Application Note

Energy Efficiency Self-Assessment in Industry

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March 2017

ECI Publication No Cu0156

Available from www.leonardo-energy.org

Document Issue Control Sheet

Document Title:	Application Note – Energy Efficiency self-assessment in industry
Publication No:	Cu0156
Issue:	02
Release:	Public
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Editorial and language review	Bruno De Wachter (editorial), Noel Montrucchio (English language)
Content review:	Patrick Thollander

Document History

Issue	Date	Purpose
1	May 2013	Initial publication in the framework of the LE Good Practice Guide
2	March 2017	Publication of a new version after revision
3		

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SUMMARY

Industrial companies seeking ways to reduce energy use often call upon external advisors to assess the energy efficiency of a plant. While this is generally a good idea, it is unwise to leave this task entirely up to the external advisor. Identification of promising opportunities for saving energy requires thorough insight into the plant's processes and a profound knowledge of the process design. Plant engineers and operators generally have a much greater insight into their plant than external advisors. It is therefore a good idea to begin the process with an energy efficiency self-assessment, either as a prelude or as a complement to an external assessment.

Where should a self-assessment begin? This paper presents a step-by-step approach for conducting an energy-efficiency self-assessment, from the definition of the scope to the implementation of the action plan. Energy-related data must be collected and analysed, energy conservation measures identified, and associated benefits and costs estimated. Along the way, we discuss a number of real-life cases from various industrial sectors, showing examples of both easily applied measures and capital-intensive solutions.

INTRODUCTION

This paper is intended for industrial plant energy managers seeking ways to reduce their energy use in a sustainable manner. It results from numerous observations and considerations regarding energy efficiency and energy conservation programmes in industrial companies.

Today, the general public is increasingly aware of the importance of energy efficiency. Most people also have a rather good idea of the kinds of the measures they could take in order to reduce their energy use. It is true however that they are often too focused on local energy efficiency rather than taking on a systems approach and assessing the design of entire production processes. But apart from that, most companies know more or less what they should do. However, a number of subtle, sometimes hidden barriers prevent plant managers from immediately initiating the necessary measures.

One such barrier has to do with **budget issues.** Implementing energy efficiency projects can take significant time since budget decisions are usually taken on the corporate rather than plant level[1]. Improving energy efficiency does not belong to the core business of most companies and many such projects require considerable corporate capital investments. Furthermore, purchase managers tend to focus on the initial investment cost and have less consideration for associated operational costs such as energy use. Even if they do consider energy use, they often impose nearly impossible payback times. Since the initial cost is only the tip of the iceberg, a lifecycle approach will often reveal that a higher initial investment pays off in the end thanks to lower energy costs.

Another barrier preventing managers from acting now is **lack of knowledge about actual energy use**. Managers concerned with industrial plant energy use have a good idea of their total energy usage, but they generally do not have it broken down in detail. They seldom know how much energy is consumed by each individual process, exactly how much it costs, and whether this energy use is efficient. Hence, it is difficult to uncover promising energy saving opportunities. This in fact, is one reason why many industrial companies call upon external advisers to assess their energy efficiency. However, these advisors face the same problem: uncovering less obvious energy saving potential requires having detailed data about actual energy usage. As a result, many opportunities remain hidden.

Industrial companies should consider conducting a self-assessment of their energy efficiency in order to reveal the opportunities. This paper argues that **a self-assessment is complementary** to an assessment by an external advisor **and may even be crucial** in finding the optimal mix of opportunities for improving the energy efficiency. Unfortunately, most companies do not know where to begin. This paper presents an energy efficiency self-assessment guide for industrial companies. It provides a framework and a step-by-step approach illustrated with *real-life examples* showing how to find opportunities to save energy and reduce the energy use in a sustainable manner.

ENERGY EFFICIENCY IN AN INDUSTRIAL ENVIRONMENT

THE COMPLEXITY OF ENERGY USE IN INDUSTRY

In commercial buildings it is a relatively straightforward matter to establish energy usage. In an industrial environment however, energy usage is much more complex.

The energy usage of an industrial plant can generally be broken down in three parts:

- Energy for the **building** itself, mainly for heating, cooling and lighting
- Energy consumed by plant **utilities** such as the internal electricity grid (cables and transformers), steam system and compressed air system
- Energy consumed by the **production processes,** supplied directly or by the plant utilities

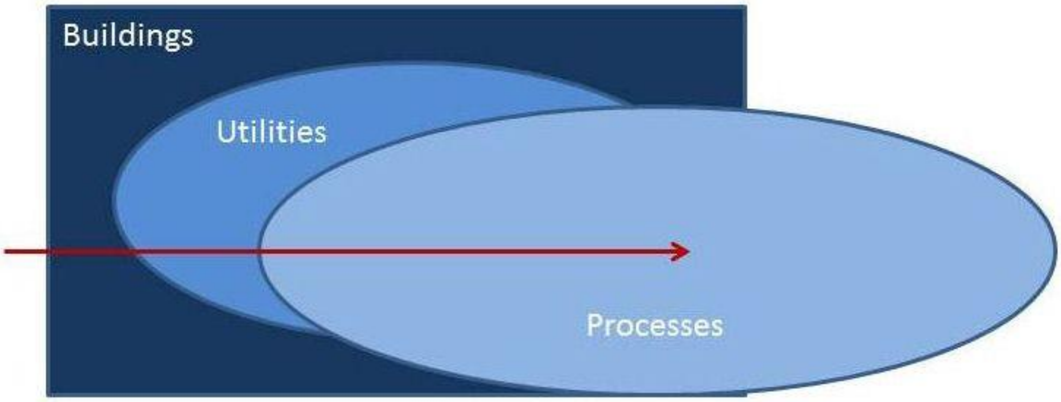

Figure 1—The main energy consumers of an industrial plant are in many cases the production processes

Buildings seldom account for the largest part of energy use, with the possible exception of high-tech clean room environments. In most energy-intensive industries, buildings account for 10% or less of the total energy use. This means that investments in this domain would only amount to marginal energy efficiency gains. The contribution of utilities is more important. Utilities convert energy from one carrier to another (e.g. high to low voltage, natural gas to steam, electricity to compressed air), a process which *always* leads to energy losses. Utilities are widely present in every industrial plant and thus represent a considerable part of the total energy use. However, the main energy consumers of an industrial plant are in many cases the actual production processes.

It is clear that important savings can be made by optimizing both the processes and the use of utilities. However, these consumers are very plant-specific and heavily dependent upon on how the processes are designed. Furthermore, the actual energy cost of an industrial plant also depends on the production capacity and schedule. Electricity tariff structures for industry can be rather complex, since they depend not only on the actual energy use, but also on the peak demand, the season and the time of day. Indeed, some industries may already be saving a great deal by optimizing their peak demand.

However, this **addresses the core of industrial activities**. The processes and production schedule are primarily designed and fine-tuned to assure quality and productivity. It is usually extremely difficult to change anything in the design for so-called secondary reasons such as energy efficiency. In other words, it is hard to convince corporate or plant management to reconsider elements of the process design in order to save energy. Yet, **companies that have the courage to address such questions often achieve major financial benefits**. In the following pages, we will outline cases demonstrating that this approach pays off.

ENERGY COST REDUCTION MEASURES BEYOND THE STRAIGHTFORWARD

FIVE WAYS TO REDUCE THE ENERGY COST

In all three domains (buildings, utilities and processes), there are five fundamental ways to reduce the energy cost:

- Choosing the optimal energy carrier
- Improving the energy efficiency of the equipment being used
- Reducing energy demand by modifying the design or the operations
- Recovering waste heat
- Load management

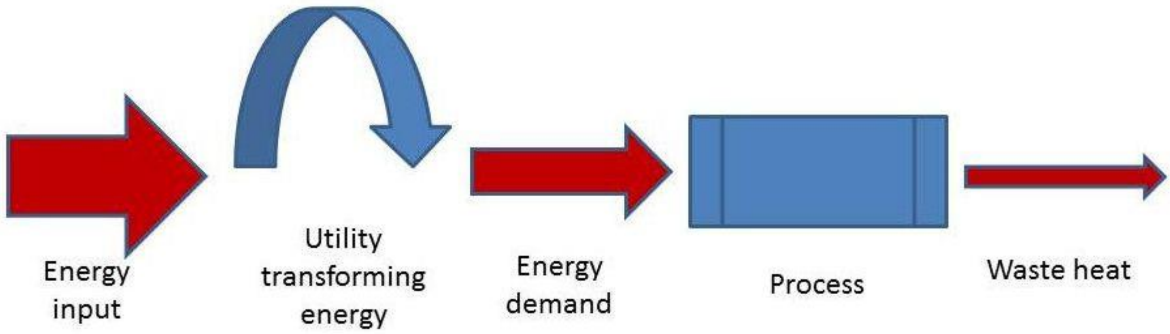

Figure 2—Reducing the energy cost means choosing the most suited energy carrier, reducing energy demand as well as optimizing the time profile of the energy demand (load management), improving the energy efficiency of equipment and processes, and recovering waste heat.

CHOOSING THE OPTIMAL ENERGY CARRIER

Energy efficiency should receive priority from the very outset of the design phase of an industrial process. One of the crucial design decisions is that of the energy carrier to be used. It is very difficult to set general rules for how to make this decision; the assessment will be different for every type of situation. But in any case it is important to take the entire system and the entire life cycle into account.

Take for example the plan to drive a series of industrial actions using a compressed air network. Electricity will drive the compressor(s), and the compressed air will actuate the required motion. In this case, it can be worthwhile to investigate the alternative solution of replacing this compressed air system with several electric actuators at the place of use. Such an all-electric system will generally have a higher purchasing cost, but often has lower energy consumption. In a compressed air system, the energy necessary to maintain the air pressure is costly, especially if not all of the actuators are continuously in use. An all-electric solution will also have lower maintenance costs. As a result, such an alternative electrical solution may result in having the lowest Life Cycle Cost.

Even though energy efficiency should receive priority, it is important to think inclusively and take elements such as carbon emissions and product waste into account. In the Application Note ***Introduction to Industrial Process Heating***, page 5, an example is given of a comparison between a natural gas furnace and an induction furnace for melting aluminium. The specific primary energy use of the gas furnace is 3,080 GJ/metric ton, that of the electric furnace is 4,527 GJ/metric ton. However, due to the lower carbon intensity of the electricity mix, those energy consumptions result in carbon emissions of 175 kg/t for the gas furnace, versus only 156 kg/t of the induction furnace. Moreover, the material losses due to oxidized aluminium are 18 kg/t for the gas furnace resulting in 132 kg of carbon emissions, compared to only 6 kg/t for the electric furnace, resulting in 43 kg of carbon emissions. The aggregated carbon emissions are consequently substantially lower for the electric furnace. The reduced cost due to material loss and of carbon emission rights therefore results in a lower life cycle cost for the induction furnace compared to the natural gas furnace.

Improving the energy efficiency of equipment being used

Many industrial companies still use older equipment and processes or have not yet optimized their equipment and processes for energy efficiency. Improving the energy efficiency of equipment and processes is a rather straightforward measure and one with great potential. However, the next two options may be even more promising.

Highest priority: reduce energy demand

From a sustainability point of view, reducing the energy demand has a higher priority than recovering waste heat. Unfortunately, it is a rather difficult approach. However, difficult certainly does not mean impossible or not worth pursuing, as demonstrated by the example of a plant treating municipal wastewater.

> *The plant uses a series of blowers to supply oxygen to the aerobic treatment process. These blowers consume a substantial part of the plant's power draw and have been carefully selected and sized for maximum efficiency. Is this sufficient? No, because even with the most efficient blowers, approximately two-thirds of the power consumed is unavoidably lost as heat, as the laws of thermodynamics allow us to calculate: one joule of blower air requires approximately three joules of electricity.*
>
> *For this reason, the plant investigated the feasibility of reducing the blower airflow by 10%. They reinvestigated the diffuser system and controls and found that by using a more appropriate control variable in the nitrification process (the ammonia concentration instead of the dissolved oxygen concentration) they could effectively reduce the blower air demand.*

Waste heat recovery: opportunities in industry

In the chemical process industry, it is common practice (and even essential in some) to recover heat from exothermic processes and use it in endothermic processes. In other industries, there are plenty of opportunities in the same vein. For example, air compressor cooling generates heat at temperatures typically lower than 50 °C, making it suitable for space heating. Other waste heat streams have temperatures around 90 °C, which means they can be used efficiently to produce chilled water using absorption chillers. Industrial wastewater, even at relatively low temperatures, can be an excellent heat source for a heat pump, allowing the production of hot water.

Load Management

If a company wants to reduce its energy costs, its primary focus should be on reducing energy consumption. However, in many cases, companies can also realize significant savings by optimizing both:

1. Their energy consumption profile
2. Their energy contract and purchasing strategy

A company can gain a better understanding of its consumption profile through energy monitoring. Once this valuable insight is in hand, it can identify both problems and opportunities for time-flexible consumption.

Accurately forecasting the simultaneity of electrical loads and time-flexible consumption can result in a reduction in the capacity component on the invoice. It also has the potential to increase the benefits of local (renewable) electricity generation through optimized self-consumption. This helps avoid costs (or lack of savings) for injecting overproduction onto the grid. Load Management can also enable a company to valorize its flexibility of consumption on the energy market, either directly on the spot or imbalance markets or through aggregated demand response.

You can read more about this subject in the Application Note ***Load Management of Industrial Systems***.

The need for an open-minded approach

Finding opportunities beyond off-the-shelf solutions

Because energy use in industrial plants is complex and plant-specific, solutions will differ from plant to plant and will need to integrate other than off-the-shelf solutions. Running a checklist will not be enough. **We must be more ingenious and resourceful**. We have to be ready to think outside the box, counteract entrenched ideas and reconsider assumptions made in the past. An open-minded approach can lead to measures that are both easy to carry out and very successful, as is demonstrated by the following examples.

10% energy saving thanks to set point re-evaluation

A construction material manufacturer used a 10% solids concentration in an endothermic aqueous reaction. As a result, they had to heat ten tons of water for each ton of solids. This 10% set point was based on extensive research carried out in the past. However, the improved accuracy of newer controls enabled shifting to a higher 11% concentration, requiring less water heating. Re-evaluating the set point meant saving 10% energy and increasing the capacity proportionally.

Bypass closed after design re-evaluation

A fine chemicals manufacturer operated a unit in a batch process. The unit was equipped with a bypass in order to avoid thermal shocks in the heat exchanger. However, the bypass used no less than 20% of the significant steam consumption of the unit, a fact that was discovered when an engineering student developed a detailed mass and energy balance of the unit. The manufacturer then consulted the heat exchanger supplier asking whether the use of the bypass was necessary. The supplier confirmed that removing the bypass would not risk to compromise the equipment's lifetime. The bypass has now been closed.

Adapting to the tariff structure

Complex electricity tariff structures must be properly taken into account. Consider two similar industries A and B, with Plant A having a rate structure with high charges for consumed energy and low charges for peak demand, and Plant B having a rate structure with lower energy charges but high charges for peak demand. Both require a continuous supply of process water. In this case, Plant A *would prefer to provide buffer tanks and fill them when energy charges are low, using on-off controls. Plant B, however, would prefer to pump water at a constant flow rate, making use of efficient controls such as variable speed drives.*

Reasons to conduct a self-assessment

Many companies hire an external consultant or even an Energy Service Company (ESCO) to conduct an energy efficiency assessment at their premises. This is generally a good idea, because consultants bring in expertise and experience from other industries and companies. However, while many of these campaigns are quite successful, all of them also are bound to miss a series of opportunities, and quite often very important ones. There are several reasons for this, one being a bias towards high-tech capital-intensive solutions rather than simple low-cost remedies. Many low-cost solutions also slip under the radar because the consultants are not familiar with the ins and outs of the entire plant. Furthermore, consultants sometimes have difficulty in identifying production process elements that can be changed or optimized. They are unaware of all assumptions made at design-time. It is not easy for a consultant to acquire profound insight into the actual energy use of a given plant. In the extreme case, this might even lead to preparatory measuring campaigns that consume virtually the entire assessment budget.

The plant engineers and operators however, are much more knowledgeable about their own plant. They can trace back past assumptions and are able to assess their current validity. Their continuous presence in the field helps them to spot low hanging fruit. It also helps them to define the focus of measuring campaigns in order to determine exactly where energy is consumed and for what purpose.

The advantage of having a **profound inside knowledge of the plant is invaluable**. It is the main reason why industrial companies should definitely consider conducting an energy efficiency self-assessment.

However, it must be stressed that a self-assessment does not eliminate the need for an assessment by an external consultant. The two are fully compatible and complementary. In fact, a self-assessment can be a perfect prelude to an external assessment because:

- It gives the company a better insight in the performance of the existing systems and helps to identify the most important energy consumers
- It provides an excellent basis for the consultant to work on
- It already creates momentum and provides a basis for implementation

Meanwhile, it is important that the consultant acknowledge the work carried out during the self-assessment and that they avoid giving a repeat performance.

Remember: energy usage in industry is a complex matter since it is very plant-specific. As a result, it is absolutely essential to have a profound inside knowledge of the plant, the more so since it might be necessary to alter some elements in the production processes. This is the main reason why we recommend conducting an energy efficiency self-assessment exercise.

APPROACH FOR ENERGY EFFICIENCY SELF-ASSESSMENT IN INDUSTRY

This chapter outlines a six-step approach for carrying out an energy efficiency self-assessment in industrial companies. It is important that each step receive sufficient attention for the self-assessment to be successful.

STEP 1: DEFINE PURPOSE, SCOPE AND RESPONSIBILITIES

The ISO 50001 standard provides a recognized framework for integrating energy performance into the management practices of companies[2]. This standard enables organizations to integrate energy management with the overall efforts for quality improvement, environmental management and other challenges addressed by the company's management systems. It includes developing a policy for more efficient use of energy, fixing targets and objectives to meet the policy, using data to better understand and make decisions concerning energy use and consumption, measuring the results, and reviewing the effectiveness of the policy to continually improve energy management. It promotes systemized energy management based on common sense. An additional advantage of ISO 50001 is that companies can benefit from it without being obliged to certify.

We recommend using this ISO 50001 framework to **define the approach** of the self-assessment and to **establish the scope and targets** of the project. Take enough time for this effort and avoid being overly cautious. The project must be carried by a team that brings together **all parties within the organization** that—both formally and informally—are relevant for the cause. Teams very often include an environmental officer, a process engineer, a project engineer, and the energy manager. The individual team member's commitment and time must be firmly secured. Finally, the commitment of top management is essential: the plant manager and the purchase manager must inspire the project and fully support all of the associated activities up to implementation. Establish a clear **communication plan** that addresses everyone in the organization, from the plant manager to the workers on the shop floor and in some cases external suppliers.

STEP 2: COLLECT ALL RELEVANT ENERGY RELATED DATA

In order to find opportunities for saving energy, it is necessary to identify the significant energy users and the relevant variables affecting energy use. All relevant energy related data must be collected. First, check the available data by collecting the monthly energy use data of the different energy carriers. Then collect the data available from any sub metering devices installed in the different systems. At present, most plants are able to provide massive amounts of data produced by meters, since the technology has become significantly cheaper in recent years and decades. However, it is essential to have the data broken down in sufficient relevant detail. The following aspects should be thoroughly checked:

- Does the metering cover **all energy carriers**?
  - Electricity
  - Steam and hot water
  - Chilled water
  - Compressed air
- Does the metering enable comparison of consumption against the most **relevant process variables**? Relevant process variables can include:
  - Throughput
  - Input concentration
  - Finished product quality (if quantifiable)
  - Ambient temperature and moisture content
  - Downtime

- Are the **metering intervals short enough** (for example one hour or one day) to enable analysis of the effect of production cycles and rate structures? This requires having a clear view on the plant’s production schedule and on the rate structures of the different energy carriers.
- Are the data **complete and correct**? Operators and engineers who know the installations very well should verify this aspect. Calibration of the metering and validation of the data sets is especially important.

Shorten the metering intervals and/or install additional meters wherever appropriate[3]. In some cases, the use of estimates can be acceptable, provided they can be calculated with sufficient accuracy and reliability. For example, the heat demand of a drying process can be estimated if the material inputs and outputs are well known.

STEP 3: MONITOR THE ENERGY PERFORMANCE AND BENCHMARK

Based on these data, draw up detailed daily energy demand profiles, showing on an hourly basis the contribution of each energy user to the total energy demand.

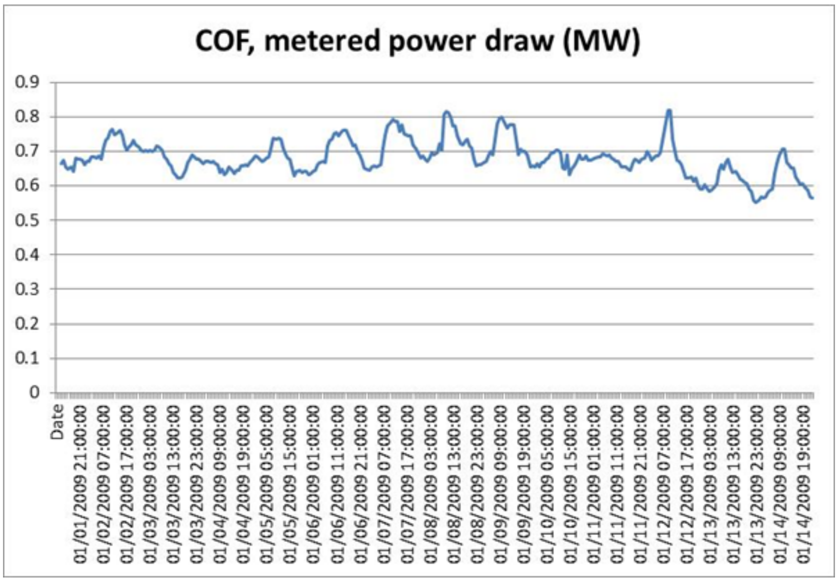

Figure 3—This load profile proves that energy can be saved by optimizing the HVAC controls (drawn power in MW on Y-axis, timeline on X-axis).

Load profiles can provide important information.

> *Consider the load profile above, showing a two week 1h-interval power metering in January of an administrative building on an industrial site. The power draw is the sum of the ventilation, electric resistance heating, cooling, lighting, IT, et cetera. The profile clearly shows a daily peak on weekdays. However, this peak is relatively small. One would expect a far bigger decrease in the electricity usage during the weekend. It proves that there is probably room for energy conservation through* ***optimization of the HVAC controls.*** *Decreasing the fresh air intake and the temperature set point during the weekend could be measures that are worthwhile exploring.*

Draw up a comprehensive **energy breakdown** of the entire plant or a specific production process. Visualize the energy flows in a **Sankey diagram**, showing the energy inputs from the different carriers, their contribution to the energy use and the energy losses.

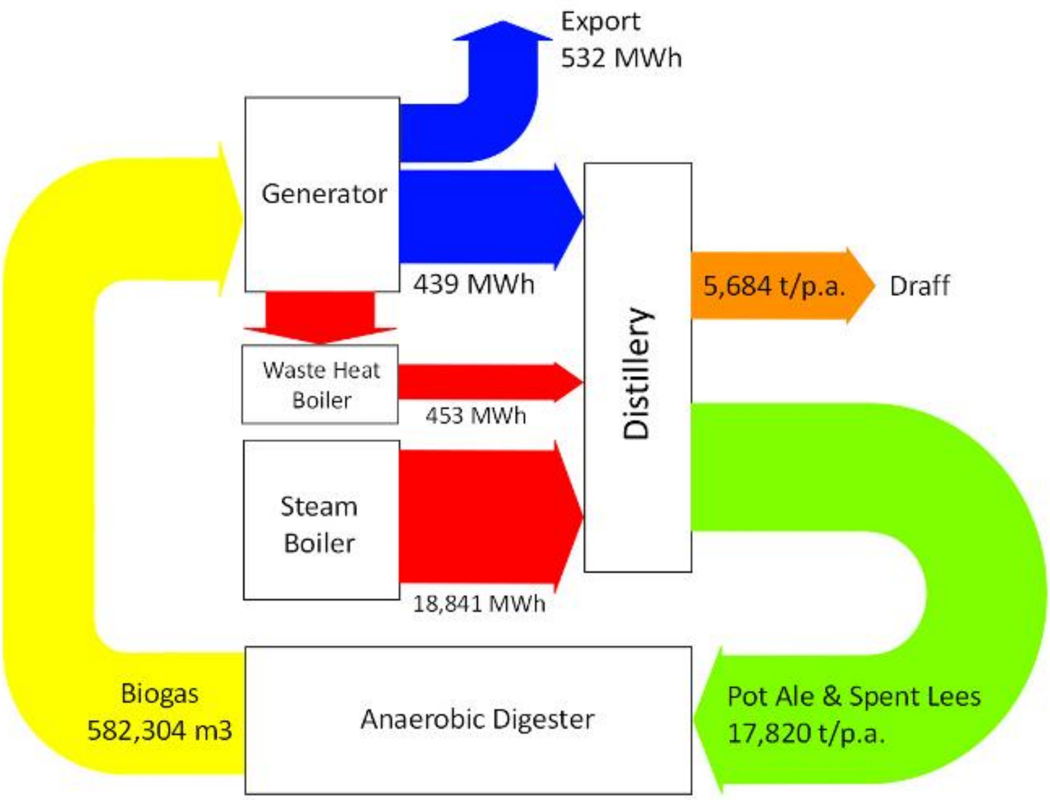

Figure 4—A Sankey diagram Visualizes the energy flows in a process.

Then, develop relevant **Energy Performance Indicators** (EPI) (also commonly called e-KPIs) to enable objective monitoring of the performance. EPIs compare the energy use of the different energy carriers with one of the relevant process variables mentioned in Step 2. Process variables should be selected for both comprehensiveness and ease of use. It can be useful to use analytical techniques such as multiple regression analysis to help make the selection. Furthermore, it might be useful to build EPIs for individual parts of the process, for example by splitting up the production process into a main process and one or more additional treatment processes. This will enable monitoring of each sub process against the most appropriate process variable, for example the main process against the throughput and the product finishing process against an attained quality level.

optimized aeration system at the Mangere WWTP

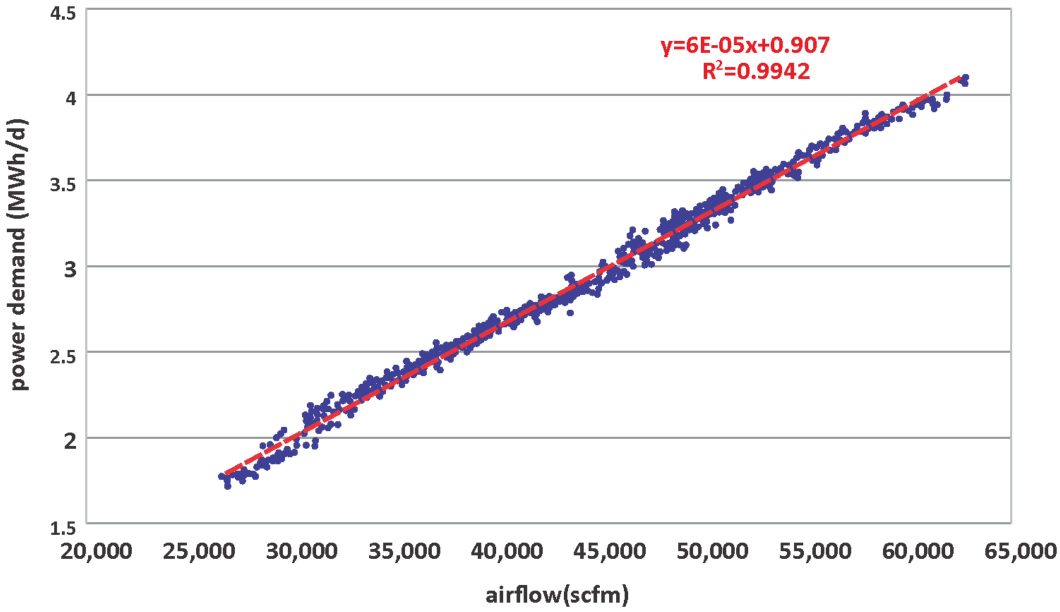

Figure 5—The graph above shows the power draw of a wastewater treatment plant aeration system as a function of the required airflow. There is a clear linearity and no scatter, so the system is well-optimized and the blower efficiency is almost constant over the entire operating range. This means that, at this particular US plant, the electricity consumption per standard cubic foot can be used as an accurate EPI for the blower air supply.

All EPIs should be visualized in graphs and systematically made available to key staff in the organization. This will enable the monitoring of energy use and performance. Since EPIs typically calculate weekly, monthly or quarterly averages of the energy use, they enable the rapid identification of any anomaly. If needed, the underlying data can be monitored at shorter intervals to enable a more profound analysis.

Use the energy profiles, energy breakdown, and EPIs to conduct a comprehensive **benchmarking** exercise. First, compare the results with relevant entities of the same company, such as other plants or specific processes with similar input and output. When differences are found, analyse where they come from. Differences in energy performance may be due to various aspects:

- The process installation may be operated differently, using alternative control systems and/or set points
- There may be slight differences in the raw material used or input
- The process may be designed differently, leading to a significant impact on energy usage and performance
- Air abatement or wastewater treatment units may or may not be present
- Quality management or final product specifications may be different.

Some of the results can also be compared with common indicators and/or best practices available in literature. You can even compare results with other companies. Competitors are sometimes surprisingly willing to share their data provided you also share your company's data set.

Step 4: Identify energy conservation measures

Take a broad perspective while identifying possible energy conservation measures. List low hanging fruit as well as capital-intensive measures, consider replacing equipment such as older motors or pumps and identify opportunities for waste heat recovery.

Identifying low hanging fruit

Many energy conservation measures are surprisingly easy to take. Consider the following options:

- Shut off users whenever it is possible. Systematically check the necessity of lighting and ventilation (throughout the day or the production cycle) and the use of air compressors, circulation pumps, hydraulic pumps and other equipment.
- Consider changing utility set points to reduce energy use.

  For example: check the set point for the excess air ratio in the flue gases of all burners being used. Natural gas fired burners require approximately 3 vol% oxygen measured in the flue gases to ensure complete combustion. Many maintenance contractors, however, adjust the burner to a more conservative set point of 6 vol% or more thereby reducing the boiler efficiency significantly (each extra vol% reduces efficiency by 0.5%).
- Continuous improvement of quality management will also improve energy performance. Indeed, every re-run will result in lost capacity, energy and possibly feedstock.

Consider capital-intensive measures

Each one of the installations in an industrial plant offers various options for energy conservation measures. Inspiration can be found in one of the numerous excellent lists of common energy conservation measures in industry. Among the lists we recommend are those provided by the Canadian Office of Energy Efficiency[4] and by the U.S. Department of Energy. This paper will provide only a brief outline of the aspects that should be examined. Since these measures usually require substantial investments, it is always necessary to check economic feasibility by calculating the return on investment (see also *Technical and financial consequences*).

Optimizing the process design—As already mentioned, reconsidering elements of the process design can lead to substantial energy savings. Optimizations can be found in the following domains:

- Re-evaluation of process set points. Even a small adaptation of a set point can have a substantial influence on the energy use of an entire industrial process. Systematically check the set points used in your process and trace their history. On what facts and assumptions are they based? Are these facts and assumptions still valid or should they be re-evaluated? Consider the technological improvements achieved since the initial definition of the process.
- Improving automation and control systems. Systematically check the control systems used in your process. Consider installing additional control systems or upgrading the existing controls to improve their accuracy and performance.
- Re-thinking the process itself. This is a much larger effort that is seldom undertaken for energy-efficiency reasons alone. However, it is very important to always consider energy-efficiency on the occasion of a process redesign.

Optimizing utility processes—Optimizations can be found in the following domains:

- Electricity:
  - Transformers: since transformer efficiencies are already very high, it may initially seem unlikely that there is any savings potential left that would be commercially significant. But a transformer has a lifetime expectancy of well over 40 years and the majority of all

transformers are operated continuously at a high degree of loading. As a result, an improved transformer design will usually pay off several times over the lifespan of the transformer[5].

  - Cables: every electricity cable has resistance, so part of the electrical energy it carries is dissipated as heat. Such losses can be reduced by increasing the cross section of the copper conductor in a cable or busbar. The cross section can be optimized to maximize the ROI and minimize the Life Cycle Cost[6].
- Compressed air is a fairly large energy consumer. In many cases there are more energy efficient technologies available for the required solution, such as lower pressure blowers. Furthermore, there are many opportunities to optimize the supply of compressed air, for example by adding control systems, reducing air leaks, and reducing the inlet air temperature and outlet air pressure[7].
- Industrial cooling is very expensive. Choosing the right cooling system (dry cooling, evaporative cooling or compression cooling) is one of the important initial decisions that must be taken in order to achieve maximum energy efficiency. Furthermore, significant energy savings can be made by installing variable frequency drives on fans, pumps and compressors[8].
- Industrial heating. Industrial heat pumps offer various opportunities in all types of manufacturing processes and operations. They can offer low-cost options for removing bottlenecks in production processes and allowing greater product throughput[9].

Optimizing building energy management—Although buildings usually only account for a small part of the energy use of an industrial plant, savings can still be made, for example in the following domains:

- Lighting and re-lighting. Since lighting has become much more energy efficient in recent years, re-lighting projects can save a considerable amount of energy. Furthermore, additional energy savings can be achieved by using intelligent lighting control systems.
- Space heating and cooling are becoming more sustainable and energy efficient thanks to improved building insulation techniques, heat pumps using a facility’s waste heat, smart building automation systems, and other solutions. In many cases, it becomes wise to replace or adapt existing systems[10].
- Building automation systems. Automation, control, and supervision systems can have a significant impact on the energy use of buildings, reducing it by 10, 20, or even more than 50%[11].

ADOPTING A SOUND MOTOR REPLACEMENT POLICY

Electric motors offer a great opportunity for improving plant energy efficiency. Electric motors are the primary mover for a vast majority of industrial activities. Some motors are visible as a separate entity; others are built into boxed applications such as air compressors, heat pumps, water pumps, and fans. Electric motors account for approximately 65% of the electricity consumed by industry and many of the motors are rather old and not yet optimized for energy efficiency. A motor with low energy efficiency will dissipate its losses as heat. This phenomenon increases energy cost significantly. In the course of time, the heat will also affect the motor condition, reducing its energy efficiency even further and increasing the risk of unplanned failure.

Despite this situation, many plant managers remain rather reluctant to invest in replacement. The reason is that most of these motors are not yet end-of-life. In many industries, it is common practice to have electric motors run to failure. Failing motors are often replaced or repaired as quickly as possible without taking into account considerations beyond the basic technical requirements. This is unfortunate, since it is fairly easy and inexpensive to take energy efficiency considerations into account. We recommend considering **early replacement of electric motors**, prior to failure. Indeed, a closer look at all cost factors will reveal that an early replacement is often paid back in a very short time.[12] This payback is not only fed by improved energy efficiency, but also by reduced maintenance costs, and by avoiding unplanned outages and their associated losses.

Being smart with waste heat

Many production processes unavoidably produce waste heat. These losses can be recovered internally or used in other processes. The case of a plant supplying car parts illustrates this.

> *The company uses a spray dryer to produce mineral powder content. Measurements showed that the off-gases of the spray dryer were hot, around 150 °C, and had surprisingly low moisture content. This means a significant amount of the spray dryer's energy input is not used and is simply dissipated. One option would be to recycle part of the off-gases to the spray dryer hot air input. For quality reasons, however, the company preferred an indirect concept: they installed a heat exchanger, using the off-gas heat for preheating the combustion air.*
>
> *A chemical process plant has several thermal oxidizers in place for decomposing hazardous gases at temperatures up to 850 °C. These thermal oxidizers were installed to bring the plant into compliance with environmental regulations, without paying much attention to their energy costs or opportunities for energetic integration. As a first step in optimizing the process, the company examined how to minimize the thermal oxidizers' input streams, a low cost solution which saves a great deal of energy. They checked whether all process gases being sent to the thermal oxidizers had indeed concentrations that require treatment; otherwise the gases only require a much less energy-intensive treatment. Secondly, they checked whether there were streams with high calorific value. Those were redirected to be used as combustion air, minimizing the use of fresh air in the system. Only as a final step, they considered the more capital intensive option of installing heat exchangers to recover any waste heat from the thermal oxidizers.*

Step 5: Estimate, prioritize and plan

Estimate the costs and benefits of each one of the identified energy conservation measures. Take your time for this; it must be done meticulously. While the costs are a one-time affair, the benefits will be felt for years to come. Furthermore, **the benefits may be manifold**. For example, changing a set point may bring about production capacity increases or reduce feedstock usage. Likewise, replacing an older motor with a newer more efficient one not only reduces energy use; it also reduces maintenance costs and improves reliability. These additional benefits must also be calculated (see also *Technical and financial considerations*).

Prioritize the energy conservation measures based on the cost-benefit analyses. Communication is very important in this project phase. Since plant and purchase managers tend to narrow the focus to measures with short-term results, it is important to widen their perspective and **advocate measures with a long-term benefit**. Secure the support of engineers and maintenance managers in budget discussions.

Draw up an action plan to carry out all agreed-upon energy conservation measures. Be sure that you have the support of all involved technical and operational teams.

Step 6: Implement, monitor, report and communicate

When implementing the action plan, it is essential to monitor the results of each energy conservation measure. Communicate the relevant EPIs to all parties involved and **report on a regular basis** (for example each month) regarding project progress and the improvements achieved. Communicate about reduced energy costs, as well as any additional benefit resulting from the actions. We also encourage communication regarding efforts made by individuals, such as an operator making a good suggestion or a maintenance technician becoming more watchful in checking measuring devices.

Remember: the six-step approach for carrying out an energy efficiency self-assessment in industrial companies is a practical guideline. It is important that each of the steps receives sufficient attention. Carefully define your scope and targets, then collect energy related data and measure your performance. Then take a broad perspective in identifying opportunities for energy efficiency measures. Estimate the costs and benefits, prioritize and plan. Make sure to communicate consistently and purposefully over the entire course of the project.

TECHNICAL AND FINANCIAL CONSIDERATIONS

The process of identifying and advocating the optimal energy conservation measures can become complicated. You must carefully take all technical and financial considerations into account to maximize everyone's support.

TECHNICAL CONSIDERATIONS

The following technical considerations should be taken into account:

- **Implementation risks**—while the implementation of a given measure may appear to be rather straightforward, it is essential to assess all associated technical risks. When replacing a motor or changing a set point, is there any risk of losing compliance with technical specifications or regulatory requirements? This has to be checked and followed-up thoroughly with the responsible engineers.
- **Context**—some measures may in practice turn out to be less beneficial than originally assumed due to plant-specific or process-specific circumstances. It is relatively easy to precisely predict the benefits of installing energy efficient lighting. It is much more difficult to calculate the energy saved from redirecting the heat of an exothermic process to an endothermic process. The heat transfer can only be implemented efficiently when both processes are normally operated simultaneously. Otherwise the benefits will be much less than expected.
- **Additional consequences**—changes made in the production process usually have additional consequences besides saving energy. In many cases, there are additional benefits such as a more stable operation, an increased capacity, a reduced number of unplanned stops, or a reduced demand for space cooling. However, the assessment team should be watchful for possible negative side-effects. Be sure to check for any negative impact on quality, health and safety, and the environment. Some of the side effects may be hard to identify. For example: drastically reducing the energy use of machines also means that the machines will dissipate less heat into the building, which may lead to somewhat higher building heating costs.

FINANCIAL CONSIDERATIONS

The following financial considerations should be taken into account:

- **Completeness**—it is essential that the cost-benefit analysis is complete. It must include the contribution of all indirect effects of the measure on the energy use, both positive and negative. Indirect costs and profits must be identified as comprehensively as possible.
- **Monetary profit**—the anticipated energy savings must be calculated down to their monetary value. Profits also depend on the rate structure. Saving one MWh at peak hours brings much more than one MWh at off-peak hours.
- **Financial feasibility**—there are several options available to assess the financial feasibility of a measure. A simple payback analysis while easy has a number of drawbacks. For example: an investment in a cogeneration unit may reach break-even after five years, but may require major maintenance costs in the following year. We strongly recommend applying life cycle costing and internal rate of return (IRR) calculations whenever plant management or corporate policies allow it[13]. Remember that some national schemes calculate rebates on the basis of IRR. Also keep in mind that for accurate lifecycle costing, you will also need an energy price forecasting model.
- **Strategy**—develop an effective strategy for receiving the necessary budgets. Budgets are not awarded based on return calculations alone. In some companies or groups, it is wise to submit individual projects, in others it is better to develop an ambitious plan that includes a wide variety of energy conservation measures. Consider clustering measures into packages, all of them containing both low hanging fruit (that help to promote the package) and more capital intensive measures (that would be more difficult to get through when submitted separately). Try to determine what the optimal strategy will be in your situation.

Remember: It is important to take all technical and financial consequences as well as any indirect ones into account when assessing the costs and benefits of each possible measure. Failure to do so may lead to losing support for your proposals.

CONCLUSION

Improving the energy efficiency of industrial plants is not a straightforward task. While there is general agreement that there is still a significant potential, many stakeholders tend to think that it is very difficult to carry out. There are many reasons for this. The actual energy use of an industrial plant is complex and often not very well known or understood. It can often be difficult to persuade plant managers of the necessity of investing in energy efficiency, especially when expected payback times are long. Many energy efficiency opportunities require redesigning part of the production processes, touching the core of the industrial activities.

This paper has suggested that industries could consider conducting an energy efficiency self-assessment in order to better understand their actual energy use and uncover hitherto hidden opportunities for improving energy efficiency. The six-step approach outlined offers a practical guideline for the entire process. Such a self-assessment does not conflict with an assessment by an external consultant. On the contrary, external consultants can conduct more accurate and comprehensive assessments as a complementary effort.

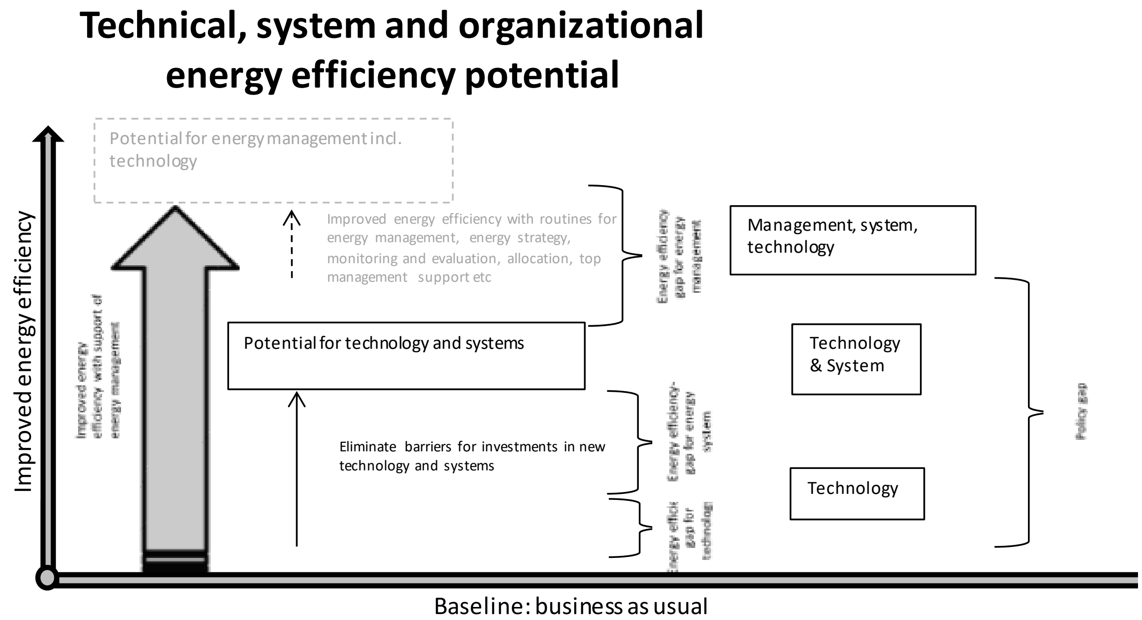

Figure 6—Energy efficiency potentials for technology, system and management (Thollander and Palm, 2012, Backlund et al., 2012, Paramonova et al., 2015).

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