to operate the system. Usually, existing control technologies are upgraded to new technologies at the point of failure. Therefore, appropriate funding is needed to encourage the adoption of these new smart technologies prior to failure of existing controls. Typically, an entire new control system is not required because these digitization tools can be integrated with the existing control systems, which mitigates some barriers to adoption.

In addition to financial barriers to adopting smart technology, there are educational barriers. Making the shift to smart technologies requires proper training as well as a passion and desire to learn new smart technologies. Software vendors should provide proper training so that building operators feel comfortable adopting their technologies. Customers should understand the benefits of digitization, including incremental savings and GHG emission reductions.

Another big barrier is related to cybersecurity. Customer IT departments are concerned about using the existing IT infrastructure for smart building tools, as there is an increase in security breaches noted by IT departments in companies where these technologies have been integrated. Also, there is no standardized communication protocol for all smart products.

Utility Programs to Overcome Barriers and Support Digitization

As program designers develop programs associated with industry 4.0 and MBCx technologies, the solutions they develop to overcome barriers discussed in the above section will be unique to their customer base and regulatory rules/guidelines. Below are some examples of how a few utilities and energy authorities have addressed these barriers in their program designs.

Eversource and other energy efficiency program implementers are developing programs to provide incentives for using smart technologies in commercial buildings. These incentive programs are transitioning from supporting traditional commissioning to including MBCx. New York State Energy Research & Development Authority (NYSERDA) introduced a program called Real Time Energy Management (RTEM) in 2016 which supports the use of sensors and data analytics to find faults in the real-time performance of building systems. The RTEM program provides incentives to support the upfront cost of installation and provides performance incentives. For qualified projects, NYSERDA shares 20% of the installation cost and 20%-30% cost share for year one to year three software subscriptions. Puget Sound Energy (PSE) also has a program to incentivize MBCx adoption which provides both upfront incentives and performance incentives. The upfront incentive is up to \$0.15 per sq.ft. and the performance incentive for year one and year two is \$0.05 per kWh savings and \$0.80 per therm savings. Eversource also supports MBCx adoption with an incentive structure that has both upfront support and ongoing support based on performance. Eversource supports the initial survey cost up to \$1,500. The upfront incentive is \$0.10 per sq.ft., capped at \$15,000. The performance incentive is paid for eligible measures, typically conventional operations and maintenance measures. The performance incentive rate is \$0.50 per kWh savings and \$5.00 per CCF savings, capped at 50% of the measure installation cost. There is also an additional performance incentive to recover the annual software license fee. This incentive structure is the lesser of 100% of the contracted annual subscription fee for MBCx, the total of \$0.05 per kWh saved, or \$0.5 per CCF saved.

For the digitization of manufacturing processes such as implementing Industry 4.0, NYSERDA, PSE and Eversource provide incentives if energy savings are realized after the implementation of smart technologies. Digitization efforts may qualify for incentives through MBCx or pay for performance programs. In comparison to building systems, the use of smart tools and data analytics in manufacturing processes is new and utilities such as Eversource are developing programs to support these smart manufacturing technologies. PSE paid incentives for smart manufacturing through their MBCx program and their pay for performance program. Eversource has launched a new initiative to support smart manufacturing in 2022. The new initiative utilizes the MBCx program incentive structure to incentivize smart manufacturing.

Conclusions

The manufacturing sub-sector is full of opportunities for energy efficiency improvements and GHG emission reductions. Digitization of building systems and manufacturing process help identify EEMs which provide incremental energy savings and GHG emission reductions. Smart technologies, telecommunications tools, and advanced data analytics are being adopted by building operators and manufacturing plant managers to some degree, but there are challenges to promoting smart technologies in this sub-sector. Big upfront costs, annual recurring software license fees, and lack of education around these new tools are roadblocks to smart technology adoption. Utility companies should develop programs that address the barriers defined in this paper based on their unique customer base and regulatory rules and guidelines to support these smart technologies, both technically and financially. For e.g., Eversource provides technical support to the customers, to identify, develop and implement MBCx projects, by providing list of eligible vendors that can assess and develop MBCx projects. Eversource also supports customers financially by providing incentives to support the survey cost, upfront cost, and annual software subscription cost. To further support the implementation of smart technologies, vendors

supporting these smart technologies and utilities should collaborate to educate their customers. Other ancillary aspects to consider including in program designs that overcome the barriers defined in this paper are sharing upfront costs, providing annual performance incentives, supporting initial study costs, educating customer, providing technical support, and offering recovery of ongoing annual software license fees.

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