CO_2 emissions from EU refineries

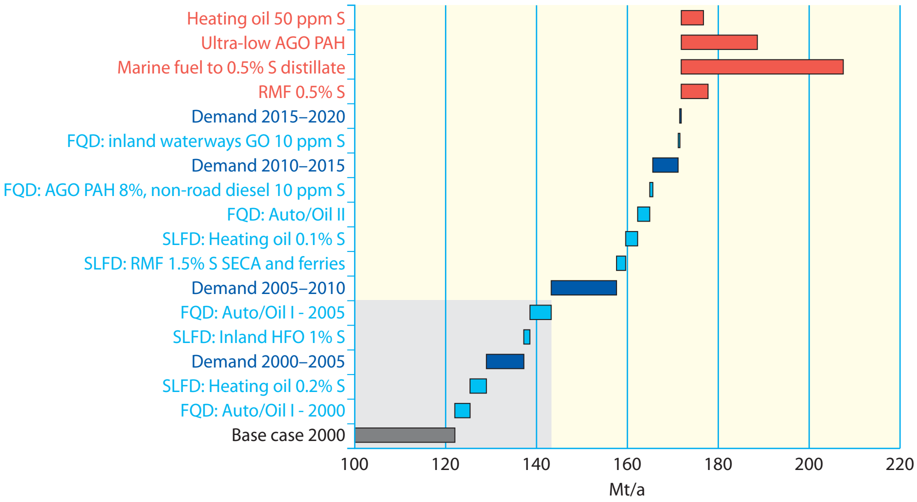
History, trends and mitigating options

The current focus on climate issues and, more specifically, greenhouse gas (GHG) emissions is generating much debate regarding emission sources and reduction options. Oil refineries are amongst the so-called 'energy-intensive' industries that do emit large quantities of GHGs, the vast majority of which is carbon dioxide, CO_2. In this article we review the current situation in EU refineries with regard to energy consumption and CO_2 emissions, their evolution in the past few years and the factors that will affect them in the future. We also consider the mitigating options available to the refiners.

Turning crude oil into marketable products requires energy to physically separate molecules and chemically modify them to obtain the desired yield structure and product quality. As demand has gradually shifted towards lighter and cleaner products, refineries have become more complex and, in the process, have gradually required more energy use. Today's EU refineries consume the equivalent of 6.5 to 7% of the energy content of their feedstocks. The majority is internally generated, although there can also be imports of electricity and natural gas. Burning fuels to generate energy is currently responsible for about 90% of EU refinery CO_2 emissions on average. The other 10% is 'chemical' CO_2 generated by decarbonisation of hydrocarbon molecules to produce the hydrogen required for desulphurising and saturating various streams (note that this proportion varies a great deal depending on the refinery configuration). This 'chemical' portion is steadily growing as more conversion of residues to light product is required and as treating requirements are becoming more stringent.

As part of CONCAWE's refinery modelling activities we have endeavoured to forecast the future refinery emission trends in the EU, taking into account the foreseen changes in demand and in product quality. For the latter we have taken into account all currently agreed legislation (some provisions of which will only come into force in future years) and also considered a few 'step out' cases to represent possible additional legislation based on current debates. We have chosen to represent the reduction of the polyaromatics (PAH) content of diesel fuel to very low levels, reduction of heating oil sulphur to 50 ppm and either a complete switch of marine fuels to distillates or desulphurisation of residual marine fuel to 0.5%. It should be stressed that these extreme changes in product quality are intended only to emphasise the impact on CO_2 emissions from refineries and do not represent the oil industry preferred end point. Although

Figure 1 Expected evolution of CO_2 emissions from EU refineries



CO_2 emissions from European refineries are on an upward trend. (The grey shaded area indicates past evolution.)

all these changes including emission mitigation measures will also have a large impact on refinery costs and investment requirements, we have deliberately left this out of the scope of this article to focus on CO$_2$ emissions.

Figure 1 shows the expected evolution of CO$_2$ emissions from European[1] refineries between 2000 and 2020, split into 5-year periods. All main legislative changes are shown while the impact of demand changes is highlighted separately. From the 2020 reference, the step-out cases (shown in red) for potential legislation have been added.

Clearly CO$_2$ emissions are on an upward trend. By 2005 Auto/Oil road fuels specifications had largely been implemented but there are other changes to come including migration of non-road diesel to road diesel specifications, sulphur reductions in heating oil and the implementation of the new marine fuels legislation. The steadily increasing imbalance between gasoline and diesel and the slow erosion of residual fuel markets create a need for more conversion, mostly of the hydrocracking type, which leads to increased hydrogen requirements and consequently to higher CO$_2$ emissions.

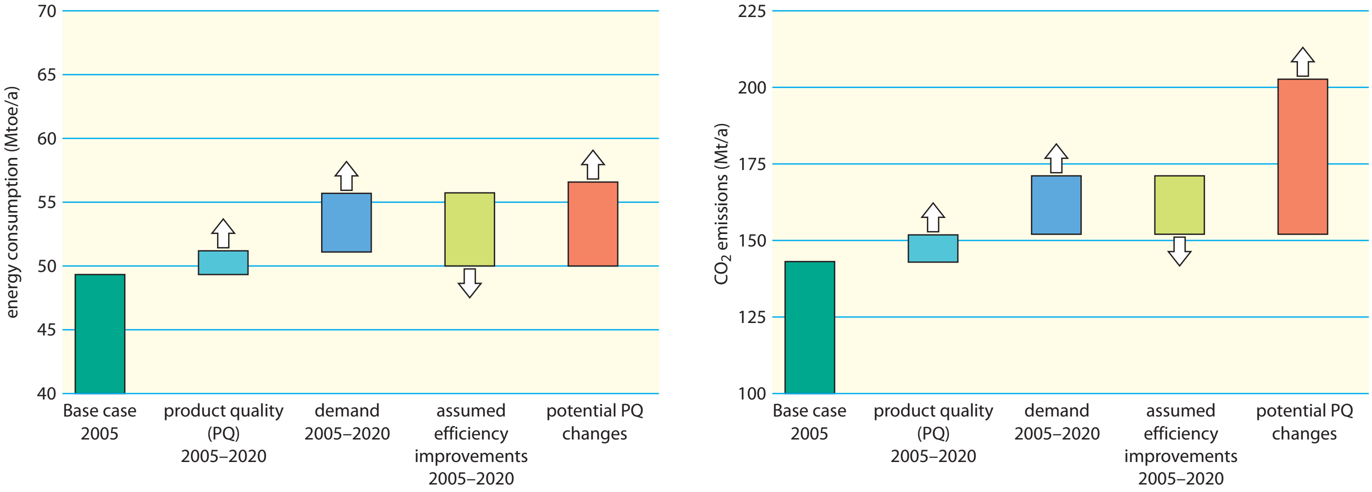
It should be noted that, although the difference between the 0.5% S residual and distillate marine fuels appears large, large-scale production of residual fuel of this quality is unlikely to occur as conversion of residues for the ever-expanding distillate market is bound to be much more profitable[3].

Faced with this reality on the one hand and with the increasing cost of carbon on the other hand, the EU refiners are considering their options to mitigate these trends.

Energy efficiency

Increasing energy efficiency i.e. using less energy to deliver the same service is undoubtedly a non-regret option, where economically justified, as it is the only one that offers both energy and GHG emission savings. This is not a new pursuit in an industry where fuel represents a considerable part of the operating costs. Between 1990 and 2005, EU refiners have increased the efficiency of their operations by an estimated 13%. This is partly the result of sustained focus on energy saving in every-day operation and of cost-effective investments, for instance in improved heat integration or energy efficient pumps and compressors. The 'low-hanging fruits' have long been picked and improvements in recent years have already involved complex and expensive schemes. As a matter of fact a significant part of the efficiency improve-

Figure 2 Impact of energy efficiency improvements on energy consumption and CO$_2$ emissions from EU refineries[2]



---

[1] *Includes EU-27 plus Norway and Switzerland.*

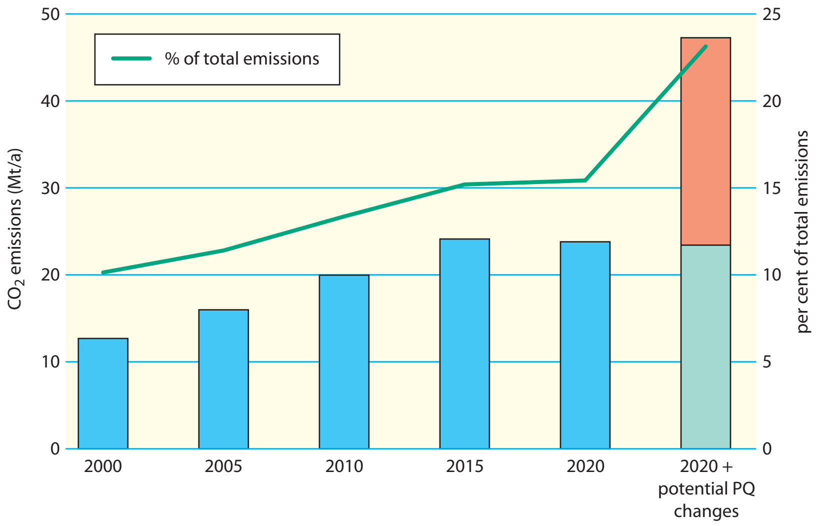
[2] *'Potential PQ changes' (Figures 2 and 4) represents the sum of the step-out cases shown in Figure 1 excluding 'Residual Marine Fuel 0.5% S'.*

[3] *See CONCAWE report 2/06,* Techno-economic analysis of the impact of the reduction of sulphur content of residual marine fuels in Europe.

CO_2 emissions from EU refineries

History, trends and mitigating options

Figure 3 'Chemical' CO_2 from hydrogen production in EU refineries



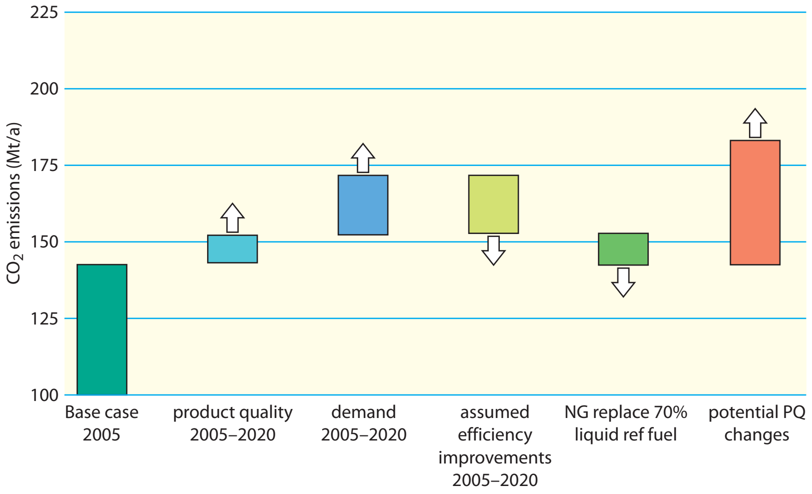
Above: hydrogen-related emissions are set to roughly double between 2000 and 2020 to reach 15% of total emissions.

ments has been achieved by installing highly efficient combined heat and power plants (CHP) in replacement of simple steam boilers and imported electricity. Further opportunities still exist but are increasingly difficult to achieve and less cost-effective.

Energy management is a site-specific issue and it is difficult to take an overall view of what might be achievable. Starting from the historical figure above we have assumed a general 0.5% improvement per year, with a 20% better energy performance for new plants compared to existing ones at any given time. It has to be emphasised that this is not a forecast based on hard technical data but rather a challenging scenario. Figure 2 illustrates the impact of such efficiency improvements in terms of energy consumption and CO_2 emissions.

The higher efficiency can, to a large extent, compensate for the increased energy requirement. The situation is less favourable for CO_2 emissions. This is due in part to small fuel pool changes, as future processing schemes tend to produce relatively less fuel gas, which is then compensated by additional liquid fuel, but mostly to additional emissions that are incurred when more 'chemical' CO_2 is produced. This is illustrated in Figure 3, which shows that hydrogen-related emissions are set to roughly double between 2000 and 2020 to reach 15% of total refinery emissions. The potential product quality-related legislation envisaged would be particularly hydrogen intensive and imply a large further increase.

Figure 4 Impact of liquid fuel substitution by natural gas on CO_2 emissions from EU refineries[2]



Fuel substitution

The majority of fuels burned in refineries are self-generated in the form of light gases (C1-C2) and, in refineries that operate a Fluid Catalytic Cracker (FCC), the coke that is formed on the circulating catalyst as part of the process. Mostly as a result of emission control legislation and specific local environmental pressure, a number of EU refineries have already replaced heavy fuel oil with imported natural gas (currently 5–10% of refinery energy). The balance (about 25% on average) has traditionally been provided by liquid fuel, mostly low value residues that the refineries are equipped to handle. Typically, refineries are very effective at efficiently burning low value fuels that would otherwise need to be upgraded or would displace other fuels on the market.

Replacing more liquid fuel by natural gas is of course a way to reduce direct CO_2 emissions from a refinery site. Figure 4 shows the additional impact of substituting 70% of the liquid fuel burned in our 2020 reference case with natural gas (100% substitution would not be realistically achievable as a number of refineries do not have access to a gas supply today and are unlikely to have it in the future).

The combination of challenging efficiency improvements and a switch to natural gas can only be expected to stabilise emissions, as long as no further product quality legislation is introduced.

The net effect of the substitution is to replace crude oil with natural gas. From the point of view of global CO_2 emissions, this only represents a true reduction if this effectively causes additional natural gas to be produced and used. In reality this may, at least partially, not be the case as the increased natural gas demand in Europe may cause users in other regions to switch to cheaper and more carbon-intensive fuels. Note that, in our modelling, we have assumed that the heavy fuel not used as refinery fuel would be converted (i.e. that the refinery output would remain constant). In reality this may not be the case in all refineries, particularly in the simplest that would seek to sell the extra fuel. It would then also displace other fuels in the market.

Using lighter crude oil

It is often suggested that processing lighter crude oil would be a way to reduce refinery emissions. It is undoubtedly correct that heavier crudes require more processing energy to achieve the same product yield pattern, because they contain more residual material that needs to be converted and also generally require more sulphur to be removed. Crudes are expected to become heavier worldwide, and the average crude diet in Europe is expected to follow this trend albeit at a fairly slow rate compared to other regions of the world. This is because a number of light crude producing provinces are within easy reach of Europe where, as a result of prolonged availability of North Sea crudes, a large number of refineries have been optimised for light crude processing.

In our modelling we recognise this reality but also use a heavy Middle East crude as incremental feed. In order to illustrate the impact of a lighter crude diet we have, in a sensitivity case, made the assumption that all heavy Middle East crude over and above what was in use in 2000 would be replaced by a light North Sea type crude (Brent). This represents a major shift of some 70 Mt/a (nearly 1.5 Mbbl/d) from heavy to light crude, which is roughly 10% of the total crude intake. The results are shown in Table 1.

The energy consumption of the refineries is reduced by 3% whereas the reduction of refinery CO_2 emissions reaches 6% for two reasons:

1. With a lighter crude, less conversion and less desulphurisation are required resulting in a lower requirement for hydrogen and a lower 'carbon loss', i.e. lower CO_2 emissions from decarbonisation of hydrocarbons.
2. The refinery fuel diet has a somewhat lower emission factor in the case of the lighter crude, with more fuel gas and less FCC coke.

Table 1 Impact of crude diet on CO_2 emissions from EU refineries

Case	2020		Difference	
	Reference	*Light marginal crude*		
Crude diet (mt/a)				
Total	715	711	-4	-0.6%
Light North Sea			70	
Heavy Middle East			-74	
% light crude	45%	55%	10%	
Average %S	1.12%	0.91%	-0.22%	
Fuel consumption (Mtoe)	50.0	48.6	-1.5	-3.0%
CO_2 emissions (Mt/a)				
Total from refineries	153	144	-9	-6.0%
'Chemical' CO_2 from hydrogen production	24	20	-3	-14.0%
Total inc. burning of fuel products	2149	2138	-11	-0.5%

When including the CO_2 emissions from burning the fuel products, the difference between the two cases increases somewhat from 9 to 11 Mt/a reflecting marginal differences in carbon/hydrogen content of the products. The overall 11 Mt/a reduction represents only 0.5% of the total emissions.

The above calculation considers only refining and does not make any assumptions with regard to the GHG footprint associated with production and transport of crude oil. There is no correlation between crude quality and extraction and/or transport energy, and the difference could go either way depending on the actual crude origins being considered.

These impacts may seem significant to some but there are other crucial points to consider:

- Whether Europe would be able to attract such a large additional amount of light crude can be a matter of conjecture but, in any case, crude oil consumption is largely a 'zero sum game' when considered worldwide. Should Europe be successful in securing more low sulphur crude, other world regions would have to process the heavier grades and emit correspondingly more CO_2. This would effectively cancel any benefit and potentially lead to marginally higher CO_2 emissions due to additional global transport of crudes.
- Over the years, refineries have become gradually more complex in order to be able to process increasingly heavier crudes, thereby transforming low value residues into high value distillates. With decreasing resources of light crudes, it is important that refineries worldwide invest in that sort of complexity. Processing light crude is in fact a kind of 'poor man's option' that can avoid investment in a more sophisticated facility. The savings in capital expenditure result in the need for more expensive crudes, thereby impacting on refinery profitability. Focusing on low sulphur crude processing capability would make refineries in the region less flexible, less able to take opportunities of cheap crudes, and more dependent on a declining and ever popular resource of light crudes.

Since crude oil composition is a given on a global basis, the major determinant of energy usage and CO_2 emissions in the global refining sector is the product pattern required in terms of both quality and quantity, which determines the required level of residue conversion, the type of conversion unit and the amount of post-treating of intermediate products.

Burning biomass in refineries

Production of heat and power, particularly when these can be combined (CHP), is the most effective way of using biomass from the point of view of GHG emissions avoidance. Refineries are indeed major users of both steam and power and offer good opportunities for CHP.

As mentioned above, only about 25% of refinery fuel on average is available for substitution, with fairly wide variations depending on the processing scheme. Biomass would be essentially solid fuel such as wood pellets or dried agricultural/forestry residues. This could realistically only be envisaged for steam boilers but not for process heaters. Reliability of energy supply is an essential safety feature and any such boiler would have to be fully backed up. Many refineries have recently installed high efficiency gas-fired combined cycle gas turbines; introducing biomass on a large scale would make such investment at least partially redundant. In addition refineries are not normally located near sources of large amounts of biomass (such as forests) and consequently fairly long distance transport would likely be involved.

Although some refineries with a particular set of favourable circumstances may find good justification for such biomass burning, it is unlikely to become a major feature in the refining sector as a whole. What biomass is available is likely to be more attractive as co-firing fuel in coal power stations or local CHP plants serving small industrial communities.

Carbon capture and storage (CCS): the Holy Grail?

CCS is a technology under development that is attracting a lot of attention as possibly the only acceptable way to continue to use fossil carbon resources in the next decades. Thus far development has focused on large single point emitters such as (coal fired) power stations where economies of scale can be realised. A number of demonstration projects are being considered with a view to developing full-size plants by 2020 at the earliest. The legislative framework still needs clarification, particularly with regard to long-term liabilities .

Although figures remain a matter of debate, CCS will inevitably be costly, not least because it requires additional energy (possibly as much as 30–40% compared to a conventional plant) for capturing, separating, possibly treating CO_2, then transporting it and safely storing it for the long term. Capture is significantly cheaper and less energy intensive when concentrated CO_2 streams are available. For this reason power generation involving oxy-combustion or gasification followed by hydrogen production are being contemplated for such applications. These schemes can produce highly concentrated CO_2 streams that are much easier to capture. Although there are trade-offs in terms of cost and energy consumption (e.g. to produce pure oxygen) many believe these schemes will result in an overall GHG reduction advantage. In refineries, only some 10–12% of CO_2 is currently emitted in concentrated form (from hydrogen production), and oxy-combustion is uncharted territory. In addition many refineries have multiple stacks making it difficult to gather all flue gases at a single point.

The other key success factor for a CCS project is the availability of a suitable geological storage structure within reasonable distance. In all cases, a CO_2 transport infrastructure will be required. Such infrastructures are only likely to develop around large emitters.

Some refineries may develop CCS projects based on a combination of local favourable circumstances. In the next 15 years this will be the exception rather than the rule. In the longer term, the viability of wider use of CCS in refineries remains to be demonstrated.

Conclusions

Effectively reducing refinery CO_2 emissions is a tough challenge. Energy consumption and CO_2 emissions in EU refineries are on an upward trend as a result of changes in demand and the need to meet ever more stringent product quality requirements. Mitigating measures such as efficiency improvements and refinery fuel substitution can at best be expected to stabilise emissions at/near their current level. Additional product quality legislation would put further upward pressure on emissions.

Although seemingly effective for individual refineries, replacing liquid refinery fuel with natural gas or processing lighter crude oils are unlikely to result in global emission reductions as they would largely result in reverse substitution elsewhere.

Although some refineries may find a justification for projects involving biomass burning, this is generally not well suited to a refinery environment. Likewise a few CCS projects may be developed in refineries in the next 5–15 years but large-scale use is unlikely before 2020 and beyond.