Refinery energy systems and efficiency

Refineries have improved their energy efficiency by about 10% over the past 18 years. Here's how they did it!

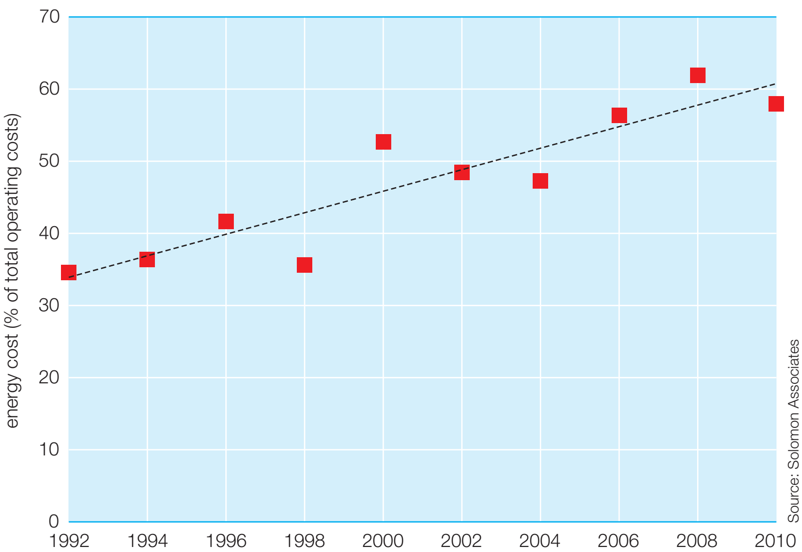
Oil refineries manufacture a wide range of petroleum products, mainly transport fuels (gasoline, diesel, jet fuel, marine fuels), heating and industrial fuels, and chemical feedstocks. All must meet market requirements in both quantitative and qualitative terms. Crude oils are the main input to refineries and are sometimes supplemented by other natural or semi-processed hydrocarbon mixtures.

Oil refining is an inherently energy-intensive activity, requiring substantial quantities of heat, steam and electricity to operate. This energy is either purchased from outside the refinery or produced on site by consuming a portion of the crude and petroleum products that are produced in the refinery.

Over time, the energy demand of European refineries has increased for two main reasons:

- Emissions legislation and other performance requirements have resulted in increasing sophistication of the equipment—cars, trucks, heating units, etc.—in which petroleum products are consumed. This has resulted in more stringent specifications for petroleum products, related to safety, performance and pollutant emissions. The most noteworthy example is the very large reduction over the past two decades in the sulphur content of petroleum products and road fuels that has enabled remarkable improvements in vehicle emissions and air quality.
- The market has demanded an ever-increasing proportion of lighter products (such as road- and air-transport fuels) and a decreasing proportion of heavier materials such as heavy fuel oil. As a result, refineries have gradually become more complex, incorporating an array of processes to 'reshape' the supply of refined products to meet the changing market demand, including treating the components of the final products. Unlike many other parts of the world, Europe has developed a large diesel passenger car fleet and a reliance on heavy-duty road transport for freight shipments, resulting in a very high demand for diesel fuel compared to gasoline.

Figure 1 The energy cost of EU refineries as a percentage of total operating costs



Just like freight transport and airline companies, refiners have long had a strong incentive to improve their energy efficiency. Environmental concerns have reinforced this incentive in recent years, notably the drive to reduce global greenhouse gas emissions. As shown in Figure 1, energy currently accounts for about 60% of the cash operating costs of EU refineries, a proportion that has doubled over the past 20 years due to increasing energy costs and the reasons outlined above.

There are many factors that affect refinery energy consumption and efficiency. These factors, and the complexity of refinery energy systems, are not well understood by those outside the refining industry. For that reason, this article provides an overview of CONCAWE Report 3/12 which addresses these issues and provides data on the various aspects of energy use and energy efficiency improvements achieved by EU refineries over the past 18 years.

Measuring and comparing refinery energy performance

Energy is required in refineries for heating, reacting, cooling, compressing and transporting hydrocarbon streams, mostly as liquids but also as gases. To achieve high liquid temperatures (higher than about 250°C), fired heaters are used in which liquid or gaseous fuel is burned and the resulting heat is transferred to the liquid process stream. A typical medium-complexity refinery may operate 15–20 process heaters of various sizes. When lower temperatures are sufficient, steam is the more flexible heating medium and is applied in many ways at different pressures and temperatures.

High pressure steam (40–100 bar pressures) can also be used to drive turbines for large rotating machines such as compressors and electricity generating turbines. This may be an attractive alternative to electricity when the steam supply is reliable and abundant.

A key element of energy-efficient refinery design is heat recovery and integration within individual process units, between process units, and with the steam system.

The absolute amount of energy consumed by a refinery is related to, amongst other factors, the refinery's size in terms of crude oil throughput. Another important factor is the refinery's configuration, that is, the combination of different processes used by the refinery. These processes, to a large extent, determine which crude oils can be processed and the type, yield and quality of the different refined products that can be manufactured. The more conversion of heavier streams into lighter products that is carried out, the higher will be the specific energy consumption. This is typically defined as the energy consumed by the refinery to process each tonne of crude oil throughput. A simple refinery performing only distillation and mild hydrotreating may consume 3–4% of the energy content of its crude oil intake. In a complex refinery with many different conversion and upgrading units, 7–8% of the energy content is more typical. A complex refinery will therefore consume more energy than a simple refinery having the same crude oil throughput, but it will also have more capabilities to meet the changing market demand.

Although the concept of energy efficiency is intuitive and easy to grasp, measuring energy efficiency requires that an energy performance metric be established, so that energy efficiency can be tracked over time between different refineries. Because refineries are all different in size, complexity and processing/production capability, simple metrics such as the energy per unit of throughput or per unit of products do not provide an appropriate view on actual efficiency and would actually lead to the wrong conclusions. Indeed, the fact that simple refineries, compared to complex ones, consume a smaller percentage of their energy input is simply a reflection of the different functions these refineries are intended to perform and does not imply that simple refineries perform these functions in a more or less efficient manner.

Over many years, and in cooperation with the refining industry worldwide, Solomon Associates (SA) (http://solomononline.com) have developed an Energy Intensity Index® or EII® which accounts for refinery size and complexity in order to focus explicitly on measuring energy performance. Figure 2 shows the normalised evolution over time of the total energy consumption of a consistent group of EU refineries and of their combined EII®.

As shown by the total energy consumption in this figure, EU refineries have been gradually using more energy as product demand has increased and specifications have become more stringent. While this has occurred, the same refineries have improved their energy efficiency as measured by the EII® by about 10% over the past 18 years. In 2010, this represented annual average savings of about 60,000 tonnes of oil equivalent (toe) per refinery, compared to the 1992 efficiency level, or about 4 million toe/annum for all of the

Figure 2 Energy consumption and efficiency trends for EU refineries

Note: lower EII® values means better refinery efficiency

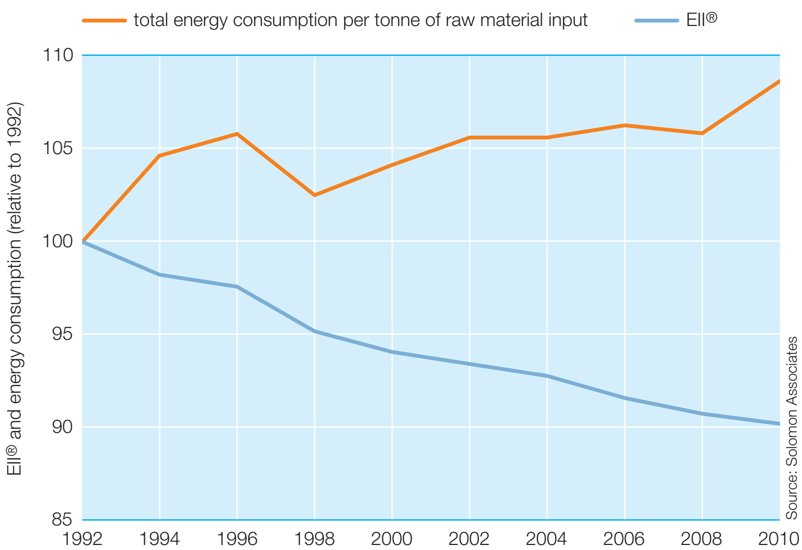
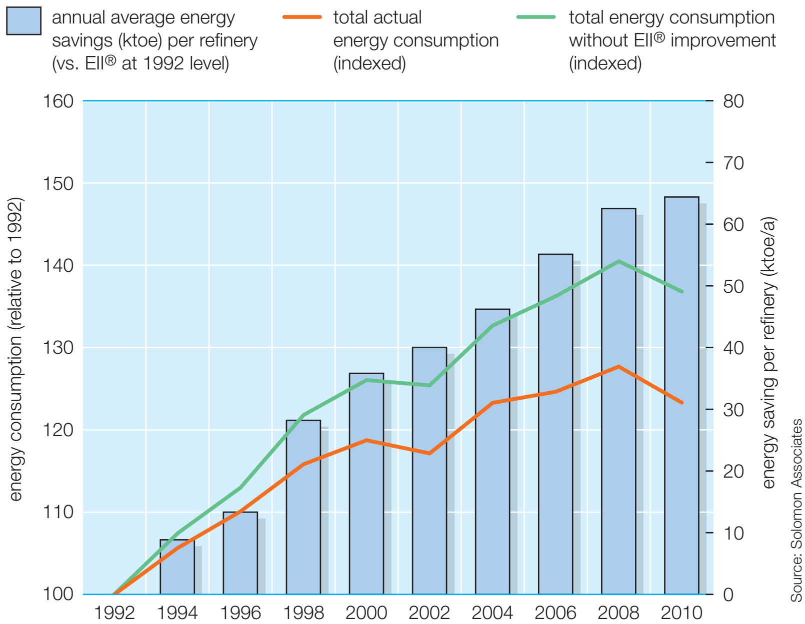


Figure 3 Energy savings from efficiency improvements in EU refineries



EU's 100 refineries (Figure 3). This annual saving is roughly equivalent to the total annual average energy consumption of four large EU refineries.

Where do refineries get their energy?

Refineries traditionally use fuels produced internally from crude oil to generate most of the energy they need. Because there were few alternatives available in the early days of refining, this is partly historical, but it is also a way to usefully consume refinery products that have low market value. A refinery fuel pool will include 'fuel gas' (light hydrocarbons generated as by-products of various processes) and various liquid fuels, often supplemented by imported natural gas. The majority of refineries worldwide, including those in the EU, use a fluidised catalytic cracker (FCC) to convert crude oil to lighter products. The fuel for this energy-intensive process is mostly generated from burning the coke deposited on the recirculating FCC catalyst. Because a relatively large fraction of a refinery's crude oil intake is processed through FCC units, FCC coke represents a significant fraction of refinery fuel. In practice many refineries also exchange energy with industries outside the refinery gate in the form of heat (mostly as steam) and electricity.

Over time, however, greater availability of relatively low-cost natural gas, coupled with environmental constraints, has driven a steady decrease in the fraction of liquid fuels consumed in EU refineries, with the proportion decreasing from 23% in 1992 to 13% in 2010.

Refineries require both heat (particularly in the form of medium- to low-temperature steam) and electricity. This is a typical scenario for 'cogeneration' of heat and power and most refineries have applied this in some form for a long time, within the limits imposed by the utilities balance in each refinery. A simple form of cogeneration is to produce steam at a higher pressure than required, then to use the high-pressure steam to drive a turbogenerator before using the steam at a lower pressure to heat process units. In recent years, deregulation of the electricity markets in Europe has enabled the export of surplus electricity to the power grid, and many refineries have installed dedicated combined heat and power (CHP) plants which combine a gas turbine and conventional steam turbogenerator.

In its refinery energy surveys, Solomon Associates uses the term 'cogeneration' to cover all electricity production schemes that also produce useful heat, including CHP. According to this definition, the share of cogeneration in electricity generation in EU refineries has grown from 76% to 92% over the period 1992–2010, while the total cogeneration capacity has increased by 125%. As a result, the average efficiency of electricity generation in EU refineries is substantially higher than the EU average efficiency of electricity production from conventional thermal plants (Figure 4).

However, physical and financial considerations continue to limit the number of opportunities for new, economically viable cogeneration projects. The tariff structure for purchased fuel and exported electricity is of particular importance when making investment decisions about installing cogeneration facilities.

Optimising energy consumption in oil refineries

In oil refineries, as in most other manufacturing industries, energy efficiency cannot be achieved in a day. Good energy performance is the result of innovative engineering, good management of available resources and the careful deployment of refinery investments.

The first step towards achieving good energy performance is to develop and implement a consistent set of organisational measures, systems, procedures and practices dedicated to monitoring, measuring and reducing energy consumption. Such measures are usually known as Energy Management Systems (EMS). The desired structure and attributes of EMS have been described in international standards and legislative documents such as in ISO 50001:2011 and the EU's Energy Efficiency BREF under the Industrial Emissions Directive. All such schemes are based on the 'plan-do-check-act' continuous improvement loop first introduced in generic quality management schemes and standards.

There are also many opportunities to maintain or improve energy efficiency by day-to-day operational measures and good practices. These include process optimisation, heaters and boilers operation and control, heat exchanger monitoring and cleaning programmes, steam system maintenance, housekeeping, state-of-the-art monitoring and control technologies, utilities system optimisation, and reliability programmes.

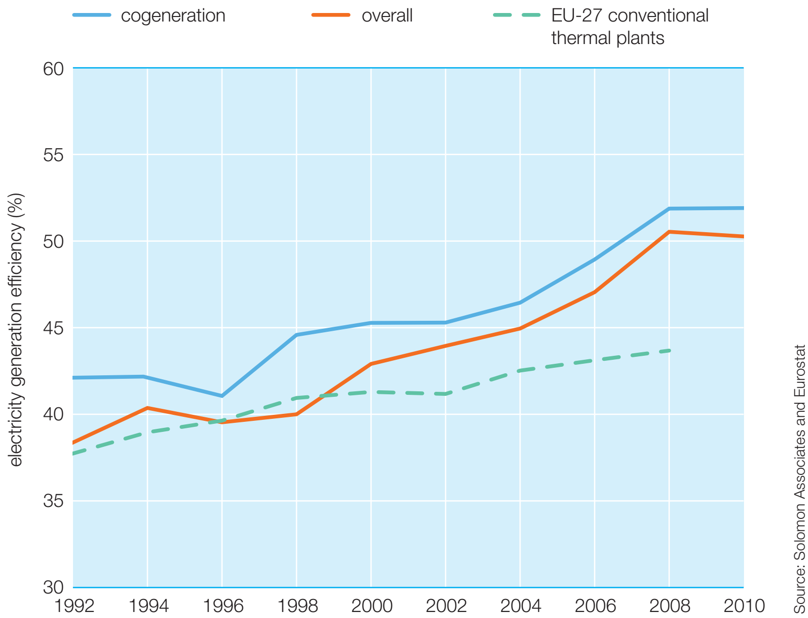
Although much can be achieved by management systems and operational measures, stepwise improvements in energy efficiency tend to require physical changes to the refinery, which in turn also require investments that may be geared to processes in either existing or new plants, or to utilities systems.

In summary

Energy consumption within refineries has always been a major cost element for refiners, currently accounting for about 60% of total cash operating costs. More and more stringent product specifications and steadily increasing demand for lighter refined products require refineries to be increasingly complex with more conversion of heavy residues and more processing of intermediate products. This, in turn, increases the energy demand within the refinery and increases the volume of crude oil that cannot be converted to marketable products. Refiners therefore have a significant incentive to efficiently manage their energy use.

Effective energy management systems and the increased use of cogeneration for electricity production have enabled European refineries to improve their energy efficiency through integrated improvements in refinery operations. Although the incentive is there to achieve further improvements in the future, the challenges are also greater because of the complexity of existing refinery operations and the pressure on efficiency investments in an uncertain economic climate.

Figure 4 Trends in electricity generation efficiency in EU refineries



Note: data for conventional thermal plants were inferred from Eurostat electricity and heat generation data, allocating a standard 90% efficiency to heat production.