The Implications of Advanced Manufacturing in a Connected Economy for a Smart, Sustainable, and Productive Economy

AMO Strategic Analysis (StA) Team

Poster Presenter:

Sujit Das, Oak Ridge National Laboratory

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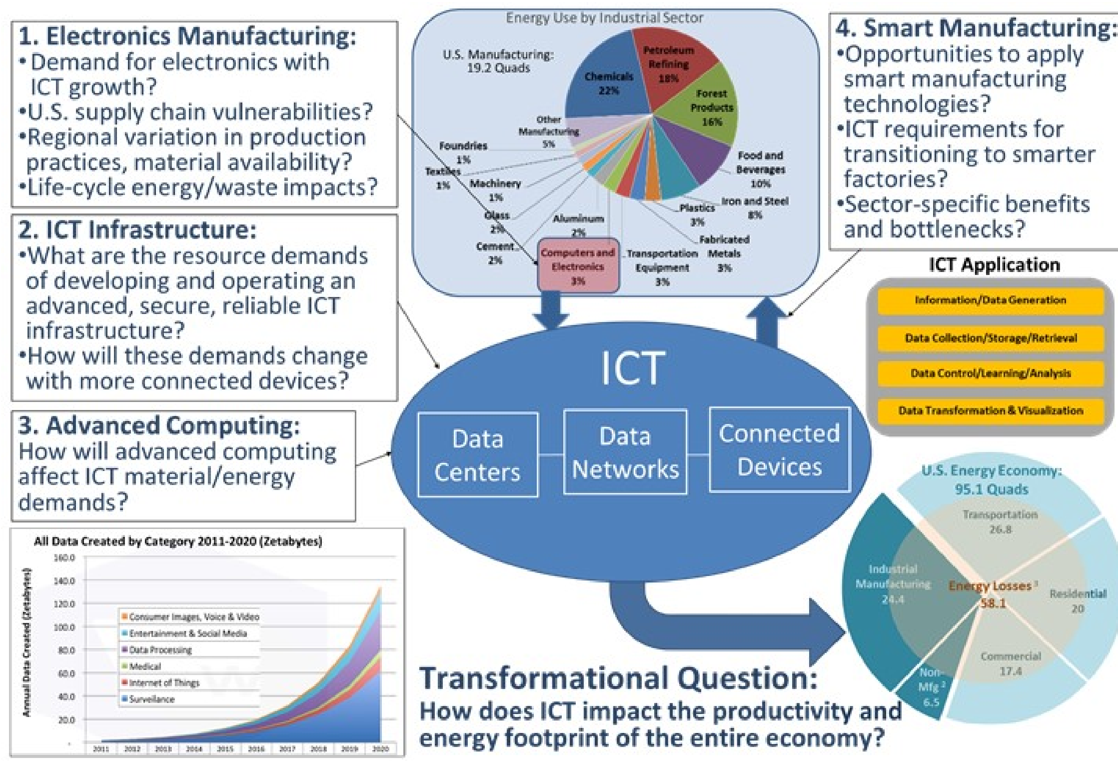
Overview

- The multi-laboratory (Argonne National Laboratory, Lawrence Berkeley National Laboratory, National Renewable Energy Laboratory, and Oak Ridge National Laboratory) AMO Strategic Analysis (StA) Team provides independent, objective, and credible information to inform decision-making.
- The StA team submitted 6 posters for this year’s Program Review; the research topics are ongoing and do not follow the typical poster format
- This poster, **“The Implications of Advanced Manufacturing in a Connected Economy for a Smart, Sustainable, and Productive Economy”,** or simply “Connected Economy” includes information on four complementary ongoing analysis project areas:
  1. Information & Communication Technology Infrastructure
  2. Upstream Electronics Manufacturing Impacts
  3. Characterizing Energy and Cost Impacts of Data Flows
  4. Smart Manufacturing Assessment Framework and Case Studies

Project Objective(s) - Connected Economy

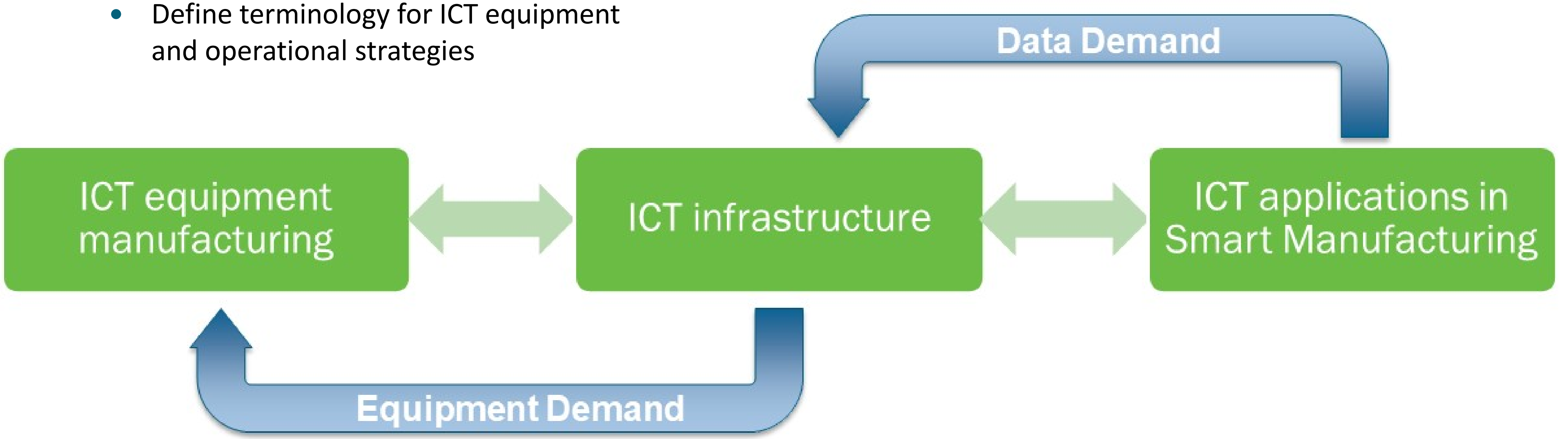
- **Impacts of Information and communication technology (ICT):**
  - Creating a connected economy (CE) with data collected, transported, stored, and processed into actionable knowledge when & where needed
  - Will reshape manufacturing practices to increase productivity & leveraged to make products with a competitive advantage
- **Benefits of Analysis:** Failing to utilize an advanced, secure, and reliable ICT infrastructure could lead to competitive vulnerabilities in the U.S. manufacturing sector
- *(see figure)* Team is conducting analysis to answer advanced manufacturing research questions that arise as demand for ICT components increases

- Each of the four research question categories *(shown on right)* affect the goals, challenges, and barriers outlined for a combination of the following MYPP technology areas:
  - **Sustainable Manufacturing**
  - **Critical Materials**
  - **Energy Efficiency Advanced Computing**
  - **Smart Manufacturing: Advanced Sensors, Controls, Platforms and Modeling for Manufacturing**



Information & Communication Technology (ICT) Infrastructure

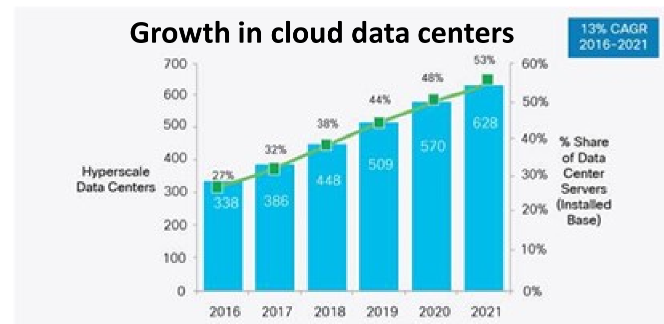
- **ICT infrastructure Project goal:** provide systems-wide understanding of the implications of Smart Manufacturing applications in advancing sustainable manufacturing (including resource consumption "beyond the plant")
- ICT Infrastructure includes:
  - **Data centers:** Buildings and rooms where data is processed and stored
  - **Data networks**: Telecom buildings, cellular towers, and other equipment used for data transmission
- End-use devices connect ICT infrastructure to the rest of the economy through microcontrollers, sensors, wireless chips, etc., which make of the Internet of Things (IoT)
- **ICT infrastructure project objectives:**
  - Understand the current state of the data processing, storage, and transmission industry and infrastructure
  - Explore future trends and needed data infrastructure investments to accommodate ICT growth
  - Discover key themes that will impact future ICT development
  - Define terminology for ICT equipment and operational strategies



Information & Communication Technology (ICT) Infrastructure Impacts

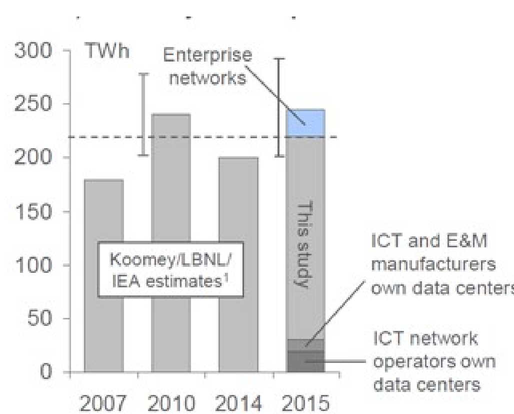
- Exponential data growth:
  - Internet Protocol (IP) traffic projected to grow at a 26% compound annual growth rate (CAGR) *(top right)*
- Increase “cloud” processing and storage
  - Hyperscale data centers projected to grow at a 13% CAGR *(middle right)*
- Global data center and network operation electricity use are similar in magnitude *(bottom figures)*
- Data center electricity demand: highly dependent on improvements in computer processer efficient (Moore’s Law) and operational practices
  - Peak output efficiency doubled energy 1.5 years since 1950s[1]
  - More recently efficiency doubling takes 2.7 years[2]
  - Operational practices vary significantly[3]
- Network energy demand and future efficiency opportunities in the U.S. are largely unknown[4]

Internet Protocol traffic

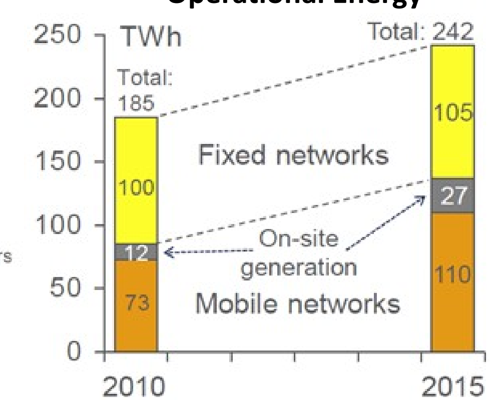


Source: Cisco, *Global Cloud Index* (2018)

Global Data Center Operational Energy



Global Data Network Operational Energy

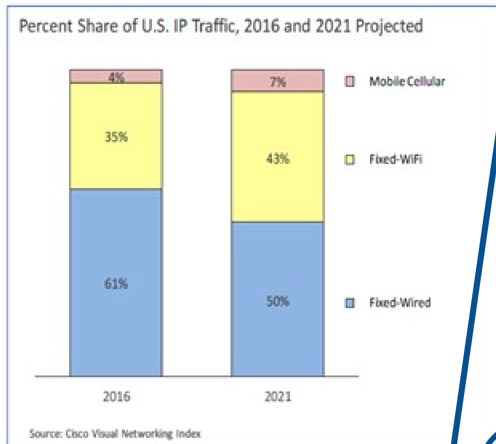


Malmodin & Lunden, 2018

Sources:
[1]Koomey et al 2011. *Implications of historical trends in the electrical efficiency of computing.* IEEE Annals of the History of Computing
[2]Koomey & Naffziger 2015. *Moore’s Law might be slowing down, but not energy efficiency.* IEEE Spectrum.
[3]Shehabi et al, 2018. *Data Center Growth in the United States: Decoupling the Demand for Services from Electricity Use* . Environ. Res. Lett.
[4]Aslan et al, 2018. *Electricity intensity of Internet data transmission: Untangling the estimates.* Journal of Industrial Ecology

Understanding Data "Transportation" Pathways

- All data transverses the same path until the "last mile" to the end use device *(see right and below)* and delivered to end devices through either:
  - Fixed network
    - Wireless
    - Wired
  - Cellular network
- Fixed wireless and cellular are a growing portion of all data transfer

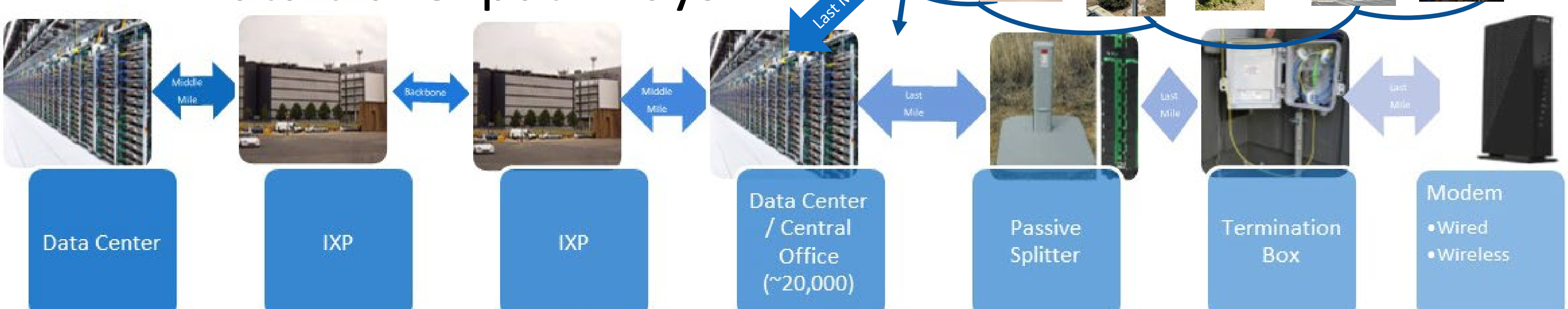


Brogan, Patrick. "USTelecom Industry Metrics and Trends 2018." March 1, 2018. https://www.ustelecom.org/sites/default/files/images/USTelecom%20Industry%20Metrics%20and%20Trends%202018.pdf.

US Internet Topography

Costenaro, David, and Anthony Duer. 2012. "The Megawatts behind Your Megabytes: Going from Data-Center to Desktop." *Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings*, ACEEE, Washington, 13–65.

Data travel pathways



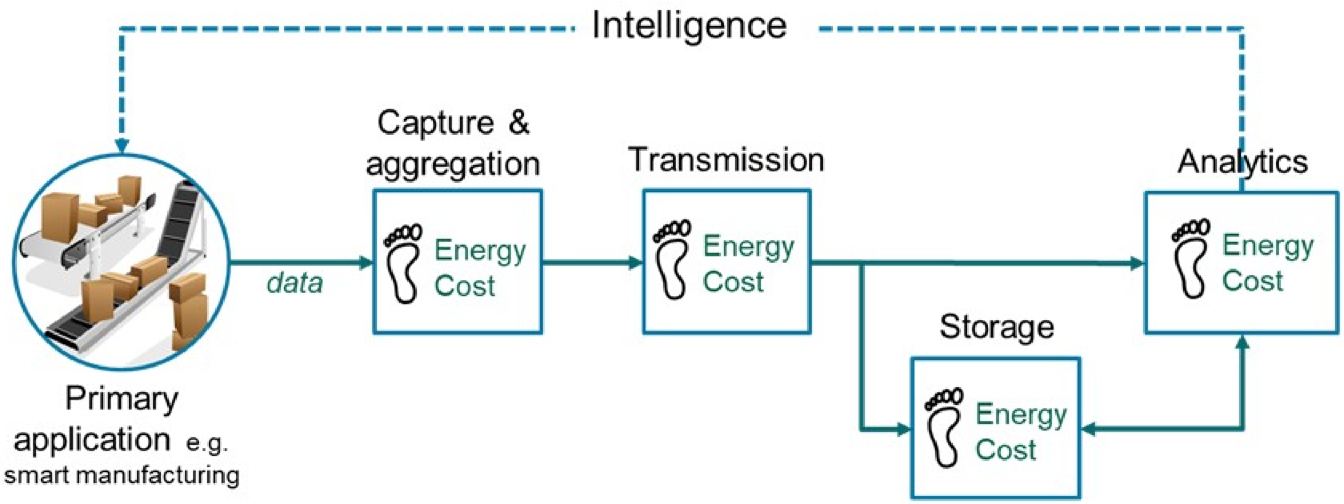
Upstream Electronics Manufacturing Impacts

- **Benefits in** studying upstream impacts of U.S. electronics manufacturing:
  - Determine how/where electronic components are manufactured
  - Quantify lifecycle energy, material, and water demands
  - Quantify technology advancements of electronics manufacturing processes (from semiconductors to final IoT devices) & ICT infrastructure to support devices
- Internet-of-Things (IoT) electronic devices in end-user facilities with built-in communication capability with ICT infrastructure contain:
  - Sensors/actuators, input/output modules, communication module, controller, and human machine interface components often as an integrated IoT device
  - Major three categories of semiconductors: Sensors, Connectivity ICs, and Processor ICs often as an integrated multifunctional IC/chip in an IoT device
  - Memory, Logic, and Microprocessor/Microcontroller major semiconductor types facilitate ICT data flows within a end-user facility (i.e., Capture & Aggregation, Transmission, Storage, and Analytics)
- Projected tremendous data growth will cause:
  - # total number of worldwide IoT devices to increase from 22.7B (2018) to 74.9B (2025), while
  - # of semiconductors/IoT device will decrease from 4.3 (2018) to 3.1 (2025)

Global Energy Footprint of ICT electronics in Connected IoT Devices

- Estimating global energy footprint with bottom-up approach based on forecasts of total annual worldwide IoT semiconductor shipments (2016-2025):
  - Limited to shipments of three major semiconductor types – Sensors, Connectivity ICs, and Processor ICs instead at the level of End-User Devices (e.g., Entertainment & Media)
  - Three major chip types (memory, logic, and processor/controller) allocated to three major semiconductor types
  - Embodied energy of manufacturing and use/operation only considered
- Chip manufacturing energy has significantly larger share of total global energy footprint of ICT electronics
  - Chip manufacturing energy trending up due to projected growth in shipments and increase in chip manufacturing energy
  - With a continued future trend in low power semiconductor devices, total use/operation energy of worldwide IoT semiconductors projected to decline several orders of magnitude despite growth in shipments
  - A simplistic alternative LCA approach for the overall ICT electronics energy footprint estimation → detailed chip manufacturing LCA considering major manufacturing steps has been initiated to examine growing technology integration trend in both chips and IoT electronic devices

Characterizing Data Flows and Their Energy and Cost Impacts in Connected Economy Systems



Data flow through connected systems is premised on the opportunity to derive actionable intelligence via analytics.

- **Context:**
  - Connected systems (from smart manufacturing to buildings) collect, transmit, store, and analyze unprecedented volumes of complex and multi-dimensional data through a network of information and communication technologies (ICT)
  - Data undergo multiple virtual transformations (raw data → actionable intelligence → leveraged to create value) – much like physical commodities are transformed from raw ores → finished products
  - Each step in data's journey from the point of collection to final actionable intelligence involves software and hardware equipment that alters the data and consumes energy

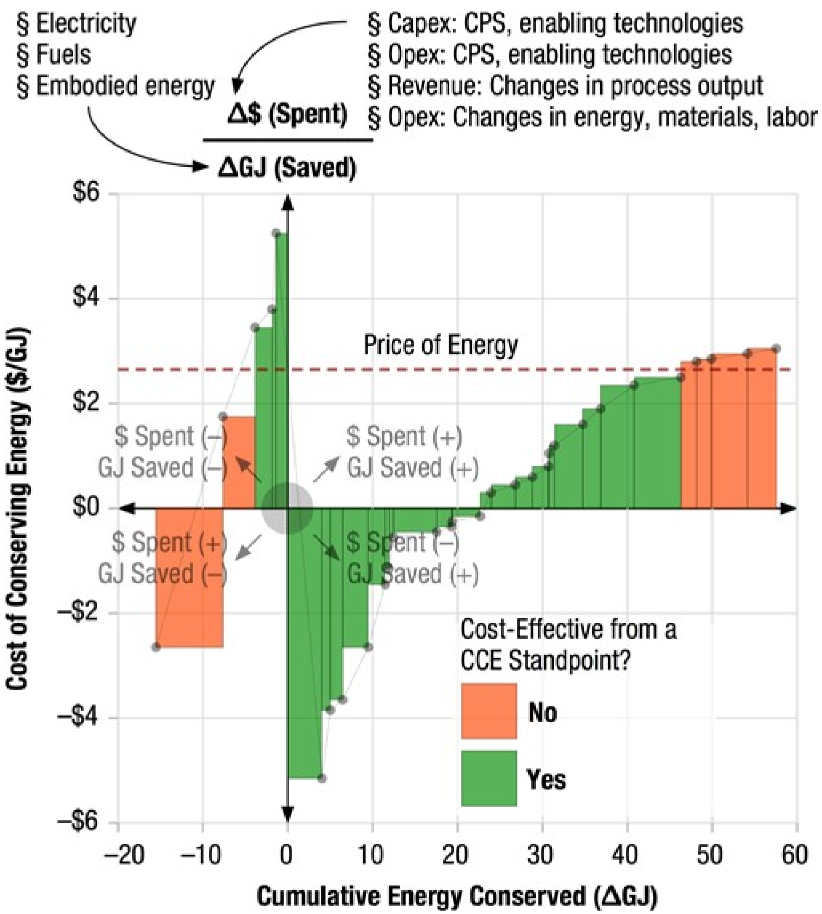
Characterizing Data Flows and Their Energy and Cost Impacts in Connected Economy Systems

- **Strategic questions:** What is the energy and economic impact of data flow through ICT infrastructure that supports connected economy systems? Can these significantly affect the true value derived from analytics?

- **Action:** Developing systematic approach for evaluating the energy and costs footprint of data as it flows through the sensing, aggregation, transmission, storage and computing devices that comprise the ICT infrastructure of connected economy systems.

- **Objectives:** Using this framework, the proposed study will:
  - Quantify (& assess) ICT costs, energy use, and associated uncertainties for "smart" applications (manufacturing buildings, vehicles, cities and utilities)
  - Increase consciousness of connected economy's energy implications and provide approach to assess energy-efficient solutions for connected economy
  - Evolve scenarios to understand potential impact of increasingly connected world on energy infrastructure needed to support it

Assessing the Cost-Effectiveness of Smart Manufacturing Interventions Using Cost of Conserved Energy



$$CCE = \frac{\Delta\$_{spent} / year}{\Delta GJ_{saved} / year} = \frac{\left(\Delta C + \Delta OM - \Delta R\right) / year}{\Delta E / year}$$

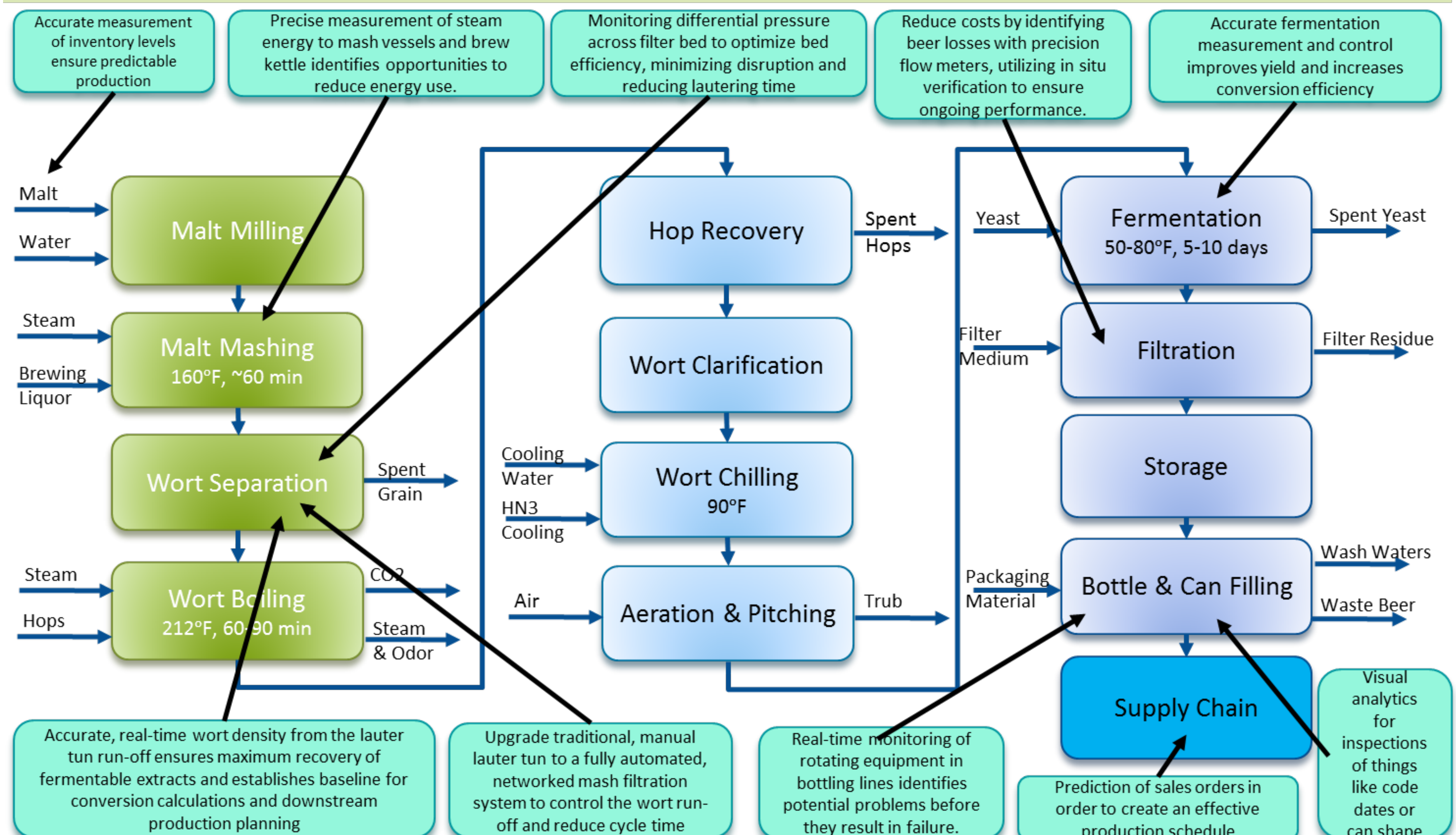
- **Needed:** Systematic framework to determine if smart manufacturing interventions create enough value and improve energy productivity *(see left)*
- **Key performance indicators (KPIs):** define system boundaries for energy and cost analysis of smart manufacturing interventions
  - Specific KPIs vary across firms/industries, but are powerful in their ability to represent operational attributes of an otherwise complex system in simplified aggregate terms
- **Cost of conserving energy (CCE):** Traditionally evaluates if the cost of an energy conservation measure is less than the price of a unit of energy (Worrell et al. 2003)
- **(see figure on left):** CCE scope is modified to include cases where energy is spent to increase value
- *ΔE* would include energy use from connected cyberphysical systems used in the smart manufacturing application

Case Study – Smart Manufacturing for Continuous Steel Caster

- **Subject:** Considering Mold level and Continuous Temperature Control (CTC) standard smart manufacturing options in continuous steel caster
- **Observations:**
  - Despite decrease in unit process energy use from CTC, overall system energy use increases due to cyberphysical system (CPS) energy use (4.93 MWh/year) contributed by mechanical actuators
  - Cost of Conserving Energy (CCE) (cost-effective measure from an energy perspective): favorable when greater than price of a new unit of energy
  - Highly sensitive to the product rejection improvement rate from CTC (0.5% - 5%)
  - Min. product rejection improvement rate from CTC is estimated to be ~ 2.3% at non-energy variable O&M (VOM) cost of $0.10/ kg of steel → less than 2 year payback period at a higher CTC product rejection improvement rate
  - Higher VOM costs necessitate greater improvements in the product rejection rate to meet the CCE threshold

Enhancing Operational Performance and Productivity Benefits by Implementing Smart Manufacturing (SM)/Internet of Things (IoT) Technologies in **Breweries**

Breweries could use Smart Manufacturing (SM)/Internet of Things (IoT) strategies to drive efficiency, productivity, and quality in their facilities in numerous ways. E.g., Create real-time visibility to enable data-driven decision-making; Improve workforce productivity; Monitor systems in operation and predictive maintenance; Increase product safety; Manage recipe variation; and Reduce the cost of quality testing

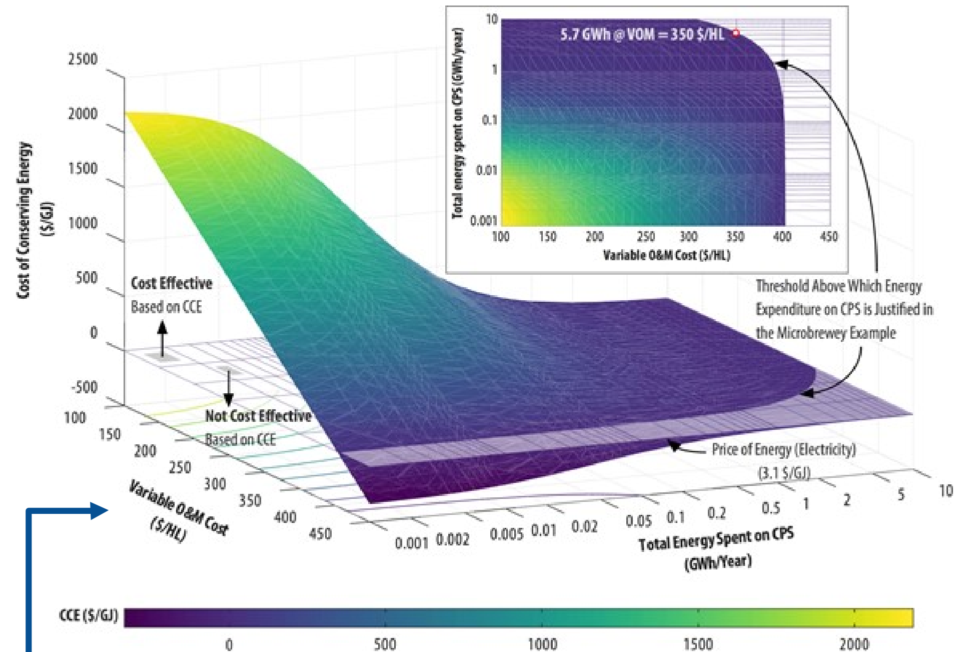


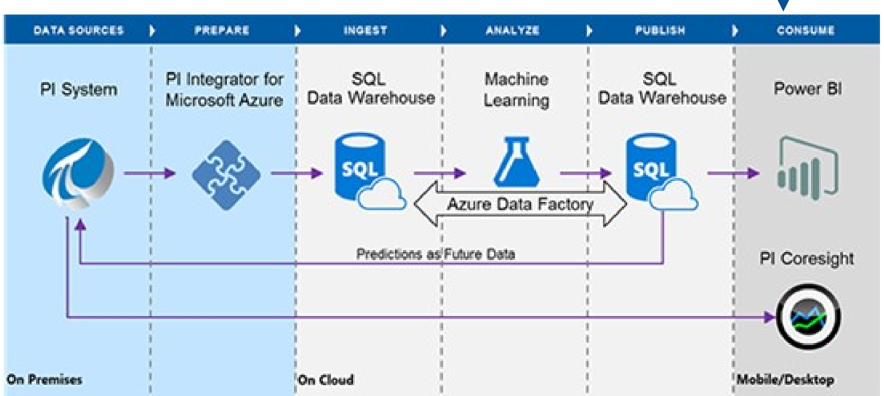
Brewery Case Study 1 - Accurate Fermentation Measurement and Control Improves Yield and Increases Conversion Efficiency

Smart manufacturing (SM) strategy: conduct predictive analytics on the apparent degree of fermentation (adf) data collected using hydrometers to monitor and appropriately control the process parameters in real-time, thereby reducing the fermentation time and reducing taste/aroma quality issues emerging from improper fermentation

Goal: increase production volume by reducing overall cycle time and improving process yield.

- Fermentation is longest process (5-10 days)
- Digital temperature sensors and hydrometers can be used to monitor the state of the fermentation *(architecture shown below)*
- Knowing exactly when a batch has completed allows the next batch to start
- Decreased process time: 12-72 hours per fermentation (Deschutes)
- A brewery could save enough time to allow up to one additional batch per year (Hexagon)
- Improved production capacity by 4%
- Fewer manual measurements





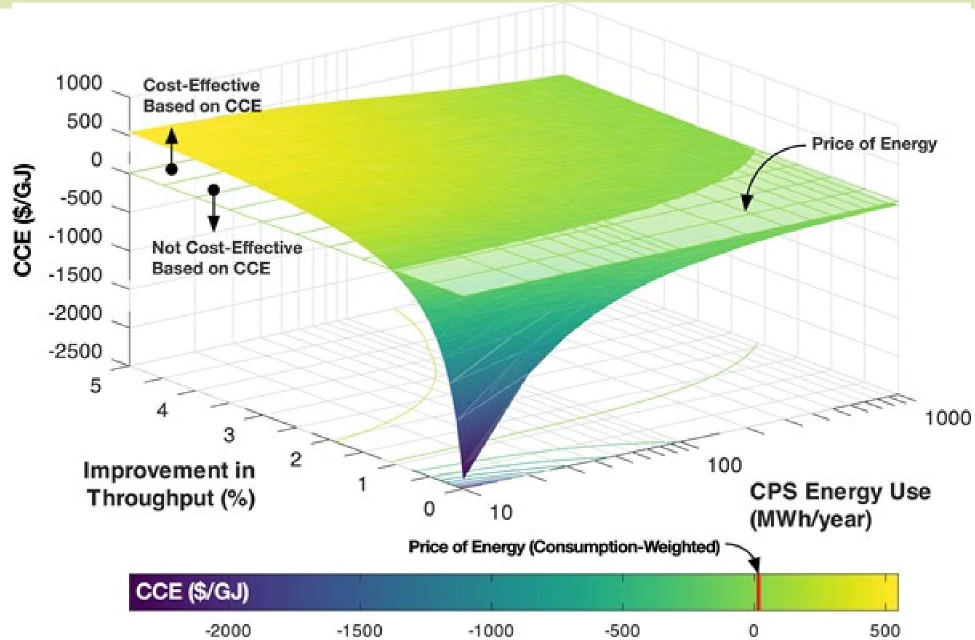
IoT Architecture

- SM may increase energy productivity at the manufacturing system level, yet life cycle energy use of the cyber physical systems (CPS) needs to be considered when evaluating the overall energy burden
- CCE framework applied to the brewery case study demonstrates the energy productivity paradigm of additional energy use to increase value when that value is greater than the cost of the additional energy used (*see figure above)*

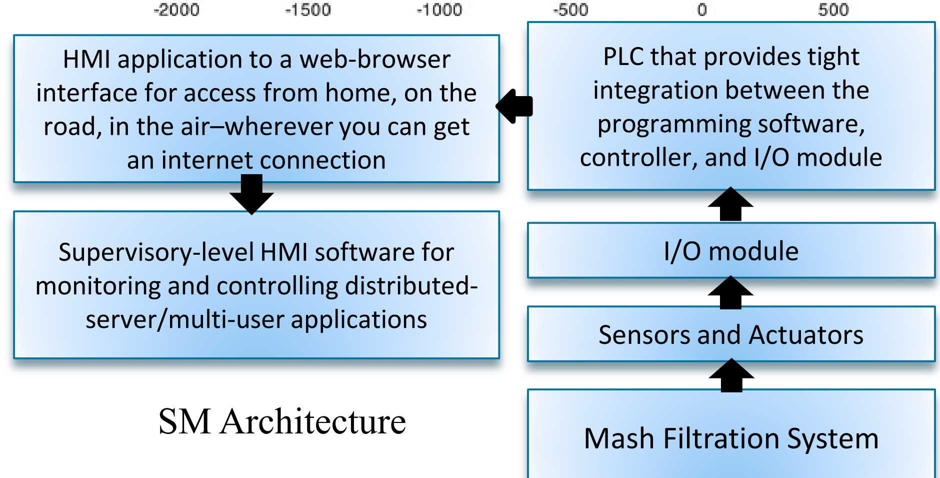
Brewery Case Study 2 - Upgrade Traditional, Manual Lauter Tun to a Fully Automated, Networked Mash Filtration System

Smart Manufacturing (SM)/Internet of Things (IoT) strategy is to leverage process automation and distributed control system (DCS) with human machine interface (HMI) software to increase brewery throughput by increasing wort liquid extraction as well as reducing the overall cycle time in the wort separation step .

- Full Sail upgraded its traditional manual lautering process (where mash is separated into the clear liquid wort and the residual grain) to a fully automated and networked mash filtration system.
- The new mash filtration system Full Sail implemented leverages the PlantPAx Process Automation System from Rockwell Automation, which incorporated role-appropriate, real-time key performance indicators (i.e., manufacturing intelligence) that Full Sail can use to improve operations.
- The system allows Full Sail to configure sequences directly into an Allen-Bradley ControlLogix controller through FactoryTalk View Human Machine Interface (HMI) software.



Metrics of Benefits	Quantity
Production Increase	25%
Brew Cycle Time Reduction	50%
Raw Material Cost Savings	5%
Water Savings	1 MG per Year
Raw Material and Spent Gain Hauling Cost Savings	$333K
Total Project Cost	$1 million
Labor Cost Savings from Reduced Site Visits	$60K
Labor Cost Savings from Improved Dispensing Processes	$150K



SM Architecture