Driving Down Energy Intensity Through Energy Management Systems

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Energy management systems measure, monitor, analyze, and optimize how energy is used across an entire plant. When implemented correctly, these systems can continuously align operations with the most efficient and profitable operating point.

The concept of an energy management system (EMS) first emerged in the 1960s in the power industry to manage transmission, distribution, and load. Gradually, their implementation has expanded into energy-intensive sectors such as refining and petrochemicals, where furnace and steam performance strongly influence operating costs. Today, these systems are widely used across process industries, from food and beverage processing — where they optimize refrigeration, steam, and compressed air — to specialty chemicals and pharmaceuticals — where they support utilities management, solvent recovery, and control of batch energy intensity.

Energy management system is a broad term. In a process facility, an EMS is not a single piece of software; it is a layered architecture integrating field measurement, actuation, control, communications, analytics, and operating routines. What defines an EMS and separates it from other types of systems designed to reduce energy costs is that it integrates software and analytics to deliver dashboards that enable prioritized decision-making. Most organizations begin with data from existing instruments, which highlights efficiency gaps. This drives the need for analytics and dashboards, often leading to additional measurements and controller upgrades to support more advanced control strategies.

Practically, an EMS should provide plant-wide visibility — *i.e.,* the "big picture" — of energy use and utility system health, plus unit-level energy key performance indicators (KPIs) tied to production and cost (Figure 1). Typical outputs include energy normalized to production — fuel energy per unit duty (*e.g.,* kWh/ton or MMBtu/ton) — and trend comparisons against targets or baselines for furnaces, boilers, distillation columns, or batch reactors. An EMS also enables faster prioritization of interventions based on quantified impact — further reinforcing its value. Most well-designed energy efficiency projects target paybacks within 1–3 years, and their rapid return on investment and ability to maximize capital efficiency often make their implementation a top priority.

According to the American Chemistry Council, one of the most significant motivations for capital investment in 2024 was energy savings *(1)*. Energy is one of the largest controllable operating cost components in refining and chemical plants, typically representing 5–15% of total operating cost. The push to improve sustainability and decrease energy costs has driven companies to prioritize energy projects in recent years. A well-developed EMS can reduce a facility's energy intensity index (EII) by 5–8%.

This article explores the components of an EMS as they apply to the chemical process industries, showcasing practical applications within the petrochemical industry. Though these case studies are drawn from chemical processes, EMSs are implemented in similar ways across industries, from water treatment to data centers to textile manufacturing and more.

Core components of an EMS and what they enable

EMSs are made up of a coordinated stack of technologies and capabilities. An effective EMS links measurement, decision-making, and action in a continuous loop. These systems translate high-quality data from the process, transmit and contextualize that data, convert it into control actions and optimization targets, and continuously refine performance through analytics.

Smart measurement devices. Instruments provide the foundational data needed to quantify energy performance and normalize it to production or duty. Typical EMS measurements include pressure, temperature, flow, and analyzers across electricity, fuel gas, steam, condensate, compressed air, water, oxygen, and related utilities. A common issue is insufficient measurement quality or coverage, which forces operators to run conservatively to maintain stability and safety. In combustion systems, for example, mass-based fuel measurement improves air-to-fuel ratio stability under changing fuel composition. When paired with oxygen and carbon monoxide (CO) measurements, it enables faster combustion feedback and improved operating confidence.

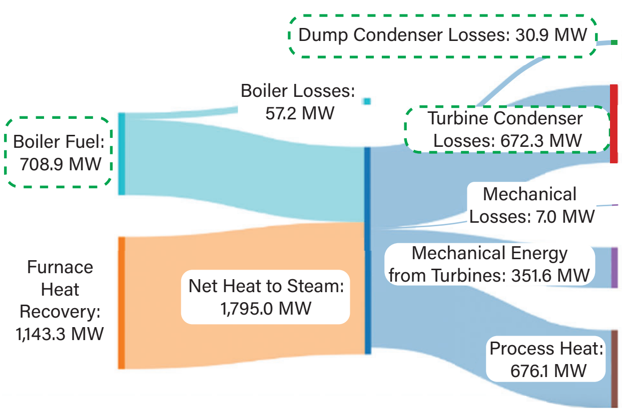
Actuation devices. Modern actuation instruments improve controllability and reduce losses by tightening response and limiting the need for manual intervention. Smart valve positioners with diagnostics improve positioning accuracy and repeatability, while variable speed drives (VSDs) match pump/fan speed to demand rather than operating continuously at full speed. In appropriate applications, VSDs can reduce motor energy use by ~20–50%.

Communications and integration. EMS effectiveness depends on moving data from the field to controls, as well as analytics layers with appropriate latency and reliability. To do this, modern processes implement a variety of advanced communications technologies. For example, edge computing capabilities process data close to its source, reducing lag time for time-critical control. Additionally, cloud connectivity enables enterprise-wide data aggregation, facilitating access to advanced analytics capabilities without requiring extensive on-site infrastructure.

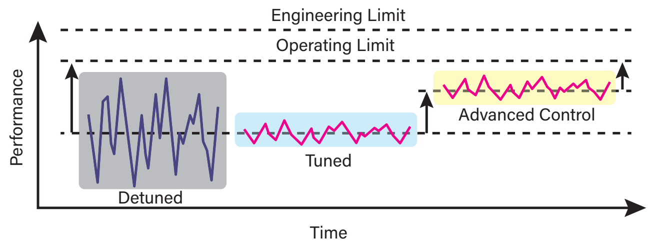
Process control. EMS controls convert measured energy drivers into operating actions. Basic controls — *i.e.,* single loop, single variable controls — keep a process stable around a setpoint. Advanced process control (APC) — which coordinates multiple variables at once — and model predictive control (MPC) — a specific type of APC that uses a mathematical model of the system to predict future behavior — provide a higher automation tier to optimize multiple variables simultaneously under constraints (Figure 2). In fired equipment applications, advanced control has been associated with documented fuel savings through improved management of temperature profiles, draft control, and air-to-fuel ratio management.

EMSs often feature real-time optimization, which extends APC beyond a single unit by coordinating targets across multiple units and even multiple plants. In doing so, real-time optimization continuously moves operations toward the best overall economic outcome. This approach connects planning/scheduling objectives and APC execution using dynamic optimization that runs continuously — without waiting for steady-state — and maintains model consistency with online data reconciliation, helping reduce margin leakage while improving throughput, yields, and energy efficiency.

Analytics. Analytics translates data into performance



▲ **Figure 1.** An energy management system (EMS) dashboard allowed engineers to determine the energy optimization opportunities at a chemical plant by calculating the mechanical and dump condenser losses.



▲ **Figure 2.** By introducing more advanced controls that reduce variability, processes can operate closer to their optimized target, reducing costs and emissions.

indicators, identifies optimization opportunities, detects abnormal conditions, and generates actionable recommendations (Figure 3). Common functions include statistical detection of drift and degradation, gap analysis that quantifies deviation from optimized operation, and multivariable methods that identify which operating parameters most strongly influence energy intensity.

The practical test of whether analytics are implemented successfully is whether they reduce the time between when you identify an opportunity and when you can justify, implement, and sustain a change. For example, a specialty chemical producer reduced energy costs by 2.6% using Emerson's AspenTech Operational Insights, an enterprise decision-support platform that integrates and analyzes operational data to predict unit-operation performance degradation and improve operations planning.

What an EMS delivers in practice

Real-time operational visibility. Real-time operational intelligence provides normalized energy dashboards and highlights deviations from expected performance, enabling earlier intervention. EMS implementations can also identify missing or unreliable datapoints — *e.g.,* absent temperatures and questionable flows — and use mass and energy balance checks to validate meters and detect losses such as steam leaks.

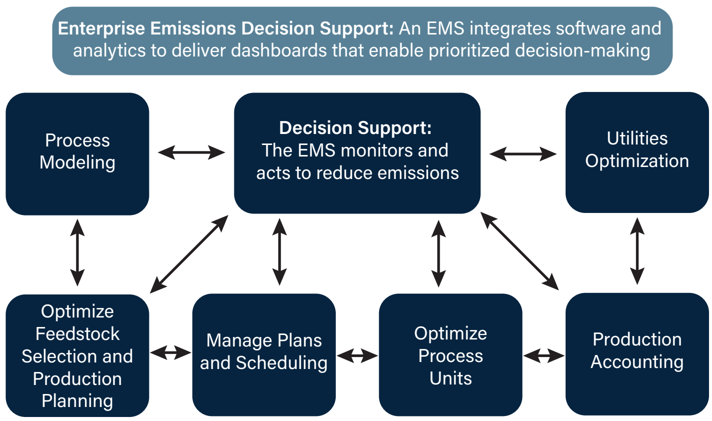
Benchmarking and gap identification. Benchmarking and performance gap analysis compare units, operating modes, or sites against design expectations and best-performance baselines. In many operations, gaps between lower- and top-quartile performance can be large enough to justify targeted projects. Benchmarking outputs typically includes prioritized "quick wins" where proven practices — such as improved combustion control, heat exchanger monitoring, or control loop tuning — can reduce energy intensity without major equipment changes.

Sustained improvement through decision support. Sustained improvements come from linking energy patterns to equipment health and economic tradeoffs. These come in the form of both process efficiency and predictive maintenance decisions. Examples include detecting heat exchanger fouling via heat balance and pressure-drop signatures, identifying rising compressor power draw at constant throughput, and determining maintenance intervals by balancing energy loss against labor costs. An example of this would be an EMS dashboard displaying and analyzing measurements from a fired heater that detected a 3% decline in efficiency over 18 months, triggering a tube cleaning before significant energy loss.

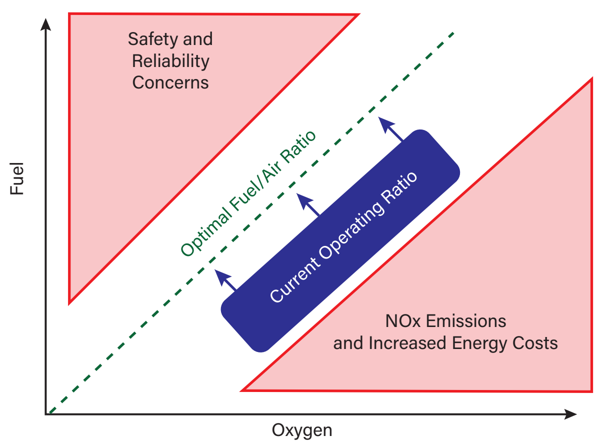
Case study: Reducing fired heater energy intensity

Fired heaters and boilers are among the largest energy consumers in refining and petrochemical facilities. Because these assets operate continuously and directly affect downstream throughput and product quality, small improvements in combustion performance can translate into significant cost savings and emissions reductions. Currently, fired equipment must operate within strict safety constraints, meaning optimization must be measurable, controlled, and defensible.

In many facilities, fuel gas composition varies either due to changes in gas supply or, more often, due to the fuel gas being blended from multiple sources. When combustion control is based on volumetric fuel measurement, changes in fuel composition translate into changes in heating value that the control strategy may not recognize quickly enough. Plants often compensate by operating with conservative excess air settings to avoid rich firing and trips (Figure 4). While safe,



▲ **Figure 3.** The various process dashboards that can be integrated into a fully developed EMS include process digital models, project scheduling software, and utilities optimization programs, all designed to help support enterprise-level decision making.



▲ **Figure 4.** Inadequate measurement of the fuel supplied to a burner drives organizations to run in the "safe" zone, resulting in higher energy costs and less-effective operations.

▲ **Figure 5.** Implementing an EMS that can analyze fired heater performance using key process measurements can help improve combustion efficiency, stability, and safety.

this approach can systematically leave efficiency on the table and can make it difficult to quantify the cost of deviations.

In this case study, a fired heater met safety and production requirements, but operators lacked real-time visibility into the true fuel energy input and the economic impact of operating away from the best achievable combustion window.

Measurement and control strategy. To address these limitations, the heater can be upgraded to a mass- and energy-based combustion control approach aligned with the American Petroleum Institute (API) 556 standard 3rd edition, which explicitly provides guidance on the measurements and controls around fired heaters (Figure 5) *(2)*. There is also a recommended practice (RP) 538 for boilers *(3)*. This upgrade to a mass- and energy-based combustion control approach includes:

• Mass-based fuel measurement using Coriolis flowmeters to provide accurate fuel flow measurements independent of composition changes.

• Fuel energy calculations using mass flow and specific gravity to estimate real-time heating value.

• Fluegas monitoring using oxygen and carbon monoxide analyzers to provide direct combustion feedback.

• Feedforward air-fuel ratio control, enabling air flow to respond rapidly to fuel energy changes while analyzer feedback trims the final setpoint within safe limits.

EMS-enabled visibility and benchmarking. Integrating these measurements and control strategies into an EMS transitions the fired heater from being a black box to becoming a continuously monitored energy asset. Energy performance metrics are displayed in real time, including fuel consumption vs. production rate, heat duty, and efficiency trends. Operators and engineers can view fuel energy input normalized to duty and production rate, alongside combustion health indicators such as excess oxygen and carbon monoxide trends. As an example, one customer identified that a particular heater was operating 3–5% below achievable efficiency because of slow response to BTU swings. Table 1 shows the variability in heating value that occurs when a system monitors fuel flow using a volumetric device vs. a mass device, specifically a Coriolis meter. Figure 6 shows the impact that this difference in heating value can have on a system's ability to keep up with O_2 demand.

Historical data also enables benchmarking against design expectations and best achievable performance metrics. Importantly, benchmarking translated "we think we can do better" into a quantified opportunity, turning efficiency gaps into estimated annual fuel cost impact. This creates a clearer business case for tuning and operating closer to optimum without compromising safety.

Fuel control analysis. An EMS analyzes data continuously to optimize combustion processes, using multivariable analysis to understand how fuel BTU, draft, excess oxygen, and firing patterns affect efficiency and NOx generation. Using this information, it can identify operating windows that minimize energy intensity within emissions limits. These tools detect subtle performance drifts and quantify their economic impact in near real time, so operators can prioritize corrective actions. In heaters and boilers aligned with API 556 and RP 538, such analytics not only capture initial efficiency gains from improved control, but also sustain and extend them as fuels and conditions change.

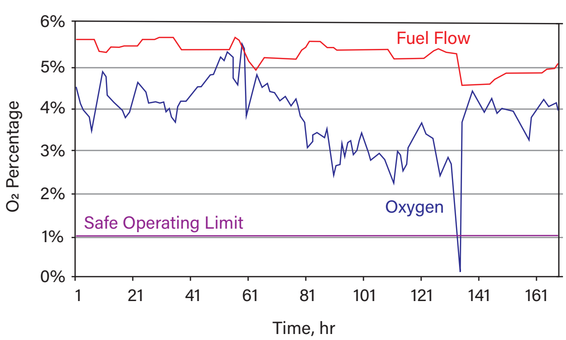
Economic impact and sustained performance. Scenario analysis, including Monte Carlo simulations of fuel variability, can help quantify the value of tighter mass-based control under realistic disturbances. In this context, tighter control can create value through reduced excess air, improved stability, and avoided trip events.

An EMS provides engineers with the historical data they can use to benchmark actual performance against design expectations and best-in-class operations. This gives engineering and operations the confidence that there is real economic value in changing control strategy, not just theoretical benefits (Figure 7).

The future role of AI in energy management. Artificial intelligence (AI) and machine learning (ML) are extending EMS capabilities from monitoring and advisory functions toward more adaptive optimization. Near-term applications increasingly incorporate time-varying energy prices and coordinate decisions across multiple units, ensuring that improvements in one area do not create inefficiencies elsewhere. For batch operations with discretionary timing, AI scheduling can also support price-responsive operations by aligning energy-intensive steps with forecasted energy prices and equipment availability.

Table 1. Variation in the composition of fuel gas can lead to significant swings in energy content that, if not accounted for using an EMS, can produce gaps between the supplied and required energy, as shown in Figure 6.

Components	Gas 1, mol fraction	Gas 2, mol fraction
Inerts	3.6	2.5
C1	90.7	85.9
C2	4.5	8.5
C3	0.8	2.3
C4	0.3	0.7
C5	0.1	0.1
Energy Content		
BTU/lb	22,218	22,294
BTU/ft^2	1,035	1,108
Variability		
By mass		0.17%
By volume		3.34%
Reduction, *i.e.,* The Ratio Between Volume and Mass Variability		19.6×



▲ **Figure 6.** When systems fail to account for compositional changes in fuel gas, rapid changes in composition and the subsequent increased demand for %O_2 might result in operating below the boundary condition.

How to begin

A practical way to begin implementing lessons learned from recent EMS applications is with a structured baseline and opportunity assessment. For example, one Middle East polyolefins complex began by quantifying losses in its steam system — about 23 million GJ of fuel, just over 1 million tons of CO_2 per year. Next, they used a study to baseline two complexes. Using the data from this study, they built marginal-abatement cost curves and Monte Carlo-based rankings to prioritize projects by CO_2 impact, net present value (NPV), internal rate of return (IRR), and annual benefit. Finally, they used APC, real-time optimization, and an EMS to cut 100 GJ/hr from losses and reduce emissions intensity by 22 kg CO_2/ton versus the baseline. This saved the company roughly $5 million per year on steam production and contributed to more than $30 million of energy operating expense (OPEX) reduction over four years.

Another olefins and polyolefins producer followed a different pattern: They held a cross-functional workshop, which generated 94 digital and energy-related ideas. These ideas were used to create a three-year roadmap and global assessment. That program has already implemented 20 projects across furnace optimization, EMS, APC, and analytics, delivering about 200 kton CO_2e/year reduction and $15 million in annual benefits.

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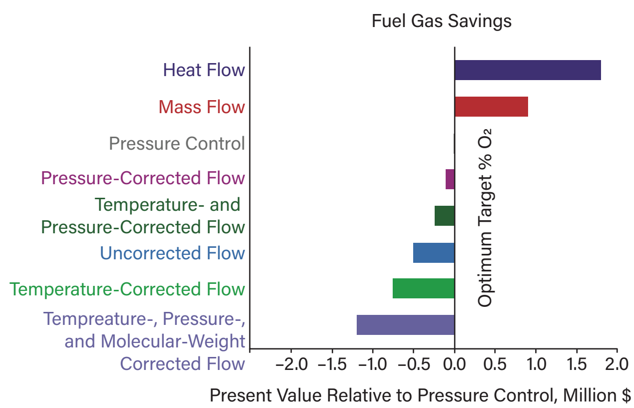

▲ **Figure 7.** Improved control of a fired heater combustion process enabled the unit to be optimized using data from heat and mass flow analysis, leading to significant savings. Attempting to optimize the process using parameters like temperature and pressure alone can lead to higher costs and increased energy intensity.

Finally, an ethylene producer deployed an EMS-style dashboard that integrates fuel, electricity, ethylene and propylene consumption, production, quality, reliability, and health, safety, and environmental (HSE) metrics for three olefin trains. Operators could see where ethylene and co-monomer consumption deviated from allocation and where utilities and polymer units diverged from expected usage. This enabled quick identification of bad actors and wasted energy.

These examples suggest a repeatable path: quantify losses, create integrated dashboards, then use economic and abatement-based ranking to drive a sequenced portfolio of EMS and control upgrades.

An effective energy management journey does not start with a blank sheet; it starts with the data, assets, and people you already have, then systematically elevates them into a structured EMS that closes the loop between measurement, analytics, and action. As the examples in this article illustrate, plants that quantify losses, deploy mass- and energy-based control strategies, and institutionalize EMS-driven decision-support achieve measurable reductions in energy intensity, emissions, and operating cost while strengthening safety and reliability. For companies facing volatile energy prices and tightening decarbonization pressures, the plants that move to modernize their energy management systems will have a competitive advantage over their peers. CEP

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