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EU refinery energy systems and efficiency

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EU refinery energy systems and efficiency

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ABSTRACT

The consumption of energy within EU refineries plays a crucial role in determining refinery operating costs and emissions and has therefore long been a focus of attention by refinery operators. Improvements in refinery energy efficiency have resulted in net energy savings which have helped to offset the increases in energy intensity associated with increasing product demand and increasingly stringent quality requirements. This report provides data on the progress made in improving the energy efficiency of EU refineries over the past 18 years and discusses the factors which have contributed to this achievement.

KEYWORDS

Energy efficiency, energy consumption, energy management, energy intensity, energy cost, refinery fuel, utilities, heat, steam, electricity, cogeneration, CHP.

INTERNET

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SUMMARY

Oil refining is an inherently energy-intensive activity. The energy requirements of refineries have increased over the years to meet the market demand for cleaner fuels that are required by vehicles and other end use technologies. Refiners in Europe and elsewhere have long had a strong incentive to improve energy efficiency, which has been reinforced in recent years by environmental concerns, notably the drive to reduce global greenhouse gas emissions. Energy currently accounts for about 60% of the cash operating costs of EU refineries, a proportion that has doubled over the last 20 years as a result of increasingly stringent product specifications, higher refinery complexity and fast increasing energy costs.

Refineries generally have a high rate of heat recovery, and only reject low temperature streams such as very low pressure steam or hot condensate for which there is no practical use. Exporting such low grade heat for use in e.g. urban heating requires a set of favourable circumstances and is only practically feasible and economically justifiable for a very limited number of refineries.

Refineries consume both heat and electricity and refiners have long recognised the considerable efficiency gains offered by cogeneration, which now accounts for more than 90% of the electricity produced in EU refineries. 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. Although some opportunities for cogeneration still exist, local physical and financial considerations limit the number of new cogeneration projects that can be justified. The tariff structure for purchased fuel and exported electricity is an important element for cogeneration investment decisions.

The absolute energy consumption of a refinery is not only determined by the amount of material it processes or produces but also, and to a major extent, by its complexity, mostly represented by the amount of “conversion” of heavy streams into lighter products that it carries out. As a result valid comparisons of energy performance can only be done with a metric which normalises energy data for size and complexity.

The Energy Intensity Index™ or EII® developed by Solomon Associates is widely used in the industry. The evolution of the Solomon Energy Intensity Index over time shows that EU refineries have improved their efficiency by about 10% over the past 18 years. This improvement was achieved in the context of more intensive refinery operations to produce cleaner fuels and meet shifts in market demand. The corresponding annual energy saving is roughly equivalent to the total annual average energy consumption of four large EU refineries.

Improving the energy performance of the interconnected and interdependent process plants and utility systems found in modern refineries is a complex and multifaceted challenge that requires addressing many issues in operation, maintenance as well as planning and investment. Comprehensive Energy Management Systems, including regular energy audits and improvement plans, are commonly in use in refineries to focus attention and initiatives towards short and long term energy performance improvement.

1. HOW MUCH ENERGY IS USED BY REFINERIES, FOR WHAT PURPOSE AND IN WHAT FORM?

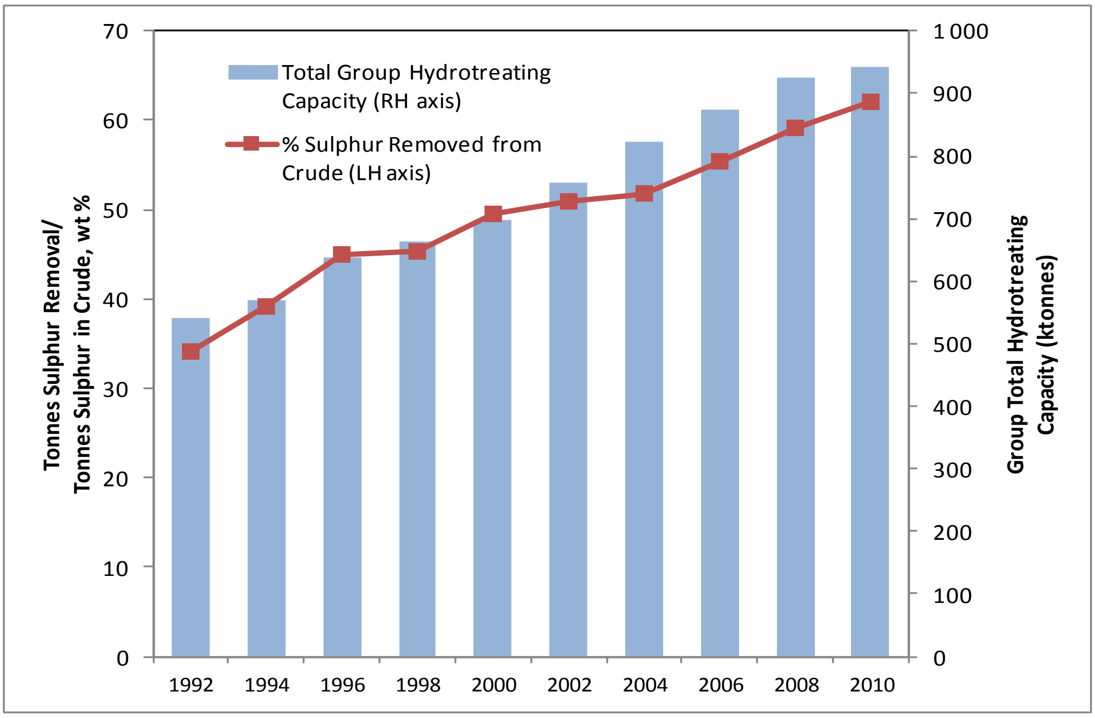
1.1. THE CONTEXT OF PRODUCT DEMAND AND QUALITY

The purpose of oil refineries is to manufacture a range of petroleum products, mainly transport fuels (gasoline, diesel fuel, jet fuel, marine fuels), heating and industrial fuels and chemical feedstocks, that are fit for the market in both quantitative and qualitative terms. The raw materials are mostly crude oils supplemented by other natural or semi processed hydrocarbon mixtures.

The manufacturing process involves three main types of activity namely physical separation of hydrocarbon fractions, treatment of individual fractions to remove undesirable compounds (e.g. sulphur) and modification of molecular structure (mainly cracking large molecules into smaller ones). Over time the final applications of petroleum products have become more sophisticated, requiring more stringent specifications related to safety, performance, and pollutant emissions. Sulphur, a naturally occurring component of all crude oils, has been particularly targeted in relation to SOx emissions abatement as well as vehicle pollutant emission control technologies. This has led to substantial reductions of sulphur content across the product spectrum resulting in an increase in the overall sulphur removal[1] from crude oil in EU refineries from about 35% in 1992 to over 60% in 2010. This is illustrated in ***Figure 1*** which also shows the concurrent increase in installed hydrotreating (sulphur removal) capacity over the same period.

[1] "Overall sulphur removal" is defined as the total mass of sulphur removed from various intermediate streams during the refining process and recovered as elemental sulphur, divided by the total mass of sulphur contained in the crude oil feed to the refinery, expressed as a percentage.

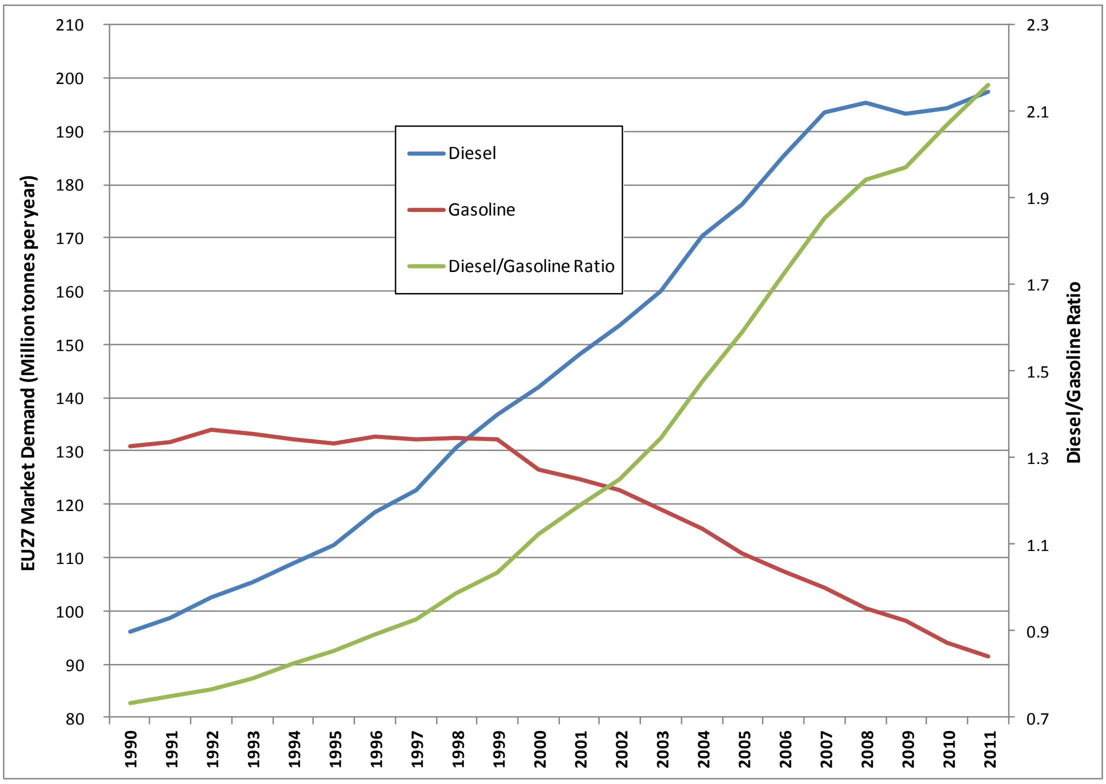
Figure 1 Crude oil sulphur content and sulphur removal trends in a consistent group of EU refineries[2]
(Source: Solomon Associates [1])



At the same time the market has demanded an ever increasing proportion of light 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 market demand including treating the components of the final products. Peculiar to Europe is the development of a large diesel light duty vehicle fleet which has resulted in a very large diesel fuel market compared to gasoline. This increasing "imbalance" illustrated in ***Figure 2***, has demanded extra complexity in EU refineries.

2 This figure and all others sourced from Solomon Associates (SA) refer to a "trend group" of 37 refineries that have consistently participated in all of their bi-annual surveys over the period and represent 50-60% of EU refining capacity. This group is considered by SA as being representative of the total EU refinery population.

Figure 2 Diesel to gasoline market ratio in EU-27
(Source: Wood Mackenzie 2011)



A common consequence of these trends has been to increase the hydrogen to carbon ratio of the combined refinery production, requiring additional hydrogen manufacturing facilities. This is particularly relevant because more hydrogen manufacturing increases the refinery's energy demand while increasing CO_2 emissions.

1.2. REFINERY ENERGY CONSUMPTION AND FACTORS AFFECTING IT

Most if not all refinery operations involve heating and cooling which require a net energy input. Even though heat recovery measures can be, and indeed are applied, the laws of thermodynamics are such that this cannot be complete. In addition cracking of large molecules into smaller ones is an endothermic process, i.e. absorbs energy. Manufacturing the extra hydrogen required in increasing quantities is a particularly energy-intensive operation.

Refining also involves fluid transportation such as pumping of liquids and compression of gases both within the process units and for ancillary operations such as product blending and storage, water treatment etc.

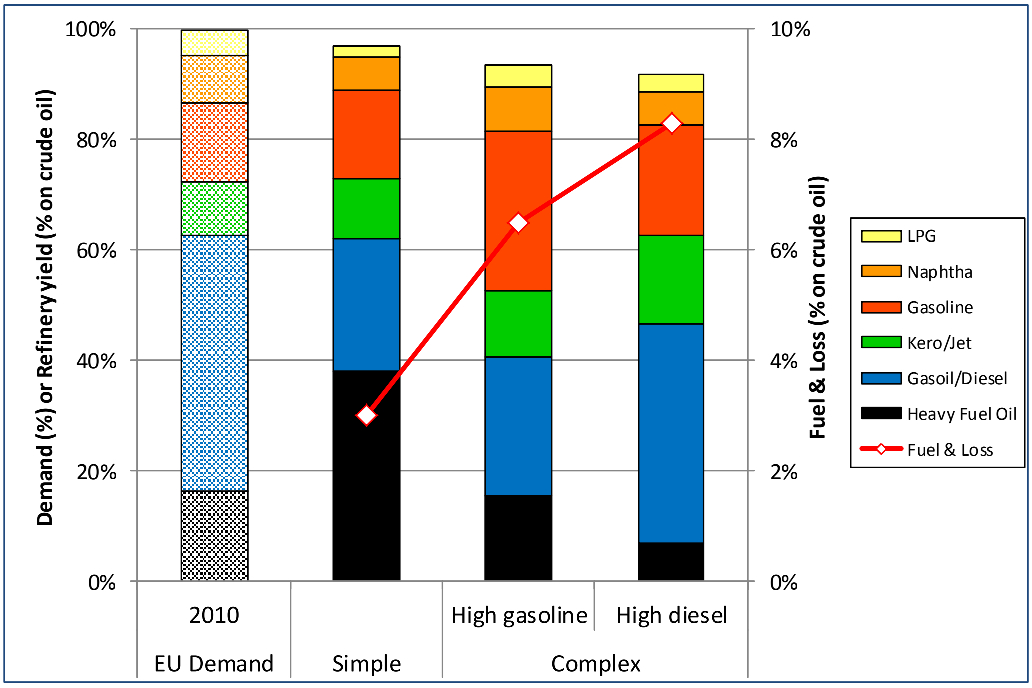
Finally small amounts of energy are required for lighting, space heating etc.

Together the 96 EU mainstream refineries consume nearly 50 Mtoe total energy per year, which is equivalent to about 7% of their crude oil intake. This means that 93% of the energy content of the crude oil processed by the refinery is ultimately available in the refined products.

The size of the refinery in terms of throughput is of course an important element but this is only one of the factors that determine energy consumption.

A major factor is what is known as refinery configuration, i.e. the combination of processes operated by a given refinery which, to a large extent, determines which crude oils can be processed and the type, yield and quality of the different refined products that can be manufactured. ***Figure 3*** illustrates that, as a general rule, the more “conversion” of heavy streams into light products is carried out and the cleaner the finished products, the higher the specific energy consumption (i.e. the energy consumed by the refinery to process each tonne of throughput). A simple refinery performing only distillation and treating and no conversion may consume 3-4% of the energy content of its intake. In a very complex refinery with several conversion units, extensive treatment etc., this figure is typically 7-8% but it can be as high as 10% in some full-conversion refineries (not common in Europe). A complex refinery will therefore consume more energy than a simple refinery with the same crude throughput. It is to be noted that on average, refineries in Europe consume less energy per tonne of throughput than refineries in North America where the market has imposed much higher levels of conversion and complexity. Individual refineries may have different configurations, being more or less complex, but the overall level of complexity of refineries within a given geographic region is determined by local and global market demand for finished products (including regulatory constraints) and the practical and economical crude oil supply available.

Figure 3 Typical EU refinery fuel consumption as % of yield in simple and complex refineries

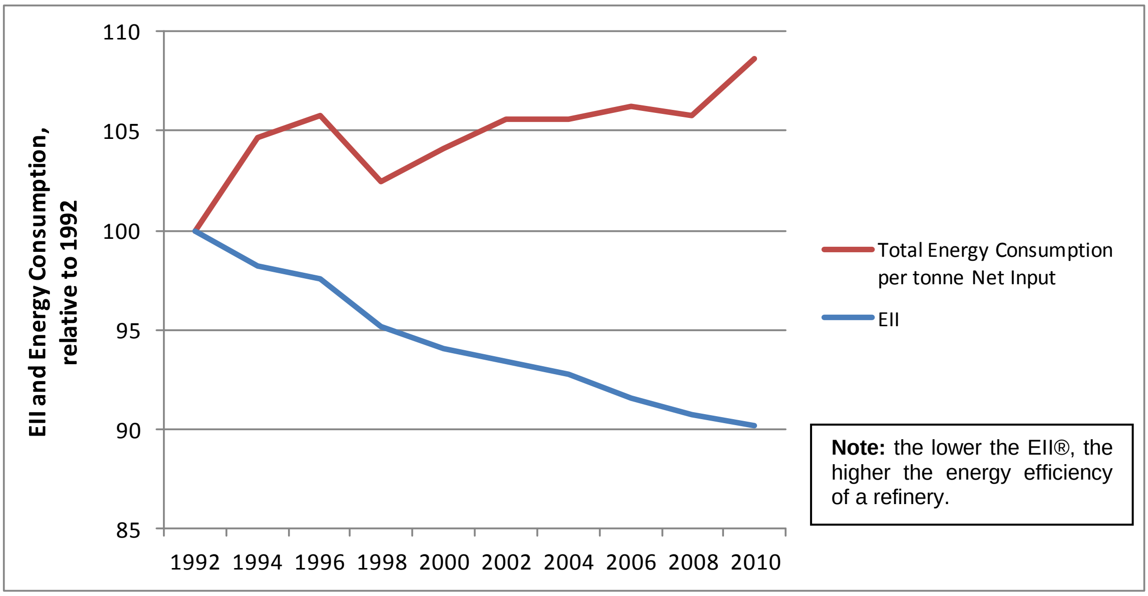


1.3. REFINERY ENERGY EFFICIENCY: HOW CAN IT BE MEASURED AND COMPARED?

Beyond the size and complexity of a refinery, another important factor determining its energy consumption is its intrinsic “energy efficiency”. Although the concept of efficiency is intuitive and easy to grasp, measuring efficiency implies that an energy performance metric can be established, allowing comparison over time and between different refineries. Because refineries are all different not only in size but also in complexity and processing/production capability, simplistic metrics such as energy per unit of throughput or products do not provide any view on actual efficiency and would actually lead to erroneous 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 in any way imply that they perform these functions in a more or less efficient manner. The appropriate metric must take into account the refinery's size and complexity. Over many years, and in cooperation with the refining industry worldwide, Solomon Associates (SA) have developed their "Energy Intensity Index"[3] or EII® which takes into account such physical differences to focus on measuring energy performance.

Figure 4 shows the evolution over time of the total energy consumption of a consistent group of EU refineries and of their combined EII®.

Figure 4 EU refineries energy consumption and efficiency trends relative to 1992
(Source: Solomon Associates)



As a result of increased refinery complexity (and some increase in throughput) to support tighter product specifications (most notably lower sulphur contents) and shifting market demand, EU refineries have been gradually using more energy.

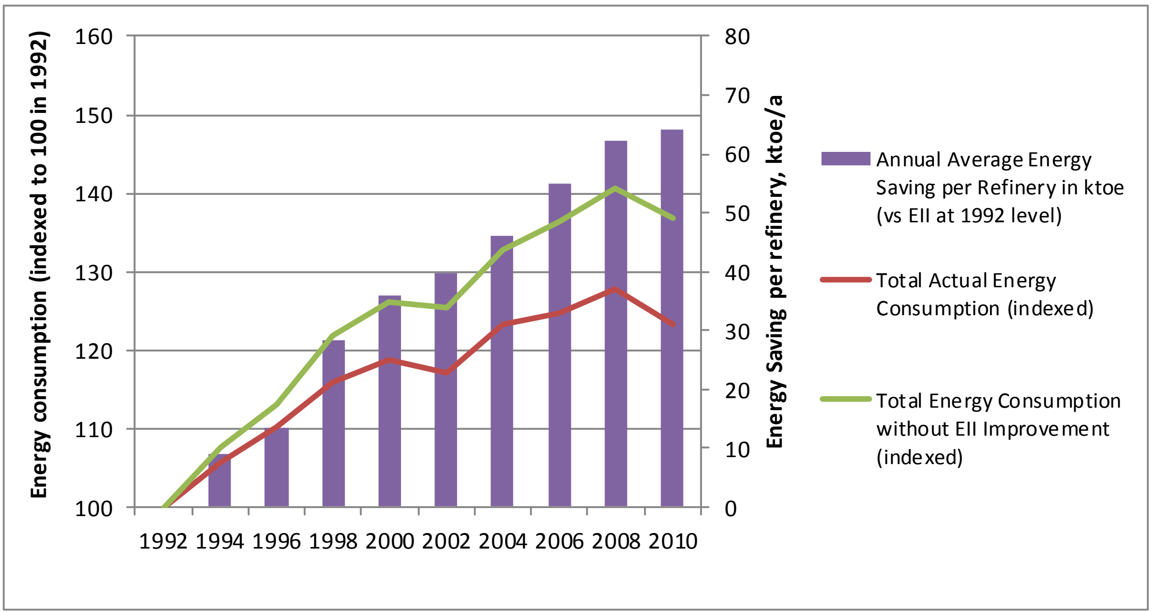
3 EII® is an index (dimensionless) representing the ratio of the actual energy used by a refinery divided by a standard energy. Both numerator and denominator are expressed in primary energy terms (i.e. electricity consumption is divided by a standard generation efficiency factor), and relate to the refinery operations proper. As a result the actual energy consumption of the refinery site has to be corrected to add energy imports and subtract energy exports.

Each generic type of process unit used in refineries has been assigned a standard energy factor determined by SA from an analysis of their extensive refinery database. The standard energy of a refinery for a given period is the sum product of the individual factors by the throughputs of the process units operated by the particular refinery during that period.

This approach effectively normalises for size and complexity so that the EII® of a given refinery over time or the EIIs of different refineries can be validly compared. The lower the index, the higher the refinery's energy efficiency.

They have, however, conducted their operations more efficiently, improving their efficiency by 10% over the last 18 years. In 2010 this represented an annual saving over the 1992 efficiency level of some 60 ktoe on average per refinery or over 4 Mtoe/a for the total number of EU refineries (***Figure 5***). This annual saving is roughly equivalent to the total annual average energy consumption of four large EU refineries.

Figure 5 Energy savings from efficiency improvements in EU refineries
(Source: Solomon Associates)



There are many aspects to a refinery's energy performance. Some are structural and associated with the original design of the processing facilities and the technologies employed, such as heat recovery within process units, heat integration between process units, types of rotating equipment, general layout etc. Older refineries were designed in a time of relatively inexpensive energy and are often less efficient than newer ones. Generally these shortcomings can only be addressed through physical changes involving investments, although some features may not be amenable to improvement short of complete rebuilding. Addition of new process units or replacement of obsolete ones often offers the opportunity to improve a number of energy aspects in a wider range of refinery facilities. In all cases though, economic justification is a consideration and other issues such as physical constraints around process units can limit the practical scope for improvement.

Other aspects are related to operation and maintenance, such as efficient fired equipment operation, heat exchangers and steam system maintenance, general housekeeping etc. They can be improved through everyday focus on energy, improved operational procedures and maintenance practices and sometimes minor investment.

Other factors such as climatic conditions also play a role but generally a minor one.

1.4. A REFINERY’S MAIN ENERGY CONSUMERS

Energy is required in refineries for heating, reacting, cooling, compressing and transporting hydrocarbon streams in liquid and gaseous state.

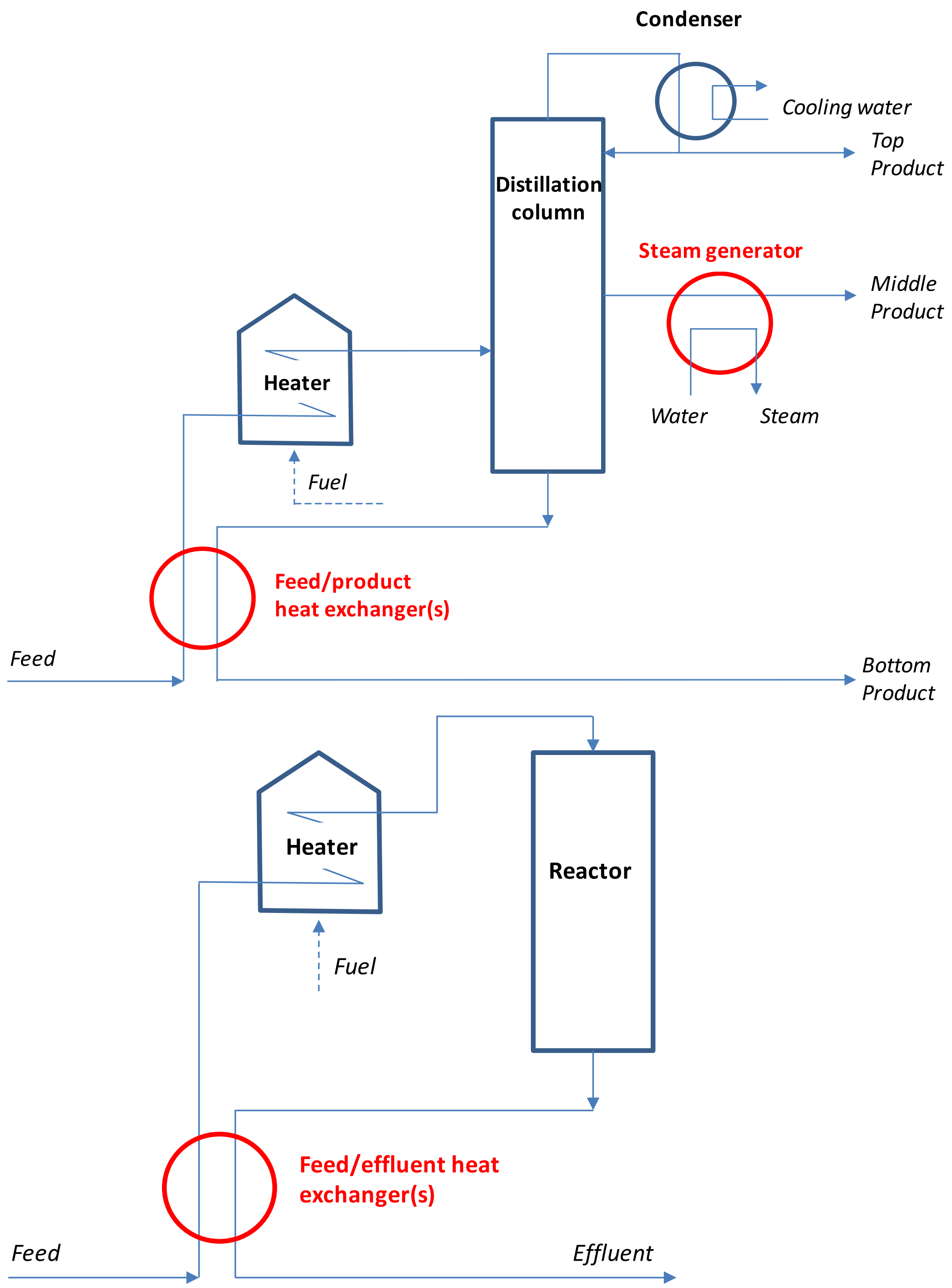
Heating is by far the main energy consumer in a refinery. The type of equipment and the form of energy used depends on the required temperature level and, to an extent, the required thermal duty. The refinery workhorse is the fired heater where liquid or gaseous fuel is burned and heat is transferred to the process stream. Such heaters are applied for providing process heat typically for temperatures above 250°C and up to about 500°C (higher fluid temperatures are not common in refineries as they lead to fast and uncontrolled decomposition of hydrocarbon molecules). A typical medium complexity refinery may operate 15-20 process heaters of various sizes.

Many phases of refining do not require such high temperatures. In such cases, steam is the flexible heat medium of choice, applied in many ways at different pressure/temperature. High pressure steam (40-100 bar) may be used to drive turbines for large rotating machines such as compressors and electricity generation turbines. Medium pressure steam (10-40 bar) can be applied for e.g. fractionation/separation of relatively light hydrocarbon mixtures. Lower pressure steam is used for many applications such as process heat for low temperature processes, continuous heating and frost protection of piping, tankage and other installations. Electricity can instead be used, though infrequently and under specific conditions, for pipe heating and process heating via an intermediate thermal fluid such as hot oil.

Refineries also need electricity for pumps, compressors, instrumentation, lighting etc. Rotating equipment such as pumps and compressors can alternatively be driven by steam, which can be an attractive option when the steam supply is reliable and abundant.

A key element of refinery design is heat recovery and integration. Most refinery processes involve heating of the feedstocks while effluent products need to be cooled down before being routed to e.g. storage. The surplus heat available in hot streams can be transferred to the cold streams through a combination of heat exchangers. Another way of recovering heat is to transfer the heat from the hot effluent to water to generate steam. This can be done within a process unit (e.g. a reactor effluent is used to preheat the reactor feed) or across process units, optimising use of the available heat flows and temperature levels. Process heaters thus only supply the energy required by chemical reactions and the heat that cannot be practically recovered from effluents, including any heat losses. Effective heat recovery and integration is essential to refinery energy performance. ***Figure 6*** shows typical examples of simple heat recovery systems.

Figure 6 Examples of typical heat recovery systems in refinery processes (indicated in red)



2. HOW DO REFINERIES PROCURE THEIR ENERGY?

Refineries traditionally use internally produced fuels to generate most of their own energy needs. This is partly historical (there were no or few alternative energy sources available) and also supported by the availability within the refinery of streams for which there are few or no attractive alternative uses. In practice many refineries also import energy from third parties in the form of gas (mostly natural gas), heat (mostly as steam) and electricity. Some refineries export heat and electricity.

2.1. REFINERY FUEL

Many refinery processes produce light hydrocarbons (natural gas type components) in various quantities. This is the result of cracking of larger molecules, either deliberately in conversion processes or as a side reaction in other cases, resulting in a gaseous residue stream. This mixture of light hydrocarbons is an attractive fuel while having mostly no practical alternative usage. It is known as refinery fuel gas and is by far the largest component of refinery fuel.

The majority of refineries worldwide and in particular in the EU, incorporate a so-called Fluid Catalytic Cracker (FCC). In this process cracking of heavy gasoils takes place in a reactor on a powder-like catalyst producing both lighter products and a coke-like material. The latter is deposited on the catalyst particles which are routed to the regenerator where the coke is burnt. The hot catalyst is returned to the reactor where it provides the heat for the cracking reaction. Coke, a product of the cracking reaction, is therefore also the fuel for the process. Because cracking is energy-intensive and concerns a relatively large portion of the crude oil intake, FCC coke represents a significant fraction of refinery fuel.

Most refineries generally do not generate enough fuel gas to cover all their needs. In the past, refineries were well balanced or even sometimes had a fuel gas excess, but current requirements for downstream treating of products and other ancillary processes are such that virtually all refineries have nowadays a deficit. Economics dictate that the balance should be provided by the lowest value product i.e. heavy fuel oil. This used to constitute an important fraction of the refinery fuel pool but has been in decline because of pollutant emissions regulations, mainly SOx. While fuel oil is still used, sometimes in combination with flue gas desulphurisation, it has been displaced in a fair number of refineries by natural gas which is today available for import in large quantities to most (though not all) EU refineries. Lighter liquid fuels (such as gasoils) are still burnt in some refineries for specific local reasons (e.g. unavailability of natural gas).

Finally a few EU refineries operate a delayed coker[4] and a coke calciner[5] where some of the wet coke is burnt to provide the drying heat for the bulk.

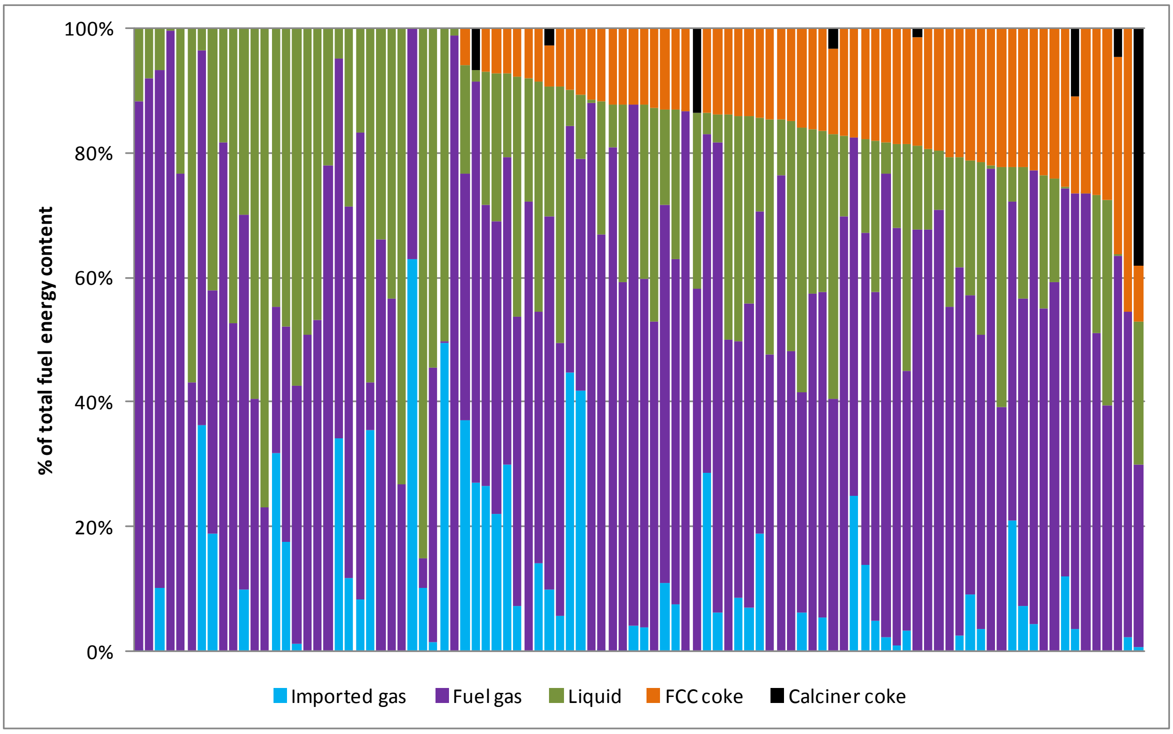
The total refinery energy mix is further discussed in **Section 2.3**.

Figure 7 shows the composition of the refinery fuel in the 96 mainstream EU refineries in 2007-08.

4 A delayed coker is a process unit that upgrades heavy residual oils by thermal cracking to produce lighter liquid hydrocarbon fractions and a low-value solid petroleum coke product.

5 A coke calciner is a process unit in which the raw petroleum coke is heated to remove volatile matter and upgrade it to speciality products such as anode coke which is used in metal smelting industries.

Figure 7 Refinery fuel mix in 2007-08 for 96 mainstream EU refineries
(Source: CONCAWE)



Gas, either self-produced or imported, is the main fuel in the majority of refineries. Overall it accounts for nearly 65% of the total refinery fuel. About two-thirds of EU refineries operate an FCC and a small number have a delayed coker with an associated calciner. FCC and calciner coke represent about 14% of the total. The balance (21%) is provided by various liquid fuels.

2.2. HEAT AND ELECTRICITY

As discussed above, a large proportion of refinery energy needs can be provided by a heat-carrying fluid, in the vast majority of cases steam. At the same time refineries need 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 within each refinery.

Steam is traditionally generated in fired boilers. Higher steam pressures and temperatures lead to higher boiler efficiency so that steam is mostly generated at pressures that are higher than required for process applications. High pressure steam can be routed through a so-called back pressure turbine driving an electric generator and "extracted" at lower pressure and temperature for use as process heat. This is the simplest case of cogeneration and is very commonly applied in refineries. Electricity can also be produced via so-called "condensing" turbines where only hot water is recovered. Though this is the least efficient scheme, it is still used in refineries to a limited extent often for operational flexibility or security of supply reasons but has been declining over time to be replaced by more efficient cogeneration systems.

Additional steam is generated in process units as a means of recovering heat from either fired-heater flue gases or hot process streams. The lower temperatures available generally limit the pressure level of such steam which is commonly reused in the processes.

In energy terms, refineries usually require more steam than electricity so that cogeneration to cover only internal needs tends to be limited by the internal electricity demand. The opening up of electricity markets in recent years has provided some refiners with a new opportunity to apply cogeneration, with the possibility to export surplus electricity to the local grid while generating all the refinery steam requirements. The refinery steam demand has now become the main constraint limiting the capacity of cogeneration in refineries.

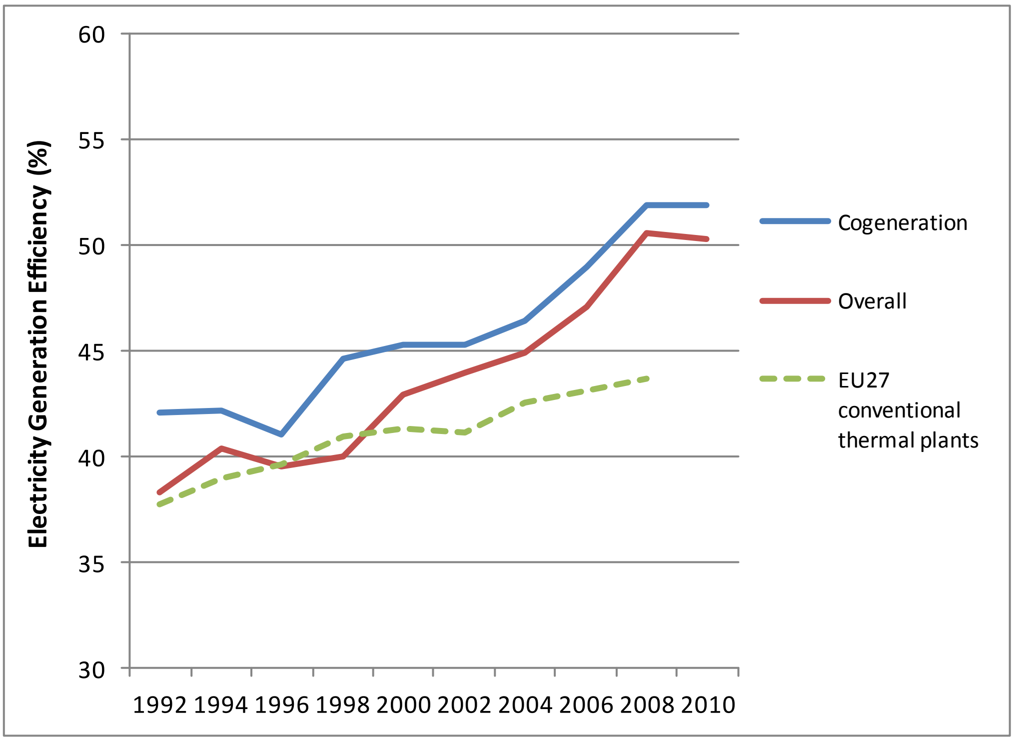
The most common dedicated cogeneration plants in refineries (also referred to as combined heat and power or CHP plants) consist of a gas turbine (usually natural gas fired) equipped with a heat recovery steam generator and a set of back-pressure steam turbines. Electricity is produced through both the gas turbine and the steam turbines while steam is made available to the refinery processes at the required pressure and temperature level (here again some steam may be completely condensed to produce more electricity, albeit at a lower efficiency). Such schemes are highly efficient and have made a decisive contribution to the improvement of the electricity generation efficiency and the overall energy efficiency of EU refineries in recent years.

In its refinery energy surveys, Solomon Associates uses the term “cogeneration” to cover all electricity production schemes, including CHP, that also produce useful heat. This includes boiler and steam turbine combinations where steam is “extracted” at an intermediate pressure level, but excludes steam turbines in which the steam is fully condensed.

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. This is illustrated in ***Figure 8*** which shows the general increase in electricity generation efficiency over time in the Solomon trend group of EU refineries. The overall generation efficiency is very close to the cogeneration efficiency, showing that cogeneration is by far the most common mode of electricity generation.

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 for cogeneration investment decisions.

Figure 8 Electricity generation efficiency trend in EU refineries
(Source: Solomon Associates and Eurostat)



Note: The EU27 conventional thermal plants efficiency data were inferred from Eurostat electricity and heat generation data, allocating a standard 90% efficiency to heat production.

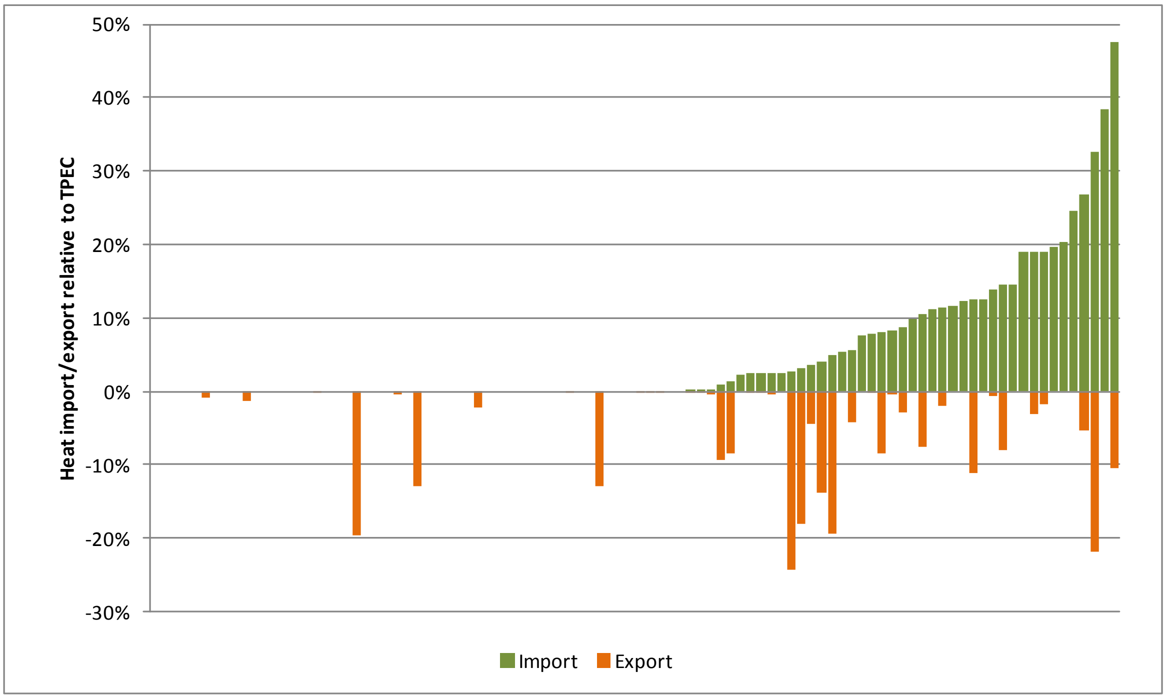
Some processes, particularly cracking, involve large amounts of gas or liquid at high pressures. This pressure energy can be recovered in so-called “expanders” and “power recovery turbines” to produce electricity. These devices, although highly efficient, only provide a minor portion of the refinery electrical needs.

Refineries rely mostly on internally generated energy from their own fuels, although most of them also exchange electricity or steam or both with third parties. The majority of EU refineries import some (or all) of their electricity needs. This may be driven by price considerations or by the need to provide a secure and reliable source of electrical power, but also by the relatively small scale of potential internal power generation facilities that would not be practical or economic. In most cases electricity is imported from the local grid although some refineries are supplied by a dedicated power plant operated as a separate legal entity and possibly supplying other consumers (process industry, petrochemicals etc.). Economies of scale are important in CHP projects and many CHP plants have been built in accordance with this model. In other refineries electricity generation is integrated in the site which then exports excess electricity either to the grid or to other consumers.

Import and export of heat (mostly as steam) is less frequent but still fairly common, often as a result of integration with other local plants such as petrochemicals. Where CHP plants are outsourced steam is also formally imported into the refinery.

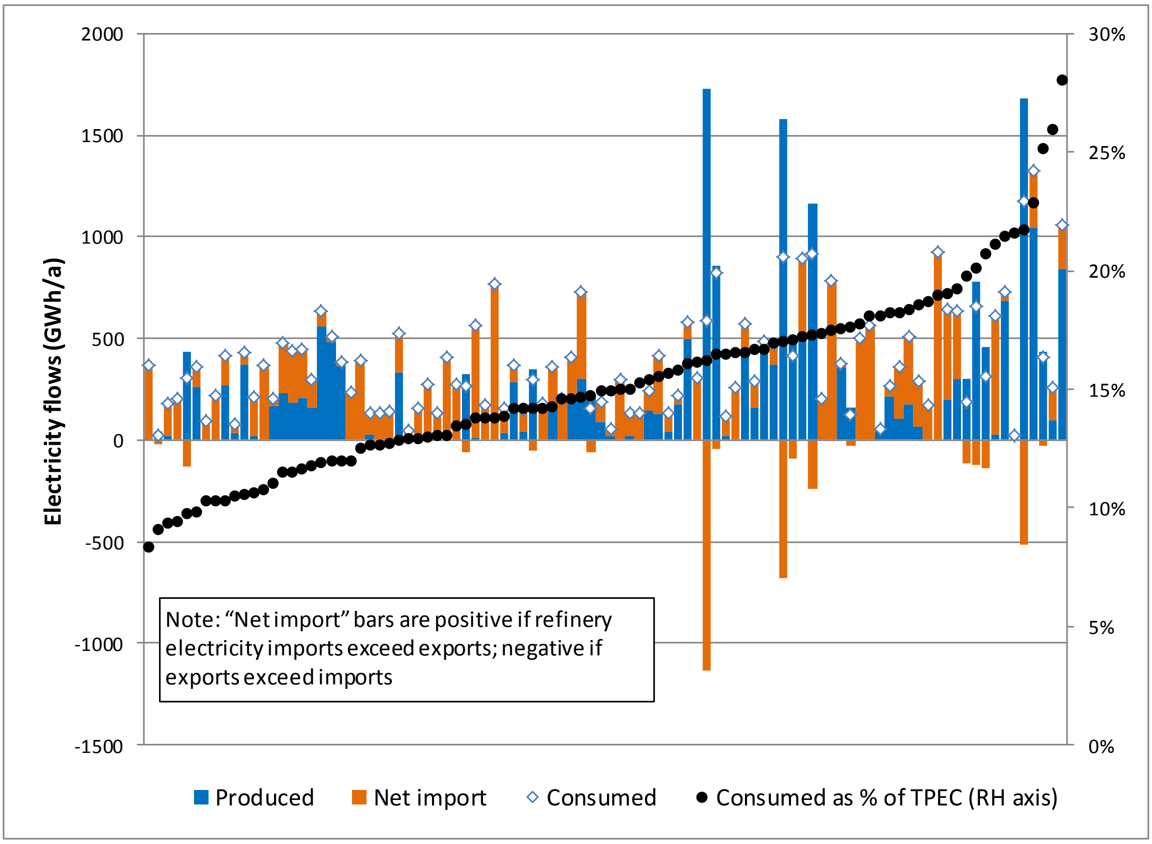
Figure 9 shows the heat import/exports in EU refineries as a percentage of total primary energy consumed (TPEC)[6]. ***Figure 10*** shows the same data for electricity, also including total own consumption both in absolute terms and as a percentage of TPEC.

Figure 9 Heat import/export (96 mainstream EU refineries, 2007-08)
(Source: CONCAWE)



[6] Total primary energy consumed (TPEC) is the total of all types of energy consumed by a refinery. Secondary energy sources such as steam and electricity are expressed in terms of the primary energy required to produce them, using standard efficiency factors.

Figure 10 Refinery electricity production, net import and own consumption (96 mainstream EU refineries, 2007-08)
(Source: CONCAWE)



About half of all EU refineries exchange heat with the outside, mostly as import and overwhelmingly in the form of steam. Large imports are likely to denote cases where the refinery is supplied by a cogeneration plant physically or administratively separate from the refinery. About 20 refineries export significant amounts of heat, often to neighbouring and/or associated complexes such as petrochemical plants.

Refineries generally have a high rate of heat recovery, and only discharge low temperature streams such as very low pressure steam or hot condensate that do not have any practical use. In a small number of cases a set of favourable circumstances (local climate, refinery location in relation to urbanised areas) has made it feasible to export such low grade heat for e.g. urban heating. Beyond the physical issues, this requires, however, a high degree of cooperation between industry and local planners and decision makers and long term commitments for all parties in order to arrive at a practically feasible scheme with acceptable economics.

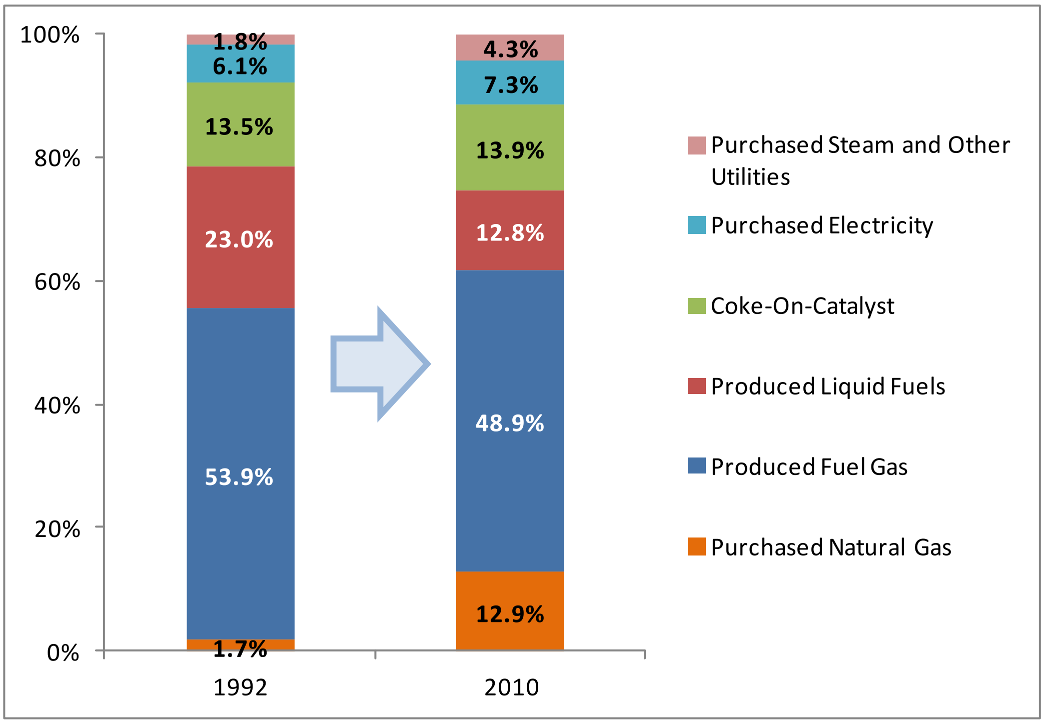
The large majority of EU refineries import at least a fraction of their electricity needs while about a third of EU refineries import all their electricity. This is mostly the result of historical choices made at the design stage, including such considerations as the reliability of the local grid and, of course, cost. A number of refineries export electricity, mostly from internal cogeneration plants, either to the grid or to neighbouring and/or associated complexes such as petrochemical plants.

The fraction of TPEC consumed as electricity varies a great deal from refinery to refinery. This is partly due to the type of processes installed (high pressure processes such as hydrocracking require large, energy-intensive compressors and pumps which are mostly electricity-driven) but also the result of mostly historical/design choices taking into account the specific environment in which the refinery operates.

2.3. TOTAL REFINERY ENERGY MIX

Figure 11 shows the evolution of the refinery energy mix in the Solomon trend group of EU refineries between 1992 and 2010.

Figure 11 Evolution of refinery fuel mix in EU refineries, as % of TPEC (total primary energy consumption)
(Source: Solomon Associates)



Although its share has somewhat decreased over the years, self-generated fuel gas still accounts for the largest fraction of the total refinery energy mix. Its reduction is the reflection of the increasing absolute energy needs whereas the fuel gas production (which is not deliberate) does not increase in the same proportion.

Under the pressure of emission regulations and thanks to the wider availability of natural gas in large quantities, a sizeable proportion of liquid fuel has been replaced by imported natural gas.

Although a substantial proportion of utilities are produced internally, imports of steam and other utilities have also increased substantially and so have electricity imports although to a smaller extent. This is mostly driven by the development of cogeneration plants often physically and/or administratively outside the refinery fence.

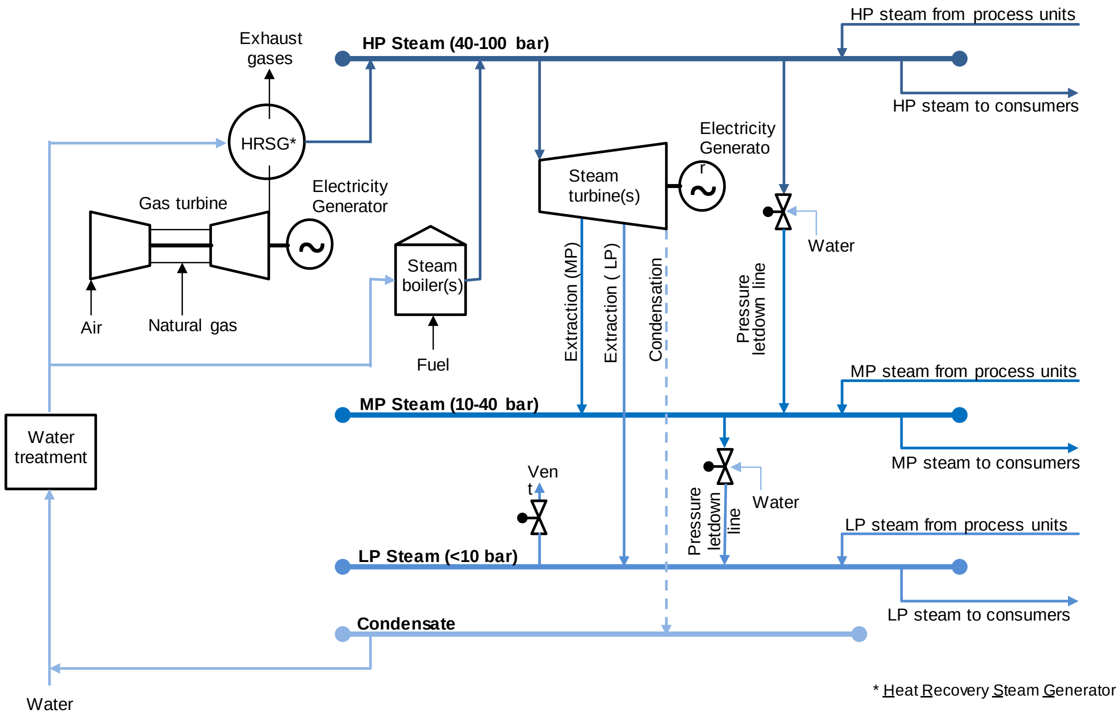
The proportion of FCC coke has remained more or less constant. Although FCC plants now represent a smaller share of the total “conversion” capacity, they tend to be operated at higher severities thereby producing more coke with a given feedstock.

3. TYPICAL REFINERY ENERGY SYSTEMS

Energy is the life blood of a refinery and its uninterrupted supply is crucial to the operation and profitability of the facility but also, and crucially, to its safety. Refinery energy systems are therefore designed to provide an uninterrupted secure source of fuel, steam and power, including appropriate back-up systems.

Figure 12 shows a typical refinery energy system designed to supply the needs of all energy consumers within the refinery using a combination of dedicated utilities plants (steam boilers and electricity generators) and steam from process units.

Figure 12 Example of a refinery energy system



Notes:

- ✓**HP steam** is mostly produced and consumed in the utilities area. Some process units may produce HP steam, e.g. FCC CO boilers. HP levels of 80-100 bar are common in modern systems, particularly with gas turbines as the high exhaust gas temperatures allow generation at such pressures. HP steam consumers are typically turbine drivers for large rotating machines.
- ✓**MP steam** may be consumed in turbine drivers for smaller rotating machines and in process heating.
- ✓**LP steam** consumers include process heating, tank and piping heating and general maintenance (cleaning etc.).
- ✓Some refineries may use additional steam pressure levels for specific applications or because of historical reasons (plants built at different times).

3.1. FUEL SYSTEMS

3.1.1. Fuel gas

Fuel gas is typically produced by a large number of process plants at different pressures and with different compositions. Some of these residual fuel gas sources contain significant levels of hydrogen sulphide that must be removed. Cleaned up gas streams are typically gathered into a single system (or occasionally two or three separate systems in larger refineries) and redistributed to energy consumers across the refinery. Production of fuel gas can fluctuate as a result of process changes or process upsets (particularly significant for large fuel gas producers such as conversion units) and it is common to use e.g. propane as make-up component to ensure a continuous supply of fuel gas.

Where natural gas is imported into the refinery, it is commonly mixed with fuel gas and can also act as a make-up component.

3.1.2. Liquid fuels

After fuel gas, imported gas and FCC coke, liquid fuels provide the balance of a refinery's fuel requirements. With relatively light, low viscosity materials, liquid fuel systems are fairly straightforward, simply circulating liquid in a loop around the consuming heaters and boilers.

Refineries have always had an economic incentive to burn low-value liquids such as heavy residual streams. Specific systems have been developed for such high viscosity materials that require special handling facilities with heated piping, pumps and fittings as well as special burners. For these reasons such systems are often limited in scope, supplying only a few dedicated heaters. Heavy residues tend to have high sulphur content and pressure on refinery emissions, particularly SOx, has gradually reduced the consumption of such fuels in refineries. Some selected low sulphur residues can still be used. In some cases high sulphur residues are used in combination with flue gas desulphurisation systems or in gasification plants where sulphur is removed as part of the process before the virtually sulphur-free synthesis gas is used.

3.2. STEAM SYSTEMS

Beside direct fuel as burnt in heaters and boilers, steam is very much the ubiquitous energy vector in a refinery, with a host of different uses for heating process streams, cooling hot streams and recovering heat, continuous heating of ancillary facilities such as piping and tankage, cleaning etc. Secure and uninterrupted steam supply is critical to the reliable and safe operation of a refinery.

Steam is produced and used at different pressure levels. The bulk of the steam is produced in dedicated boilers or in a CHP plant, usually at high pressure (100 bars is common) and high temperature (<500°C). Some steam may also be produced in heat recovery boilers, usually at lower pressure/temperature. An important aspect of steam production is preparation of boiler feed water of appropriate quality (the higher the pressure, the better the purity of the water needs to be). This involves several treatment stages including demineralisation.

A typical refinery steam system may have three pressure levels:

- High (40-100 bar)
- Medium (10-40 bar)
- Low (< 10 bar)

There is no standard terminology and actual pressure levels may vary considerably from refinery to refinery depending on local requirements, design history and other factors. For each pressure level the temperature of the steam is kept well above the dew point (the steam is "superheated") to avoid unwanted condensation.

At each pressure level a network of pipes connects producers and consumers. Each level is connected to the next one down through a combination of letdown stations and steam turbines.

Hot condensate is generally recovered, cleaned and returned as make-up boiler feed water.

Some refineries have a structural, often seasonal, surplus of low pressure steam that may be vented.

3.3. ELECTRICITY SYSTEMS

Refinery electrical systems are also designed to provide secure and reliable supply. In most EU refineries supply is either entirely or partly from the local grid. Internal generation may be from integrated CHP plants, individual steam turbines, expanders and power recovery turbines.

4. OPTIMISING REFINERY ENERGY CONSUMPTION

In refineries, as in most other process industries, energy efficiency cannot be decreed or achieved in a day. Good energy performance is the result of a number of elements involving organisation management as well as investments.

4.1. ENERGY MANAGEMENT SYSTEMS

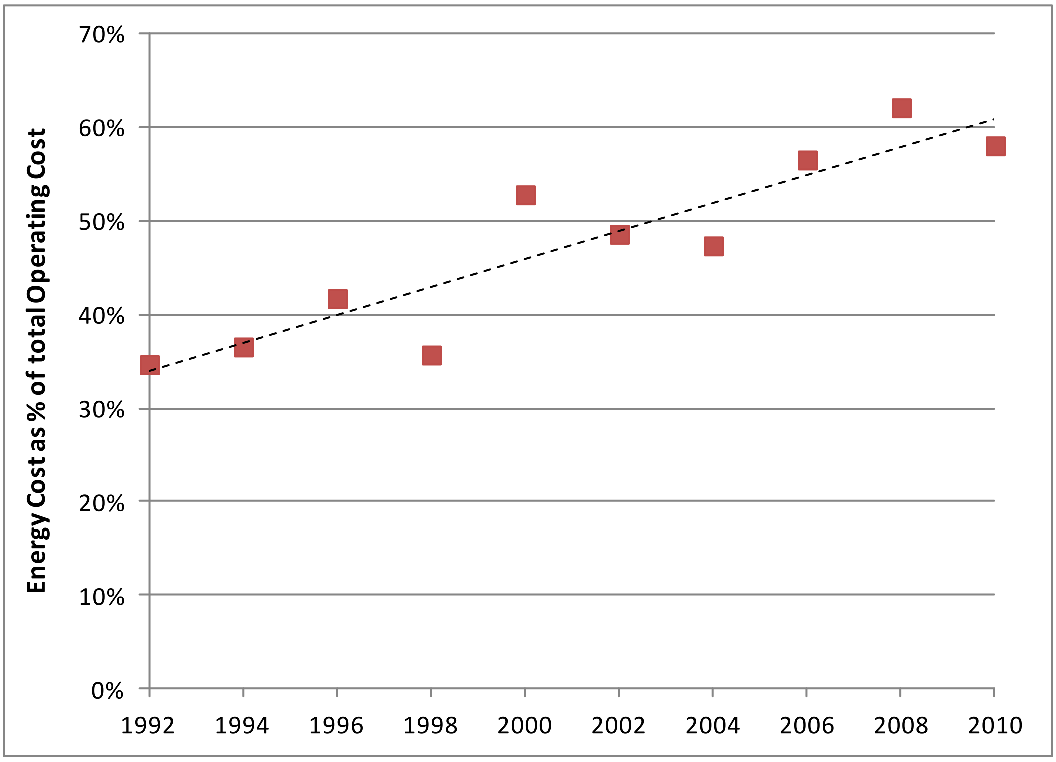
The first building block to achieve good energy performance is to develop and implement a consistent set of organisational measures, systems, procedures and practices dedicated to monitoring, measuring and reducing energy consumption. Such packages are usually known as Energy Management Systems (EMSs).

The desired structure and attributes of EMSs have been described in many documents and international standards such as the EU's Energy Efficiency BREF under the Industrial Emissions Directive (IED) and the international standard ISO 50001:2011 which superseded the earlier European standard EN 16001 (see **Section 8**, Additional Reading). All such schemes are based on the "Plan/Do/Check/Act" continuous improvement loop first introduced in the generic quality management schemes and standards.

The main elements of an EMS are

- Management responsibility: This sets out the role and duties of top management in the setting up, implementation and running of the system,
- Energy policy: This states the organisation's commitment to energy performance improvement
- Energy planning: this is the heart of the system. It identifies the legal and other requirements that the system has to comply with. It includes an energy review where areas of significant energy use and opportunities for improvement are identified, and an energy baseline which serves as a reference for measuring progress. The review also includes development of performance indicators and setting of objectives and targets, at both corporate and facility level and define the means to monitor and measure progress, including regular auditing of facilities. This usually requires an assessment of relevant measurement facilities and a plan to improve them as necessary.
- Implementation: this includes communication, training and documentation, measurement protocols, auditing schemes and procedures to implement recommendations (e.g. investments) and initiate and complete corrective actions.
- Most oil companies have been early adopters of quality management systems and are therefore familiar with the requirements of such schemes in terms of management commitment, organisational discipline, documentation and communication. As major energy consumers, refineries have long had a strong financial incentive to reduce energy consumption and improve efficiency. ***Figure 13*** shows that energy cost in EU refineries has long represented a substantial portion of total operating cost and the proportion has nearly doubled over the past 20 years.

Figure 13 EU refineries energy cost as % of total cash operating costs
(Source: Solomon Associates)



As a result, most of the companies operating refineries in the EU operate a form of EMS. Depending on the company's size, structure and culture, EMSs may cover the whole company, specifically the refining division or individual facilities.

Energy consumption monitoring is widely practised, with energy balances produced on a regular basis, in some cases every day or even every shift.

Solomon's performance indicators are very widely used by the refining industry, including the EII which is commonly used, at the level of a site, for monitoring energy performance over time, comparing performance with others (both internally and with peers) and setting improvement targets. Many companies use a range of other performance indicators often at a more disaggregated level (individual plants, individual shifts etc.).

4.2. OPERATIONAL MEASURES

There are many opportunities to maintain or improve energy efficiency by day-to-day operational measures and good practices.

4.2.1. Process optimisation

Most refinery processes and particularly physical separation processes involve heating, cooling, compressing, pumping, all operations that consume energy and should only be carried out at the rate that is strictly necessary to achieve the objectives of the process. For example, the degree of separation between two streams is commonly controlled by a rate of reflux, stripping steam or solvent circulation which can be optimised to just deliver the required level.

Producing the correct product in quality and quantity also reduces the need for inefficient reprocessing.

4.2.2. Heaters and boilers operation and control

Heaters and boilers are by far the largest energy consumers in a refinery and their optimisation is crucial to the overall energy performance. This includes close monitoring and control of the firing conditions, particularly excess air, as well as maintenance of burners, firebox and heat recovery systems to minimize losses.

4.2.3. Heat exchanger monitoring and cleaning programmes

Heating and cooling involve large banks of heat exchangers which need to be kept clean through appropriate maintenance programmes.

4.2.4. Steam system maintenance

Most refineries have an extensive steam system representing long distances of piping with many fittings which all have potential for leakage. Most refineries have on-going programmes for tracking steam leaks, maintaining and repairing steam traps, etc.

Steam turbines need regular maintenance in order to perform optimally.

4.2.5. General housekeeping

Good housekeeping is generally a component of good performance and this also applies to energy. Regular inspection and minor maintenance of insulation and other pieces of ancillary equipment, early detection and repair of minor steam leaks all make for an energy-efficient operation.

4.2.6. Role of modern monitoring and control technologies

Over the years, most refineries have introduced increasingly sophisticated data collection, monitoring and control systems. On-line quality measuring instruments and real-time optimisation routines, sometimes with closed-loop control, have greatly improved the scope for continuous optimisation in all areas.

Process optimisers help determine and apply just the required amount of heat or circulation rate required for the desired outcome. Real-time monitoring and advanced control of operations maximises efficiency. In-line blending systems reduce the need for physical movements of products and achieve a lower rate of re-blending and adjustments.

4.2.7. Utilities systems optimisation

The utilities system of a refinery can be very complex with several interconnected steam networks, alternative electricity generation systems, interdependent steam and electricity systems etc. Beyond the real-time optimisation of sub-systems, it is often beneficial to consider the bigger picture and look at the utilities system as a whole. To this end refiners have devoted much effort to the development and implementation of optimisation programmes to identify the best strategy to minimise energy consumption (or cost, which is closely related).

4.2.8. Reliability programmes

In addition to the preventive maintenance and housekeeping schemes described above, many refiners have developed and implemented so-called "reliability programmes" that focus on the optimisation of equipment inspection and maintenance in order to reduce unplanned shutdowns.

This promotes the continuous operation of refinery facilities, thereby reducing the unnecessary energy consumption associated with equipment shutdown, idling and start-up operations.

4.3. INVESTMENT OPPORTUNITIES

Although much can be achieved by operational measures, stepwise improvements in energy efficiency tend to require physical changes, which in turn require investment. Proposals for changes in operational practices or investment are as a rule generated through the energy review and energy auditing schemes under the overall umbrella of the EMS. Investments may be geared to processes in either existing or new plants, or to utilities systems.

4.3.1. Energy-specific investments in existing process plants

Energy consumption reduction in existing plants is generally achieved by increasing heat recovery by better integration and use of heat exchange opportunities between hot and cold streams. Integration can take place within a single process unit or across several units. In complex cases specific analysis such as the so-called "pinch technology[7]" can be used to identify the optimum heat exchange configuration.

In heaters and boilers, improved efficiency can be achieved by adding air preheaters and boilers and/or installation of more efficient burners.

Replacement of internals (trays, structured packing etc.) in distillation columns can provide an opportunity for reduction of reflux rates at constant quality of the products.

There may also be opportunities for recovery of pressure energy such as in expanders and power recovery turbines.

Energy efficient technologies can also be used on rotating equipment such as variable-speed motors and high-efficiency motors for pumps which avoid energy losses through valve throttling.

Modifying an existing unit is a complex and costly operation, generally requiring operating units to be shut down and incurring production losses.

7 Pinch technology is a set of rigorous analytical methods used to design heat exchanger networks that achieve the thermodynamically optimal level of heat recovery from hot to cold streams.

Ultimately, there is a practical limit to the level of energy efficiency that can be physically, realistically and cost-effectively achieved in an existing process.

4.3.2. Energy efficient designs for new plants

Building new plants in an existing refinery provides wider opportunities to implement energy-efficient technologies. In addition to all the points mentioned above, specific energy-efficient technologies which cannot easily be retrofitted in existing plants can be selected.

More generally energy efficiency can be fully integrated into the design from the outset.

4.3.3. Energy efficient utility systems

Utility systems efficiency can be maintained and perhaps marginally improved by operational and maintenance activities. Similarly to process units, large gains require investment.

The main opportunities for stepwise improvement are related to exploiting opportunities for cogeneration, which require that a simultaneous need for heat and electricity must be identified either within the refinery or with third parties.

Most refineries consume more steam than electricity so that additional cogeneration opportunities often involve electricity export when steam is generated on-site. In other cases both steam and electricity are imported, mostly from third party cogeneration plant.

There are two main caveats that limit the potential for improving the efficiency of utility systems by means of cogeneration. First and foremost, a continuous electricity and steam supply is crucial to the safe operation of a refinery. Any interconnection with other systems potentially reduces the reliability of the refinery supply and appropriate back-up must be provided and available at short notice at all times. Secondly, successful cogeneration projects require a set of favourable physical and financial circumstances, including but not limited to a secure outlet for electricity export, reliable and guaranteed long term access to the design fuel (mostly natural gas) and a financially supportive tariff structure for consumed fuel and exported electricity. Cogeneration plants also require a minimum size to be economically justifiable, while larger plants often have the potential to be more efficient. This tends to limit practical cogeneration opportunities to large and medium size refineries.

5. GLOSSARY

BREF	Best Available Techniques (BAT) reference document
Cogeneration	A process in which electricity and useful heat are produced simultaneously.
CHP	Combined Heat and Power
EII®	Energy Intensity Index™
EMS	Energy Management System
FCC	Fluid Catalytic Cracker
IED	Industrial Emissions Directive, directive 2010/75/EU of the European Parliament and Council
SA	Solomon Associates
SOx	Sulphur Oxides
TPEC	Total Primary Energy Consumed

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