Are We All on the Same Page?
Bridging the Knowledge Gap between Plant Personnel and Energy Consultants to Create Sustained Savings

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ABSTRACT

While custom industrial energy efficiency programs have been in place for a long time, a knowledge and communication gap persists between program providers (including energy consultants) and onsite personnel that sometimes prevents realization of their full savings potential (NEP 2001). Bridging this gap would help program providers and energy consultants to better understand industrial processes, process variables, and their interactions. From another standpoint, onsite personnel would develop a better understanding of how energy consumption is estimated and process interactions are accounted for. This would help all parties to better consider both the opportunities and limitations associated with proposed energy-efficiency modifications. It would also ultimately lead to more accurate savings estimates and more effective program design.

Since industrial energy systems are often unsuitable for field energy monitoring with portable loggers, simplified approaches involve establish pre- and post-retrofit energy consumption indices to inform project savings estimates. One common approach is to utilize the energy intensity (EI) method or the energy used per unit production. While EI is a powerful tool to determine energy impacts, it also poses some challenges that can be overcome by improving the way that energy consultants and site personnel share information. This paper describes three examples of communication approaches that led to energy consultants' improved understanding of process potentials and limitations as well as determining the best process variables for effective measurement and verification (M&V) plans: at a bioethanol plant, a wastewater treatment plant, and a manufacturing plant.

Introduction

Industrial processes and facilities constitute the largest energy end-use sector and consume about 54% of the world's total delivered energy (EIA 2016). Medium and large industrial facilities therefore offer a wealth of potential opportunities and challenges to reduce their overall energy consumption. Unlike commercial building equipment, industrial energy equipment is often larger, supplied with higher-voltage power, and cannot be interrupted thereby making it unsuitable for installation of temporary energy-monitoring equipment. Furthermore, the many simultaneous and highly-interactive processes involved are too complex to readily apply basic engineering equations. As a result, the implementers and plant personnel typically adopt a simplified approach to quantify the energy-conservation measure (ECM) savings by using facility-wide, energy-consumption indices without understanding the highly interactive and complex industrial systems. This generally entails determining the facility-wide energy intensity

(EI) by dividing the facility-level energy consumption by the production rate.[1] The pre-ECM annual EI is calculated by dividing the plant's annual energy usage by its annual production. The post-ECM EI is calculated in the same manner but is often limited by the amount of post-ECM data available for energy usage and production. The pre- and post-ECM EIs are then compared at the target annual production rate to quantify the project's annual impact (Papadaratsakis, Kasten, and Muller 2003).

While facility-wide EI is an effective tool to estimate energy impacts, it also poses significant challenges because it can prove overly broad. Many of these challenges can be overcome, however, by improving the way that energy consultants and site contacts share project information. Specifically, acquiring an understanding of the process, production, and seasonal dependencies can help the energy consultant to narrow the affected boundaries of ECMs and provide a more focused analysis. This paper presents a list of the most common challenges and three distinct examples of successful projects that benefitted from such knowledge: a wastewater treatment plant, a bioethanol plant, and a manufacturing plant.

Challenges Facing Energy Professionals:

While it is a common practice to use the facility-wide EIs to assess industrial ECMs, energy consultants encounter many kinds of challenges to calculating accurate energy savings.

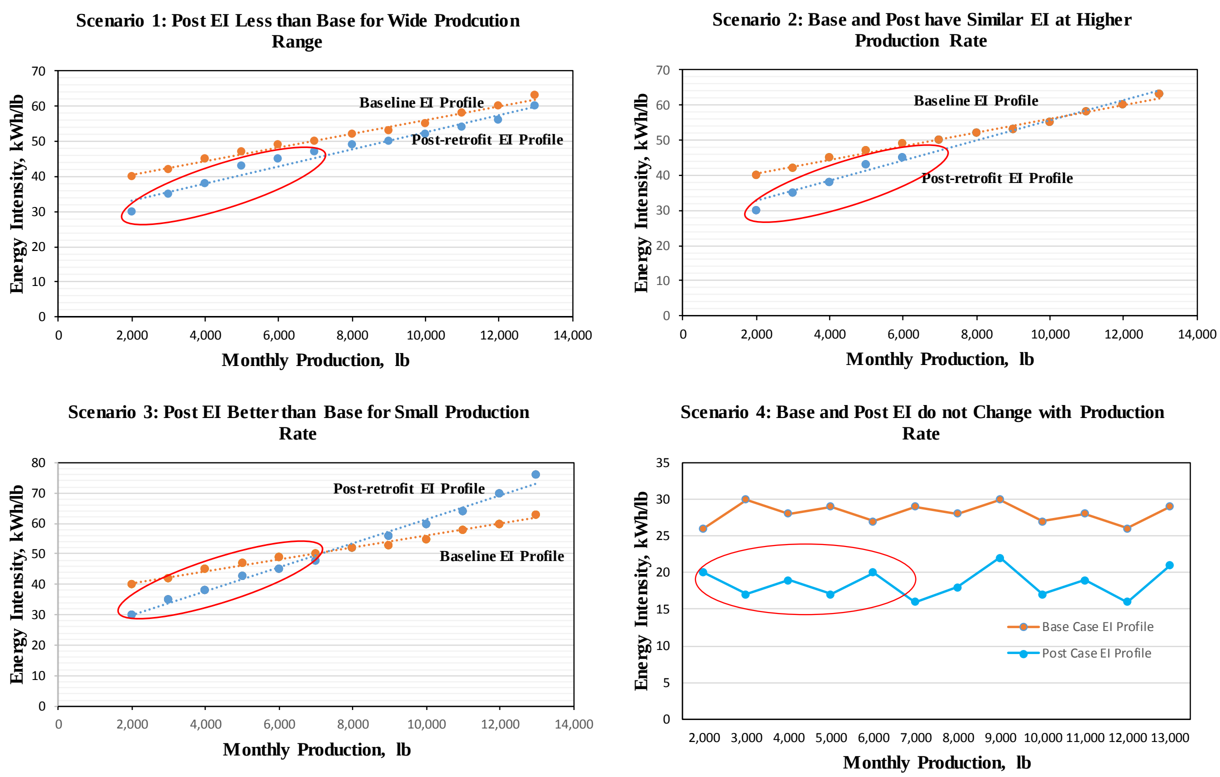
- **Energy consultants may lack in-depth industrial knowledge**: Since energy consultants often work across many sectors, they do not often possess process and plant-specific knowledge. It takes considerable experience to understand that each facility faces unique limitations on production and operation parameters such as process inter-dependencies, capacity constraints of upstream and downstream systems, operation bottlenecks, and the effects of process cycles, etc. Without this knowledge, the savings analysis may misrepresent the ECM impacts. Hence, energy consultants need to engage with plant operators to fully understand the production process and its impacts on energy usage.
- **Facility-wide energy and production monitoring**: Many industrial facilities have only facility-wide energy meters thereby preventing energy consultants from reviewing measure impacts on smaller or isolated sections of the plant. Furthermore, even at facilities with multiple sub-meters, facility personnel sometimes manually read the sub-meters and record those readings. In the author's experience, however, these sub-meter records are often erroneous and subject to individual record-keeping quirks.
- **Plant data granularity**: Among sceptics, EI is only considered appropriate when the facility's daily average power and production rates are available (LaPalme, Prather, Ishii, and Church 2007). However, as most older industrial facilities still lack "smart" meters or energy management systems (EMS), the plant operator can only determine the monthly EI—often after considerable delay. Production data may also be available only at monthly intervals. This means that little is known about how energy consumption varies at different times of day or how to correlate it with fluctuations in daily production or ambient conditions. In such cases, the facility logs can sometimes offer a tool to understand these patterns.
- **Isolating of ECM-affected systems from the facility**: If the ECM affects an entire plant's operation, the use of facility-wide, metered energy data is reasonable. However,

[1] Often designated as kWh/lb, kWh/ft, kWh/unit, etc.

for measures affecting a small section of the plant, the ECM-effects may be lost in the facility-wide meter data. Furthermore, it may be challenging to locate production records for the equipment within the ECM boundary—if they exist at all.

- **Utility programs incentivizing only one energy stream**: Some of the utility-sponsored energy efficiency programs incentivize savings for a single fuel. Thus, plant personnel and energy professionals focus on those energy savings to the exclusion of other fuel impacts. This may lead to projects that yield savings for one fuel, but increase the overall energy consumption across all delivered utilities.
- **Feedstock changes**: Plants sometimes initiate modifications when they change raw materials or feedstock—typically for reasons not associated with energy efficiency. New process technology and equipment may be needed to implement the feedstock change. In such cases, a direct comparison of the old and new EI may not be meaningful.

***Limited project-implementation timeframe**: Since industrial modifications are complex, they require a longer project period than their counterparts at commercial buildings. Often, however, the program timeframe does not allow involved parties to collect enough data to represent the facility's year-round operation. Thus, using only short-term, post-ECM data, energy consultants must try to forecast the annual performance. Without sufficient facility data to support such projections, the actual savings may differ significantly from those estimated. In such cases, the program and the site personnel need to work together to understand whether monthly production remains flat over a typical year or exhibits seasonality to assess whether sufficient post-ECM data were gathered. Figure 1 below presents four scenarios of EI findings that an energy consultant might produce with limited (five months) post-ECM observations. In the four scenarios in*



- Figure 1, the x-axis represents either the units of product produced and the y-axis represents the facility-wide EI. While a cursory look shows a reduction of the post-ECM EI (in Scenarios 1 and 4), a closer look suggests that—in some cases (exhibited in Scenarios 2 and 3)—there is a production threshold beyond which the plant operation will produce negative energy savings. This underscores the importance of understanding the full range of facility operations and the limitations of short-term data.

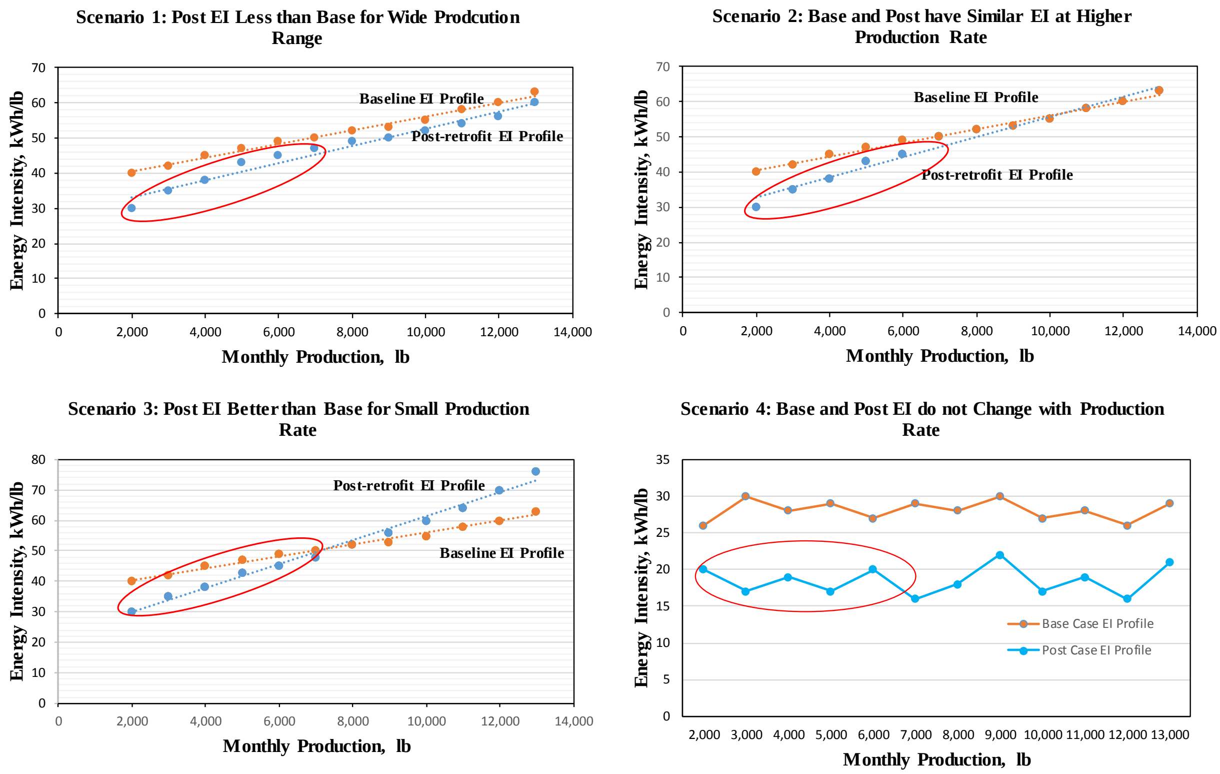


Figure 1: Possible Scenarios for Variation of Energy Intensities at Different Plant Operating Condition:

Examples of Projects Using EI Methodology

The following section examines three efficiency improvement projects that benefitted from gathering plant and process details, associated savings potential, and production limitations. These illustrate:

- The relationship between plant processes and equipment energy consumption and that energy benefits at one section of a plant might pose trade-offs at another
- Effective project and process boundaries that isolate the ECM-affected area from the rest of the facility
- Using available facility resources and knowledge to refine conventional EI analyses.

Bioethanol Plant

An energy efficiency project in a corn ethanol plant added a new fermenter to its existing set of fermenters to increase the overall ethanol production and to improve the facility-wide EI. The project implementer calculated the pre-ECM EI using more than one year of ethanol production data and facility-wide kilowatt-hours (kWh). For the post-ECM case, the project implementer applied the pre-ECM EI to the new fermenter and estimated the annual savings using the forecasted annual ethanol production. On the surface, a new fermenter would be expected to increase the overall plant ethanol production and to decrease the overall plant EI, the author investigated the overall process layout and current operations to determine whether other conditions might be limiting how much the overall EI could be improved.

1. The author reviewed the plant process layout, the measure-affected process equipment, and other upstream and downstream processes (Figure 2) and determined that the ECMs only affected the fermentation part of the overall process. Upon further investigation, the author learned that—for corn ethanol plants—feedstock mashing, distillation, dehydration, and stillage are the more energy-intensive processes whereas the milling and fermentation processes consume relatively little energy (Easley 1987). Thus, the author reduced the ECM-analysis boundary to only include the fermentation process.

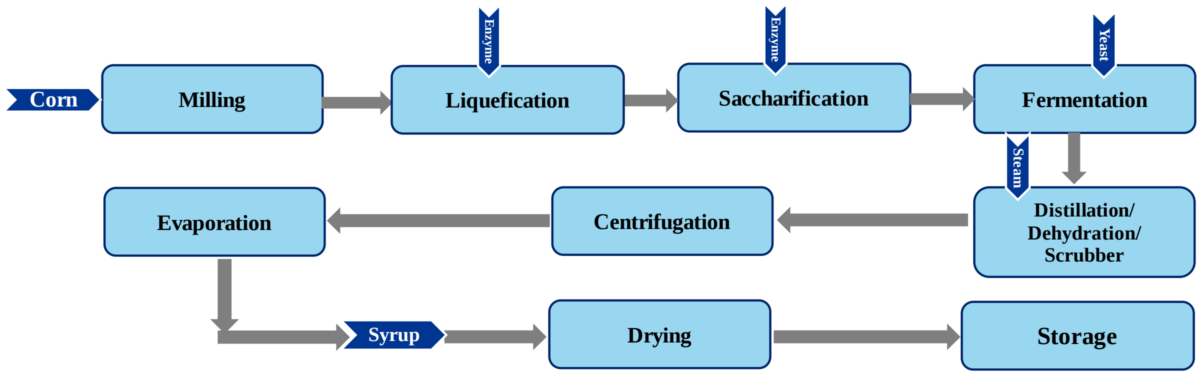


Figure 2: Overall Plant Schematic of a Corn-Based Ethanol Plant

2. The plant operations are typically continuous; this continuity is maintained with upstream systems that continuously feed the downstream systems. Increasing the capacities at upstream processes cannot increase the production rate since the maximum capacities at the downstream processes remain unchanged. The facility data indicated that the pre-ECM operations had no process lag time and, more importantly, the new fermenter would not result in a bottleneck at the downstream process. Since the flow continuity and capacity balance would be maintained both pre- and post-ECM, it was discovered that the new fermenter could accommodate an increased fermentation-cycle time without causing any process lag. This was a noteworthy finding because it offered the potential to increase the facility's annual production without consuming much more energy.
3. The author investigated the current and potential fermentation-cycle times and the how they would affect throughput rates since ethanol concentration increases with longer fermentation-cycle times. Early in the fermentation cycle, as the sugar concentration decreases, the ethanol concentration increases exponentially and approaches a plateau after about 48 hours. After this period, only a fractional potential to increase the concentration remains to convert the last trace starches to ethanol.
4. It was necessary to determine the pre-ECM ethanol concentration at the end of current cycle time and the proposed ethanol concentration to be achieved by increasing the cycle time. (The ethanol concentration usually ranges between 5% and 8% at the end of the fermentation and no additional benefit results even after a cycle time of 72 hours.)
5. The author gathered the current and proposed ethanol concentrations along with the current and proposed fermentation-cycle times. Using these, the author determined that

the facility had the potential to increase its annual ethanol production with the added fermenter. Hence, it was confirmed that the proposed change would result in a lower EI because the production would increase without consuming much more energy.

6. To estimate the amount of additional energy needed to increase the fermentation-cycle time, the author investigated the new fermenter further. With a motor-driven agitator and a jacket that is temperature-controlled by chilled water and steam to maintain the desired fermentation temperature, it was necessary to account for the electric energy used by these to determine the post-ECM fermentation EI. The author utilized short-term metered data at the agitator-motor to determine its energy usage estimate and studied the process specifications to estimate the energy used to generate the additional chilled water and steam.
7. In addition to previously-mentioned chemical limitations, most plant processes also have physical limits as well. In this case, since all fermenters, both pre- and post-ECM, share the unchanged downstream equipment including distillation chambers, savings estimates must be limited by the capacities of the downstream equipment and processes.

This example demonstrates that—when the measure-affected process is confined to a section of a facility—it is advisable to use the affected process-level EI rather than the facility-wide EI to estimate savings. Furthermore, in-depth interactions with plant personnel help the energy consultant better estimate the realistic measure benefits—by understanding the process and production limitations—as well as the additional energy impacts of facility-capacity expansion projects.

Wastewater Treatment Plant

A wastewater treatment plant retrofitted low pressure-drop membranes in place of old membranes that induced a greater pressure drop. This retrofit enabled the plant to treat more wastewater per day while using no more energy, thus reducing the plant's EI. The plant has identical and parallel treatment units; one such unit is shown in Figure 3. Each of these units operates independently and varies with plant load at different times of the year. The plant records the amount of wastewater treated every day and the daily total electricity consumption. The author reviewed this project when the plant had multiple years of pre-ECM data and one year of post-ECM data (monthly flow and month plant kWh). However, instead of using the plant-level annual electricity consumption (kWh) and the annual water treated to develop the plant's EI, the author utilized in-house data and metering capabilities to determine the plant's performance for pre- and post-ECM periods. It is often worthwhile to reduce the project boundary by relying upon facility sub-meters for the ECM-affected equipment (MT&R Guideline 2015), if they are available.

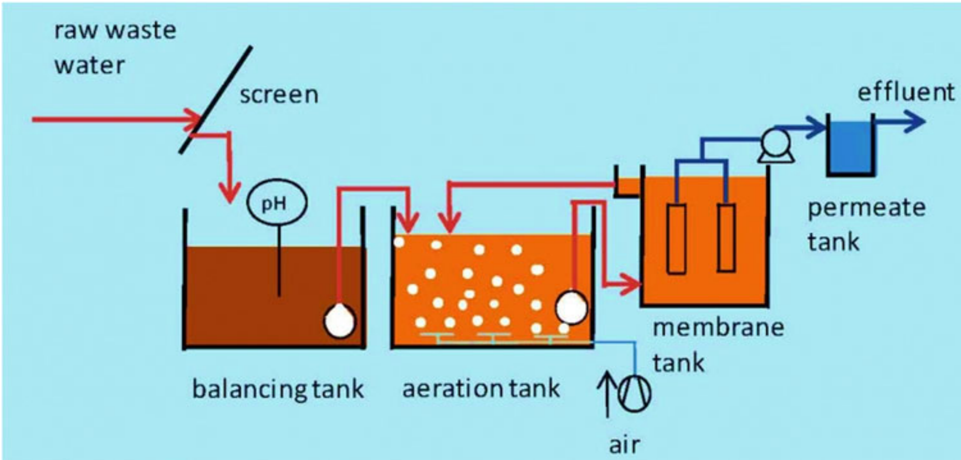


Figure 3: Typical Arrangement of Membrane Bio-reactor at Wastewater Treatment Plant

1. Since the plant had sub-meters that were programmed to collect the daily kWh consumption of all aeration blowers, metering effort could be narrowed to gather two weeks of data for four process pumps installed at two of the units. Further, the facility informed the author that the wastewater flowrate is not likely to vary during a short observation period, but that it changes seasonally and does correlate with average unit-level energy usage.
2. Given the reported correlation, pre- and post-ECM data were used to develop respective regressions between the average daily wastewater flowrate and the corresponding average daily power draw (see Figure). The post-ECM flowrates were significantly higher than the pre-ECM flowrates even though they were recorded only a brief time apart; this was attributed to the reduced pressure drop across the retrofitted membrane. Moreover, the post-ECM system processed the greater flowrate using the same power draw.
3. The author also made a confounding observation, however, within the annual facility data (see Figure): the monthly post-ECM flowrate was lower than the monthly pre-ECM flowrate. The facility personnel informed the author that sometime after the post-ECM period of observation, the facility had permanently reduced its load when the jurisdiction had brought a new wastewater plant online to share the previous load. To verify this, the author checked the utility bill.
4. To exclude the observed "non-measure" effect of a system outage from the final savings estimation and thereby treat pre-and post-ECM cases with equal load conditions, the author applied the pre- and post-ECM regressions to the post-ECM average daily flow for each month of the year to estimate the annual, adjusted pre- and post-ECM energy consumption. Doing otherwise would have overstated the savings.

While this example confirms the benefits of acquiring as much—and with as much resolution—historical data as possible to verify the correlation between various facility performance parameters at the annual level, it also reaffirms that questions must be asked of plant personnel when anomalies are observed.

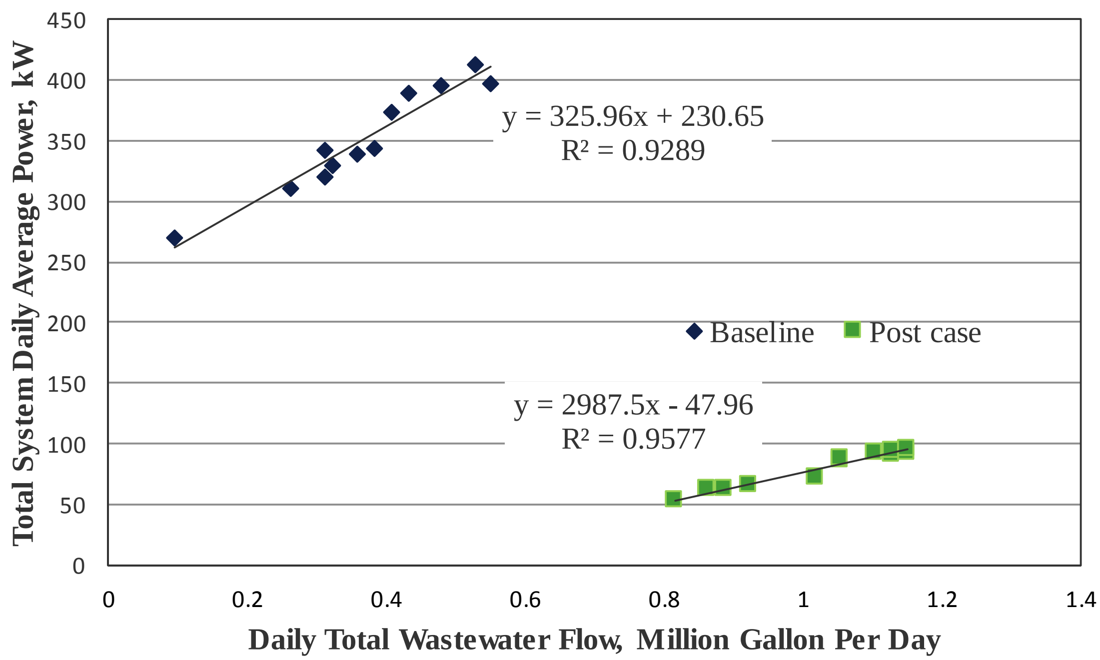


Figure 4: Case Study 2 – Correlation Between Wastewater Flowrate and Treatment System Power Consumption

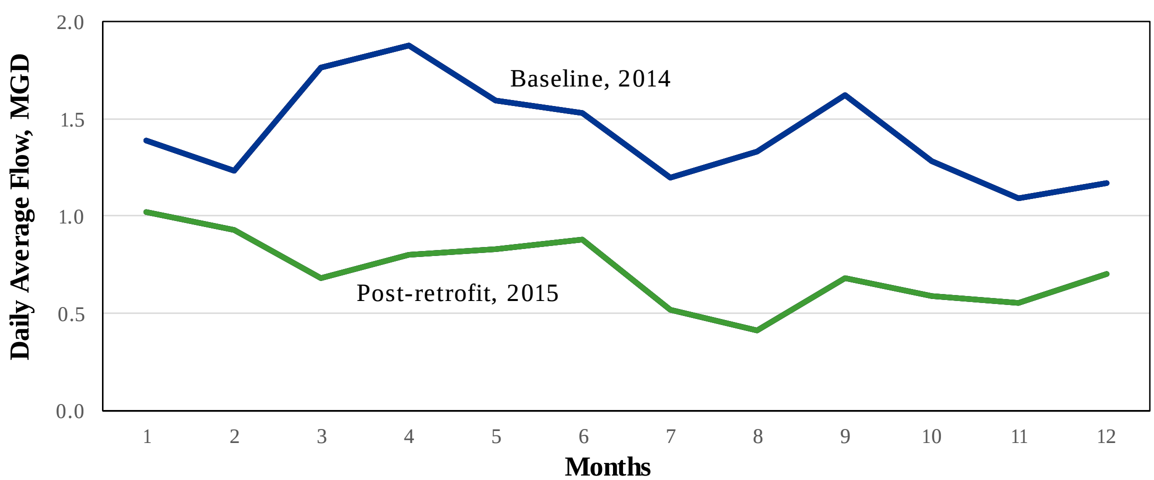


Figure 5: Case Study-2: Variation of Pre- and Post-ECM Monthly Flowrates

Manufacturing Plant

An insulation manufacturing plant installed variable-frequency drives (VFDs) at multiple, large, forming blower motors. Since the plant produces 24 products of varying widths and densities, there would be benefit to varying the fan speeds to match what was needed for each product width and density. Since the industrial-blower power ratings exceeded the measurement ranges of traditional, portable power loggers, installing power loggers was not an option. Rather, the review involved scrutinizing all available process-related resources to estimate the measure savings using EI methodology. Since the process improvement was confined to the fans, other processes such as conveyor motors and process heating were excluded from the analysis.

1. The facility pre-ECM records contained three years of daily kWh consumption and daily production (lb) for each of the 24 products. The author used these data to develop the baseline EIs for each product. The pre-ECM production records allowed the author to create a matrix to represent the proportional contribution of each product to the total annual throughput to yield the weighted annual energy consumption.
2. To track daily operations, the facility personnel record the forming operation of a given product as “full-day” or “partial-day,” depending on the number of operating hours. A separate analysis of daily EI revealed that the average full-day EI was about 25% higher than the average partial-day EI. Thus, EI need not be treated as a static parameter for any facility’s year-round operation, but can vary with production level. The estimated pre-ECM EI was calculated by taking a weighted average of the full- and partial-day EIs.
3. The post-ECM facility data also included three months of blower-motor interval power (kW) and speed (rpm) along with the post-ECM product width, product density, and forming conveyor speed. The conveyor speed is inversely proportional to the product density, as denser material requires slower conveyor speeds to allow more time for the insulation to form.
4. To determine the final measure savings, the author compared EI improvements across all product types. In one such comparison (see Figure 6), the post-ECM EIs are consistently lower than the pre-ECM EIs. Since these comparisons were available for all product widths recorded in three years of pre-ECM data, it was thought that three months of post-ECM monitoring were adequate to validate the measure savings.
5. The author also made a similar comparison of pre- and post-ECM EIs at different conveyor speeds. The pre- and post-ECM data were adequate to represent the entire product range. As with the comparison of the EIs observed for each product width, the post-EIs were consistently lower than the pre-ECM EIs for each product density.
6. Finally, since the savings analysis made use of a weighted blend of EIs across all product types proportional to their total annual production, the matrix was shared with the plant personnel and program administrator to help guide them with any future the plant modifications.

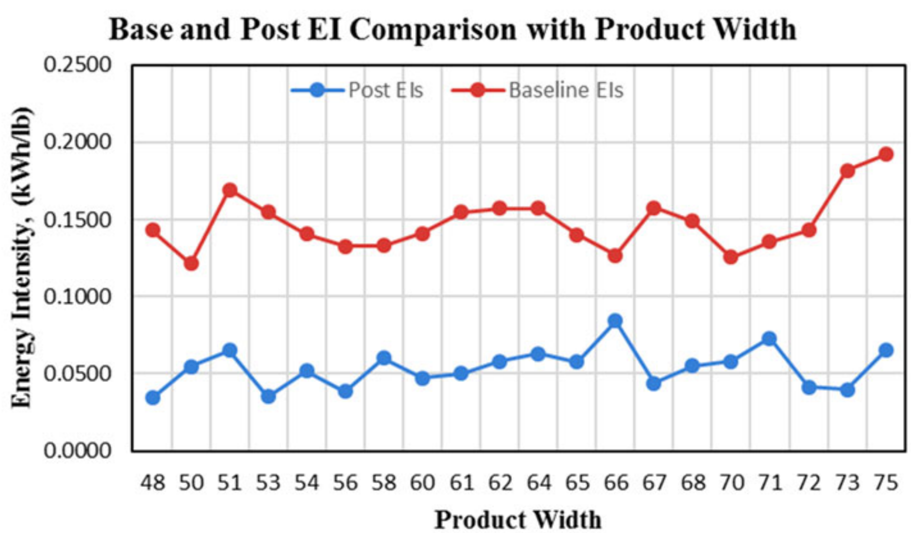


Figure 6: Case Study 3 – Variation of EI Across Product Widths

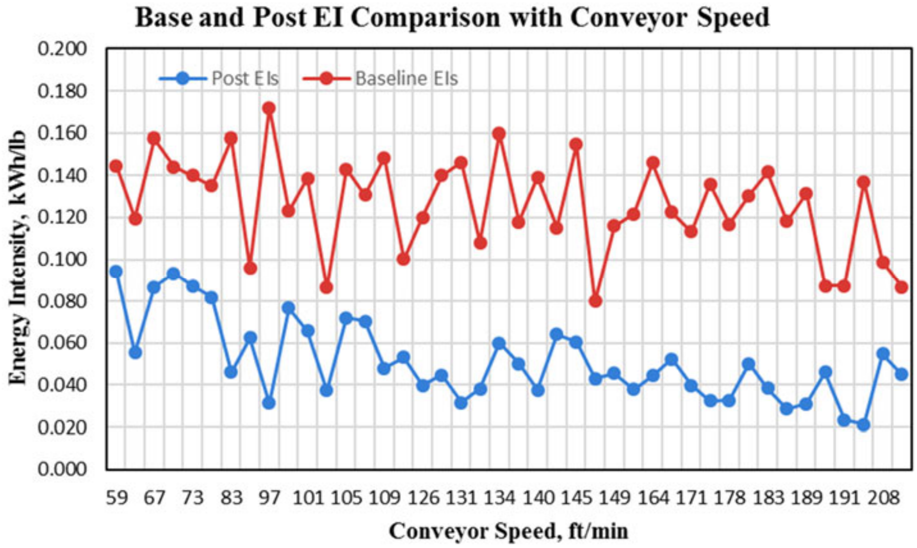


Figure 7: Case Study 3 – Variation of EIs Across Conveyor Speed (Product Density)

This example shows that energy consultants can prepare more nuanced, accurate, and comprehensive savings estimates if they have access to facility production records and understand the process variables. Furthermore, sharing the savings analysis can help to inform future plant modifications.

Recommendations

Since every industrial project is unique, a fixed set of recommendations for all projects that use energy intensity to estimate the project savings is unrealistic. However, based on experience in the technical reviews and evaluations of some the industrial projects, the author offers the following:

- Since there are many actors involved in energy conservation projects (see Figure 8), collaboration between facility personnel and energy consultants should be encouraged to develop measure-specific M&V plans and to utilize their M&V capabilities.
- Understand the plant, equipment layout, process flow, and their interactions.
- Estimate the equipment and process potential to maximize the savings opportunities.

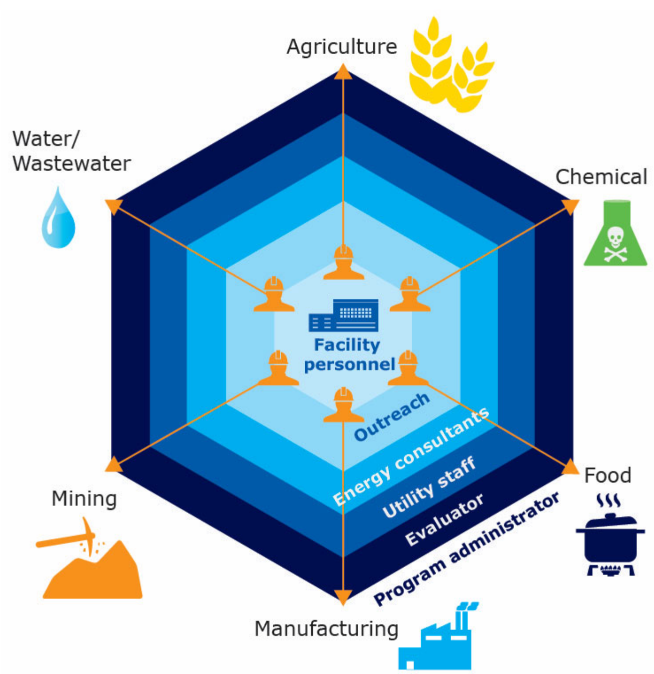


Figure 8: Flow of information to program administrator

- Draw boundaries around equipment and processes that will be affected with the modification to focus the analysis.
- Document the operation variables for equipment and processes needed to verify the pre- and post-ECM conditions, such as temperature, pressure, flowrate, and cycle time.
- Explore opportunities to estimate measure impacts for more confined sections, equipment, and process streams of the plant. Ask plant personnel whether there are sub-meters, plant log books, or production records for individual sections to help isolate a measure's impact.
- Verify that ECMs are effective across all likely operating conditions or specify the operating ranges or production rates that yield lower post-ECM EIs.

Conclusion

While EI methodology is a powerful tool to quantify the energy savings from an industrial modification project, it is always prudent for both energy consultants and facility personnel to explore tailoring it to fit the pre- and post-ECM operations, production and process limitations, and key process variables. Strong communication between the energy consultants and the facility personnel increases the likelihood that the EI analysis is appropriately tailored and yields accurate savings estimates.

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