The evolution of oil refining in Europe

CONCAWE's contribution to understanding the challenges ahead

Back in 1963 when CONCAWE was founded, the world looked very different from what it is today, and so did the global and European refining industry. Oil product markets were expanding fast and new refineries were being built at a steady rate. The oil crisis of the 1970s brought an abrupt end to this, heralding a long era of consolidation and stepwise adaptation. At the same time the nature of the global oil business shifted from fully integrated companies producing, transporting and refining their own oil to a much more diversified situation where oil production ('upstream') and refining/distribution ('downstream') gradually became two essentially separate businesses. From being purely a 'cost centre' in an integrated chain, refining has become a separate activity in its own right, operating as a 'profit centre' between two global markets—crude oil and products—which, although not entirely independent, have their own dynamics and influences. In addition demand gradually shifted towards lighter products while the quality requirements on all products were considerably tightened.

This article explores the new challenges that these changes have imposed on EU refiners, and describes CONCAWE's contributions to understanding their impact on refinery production and investments.

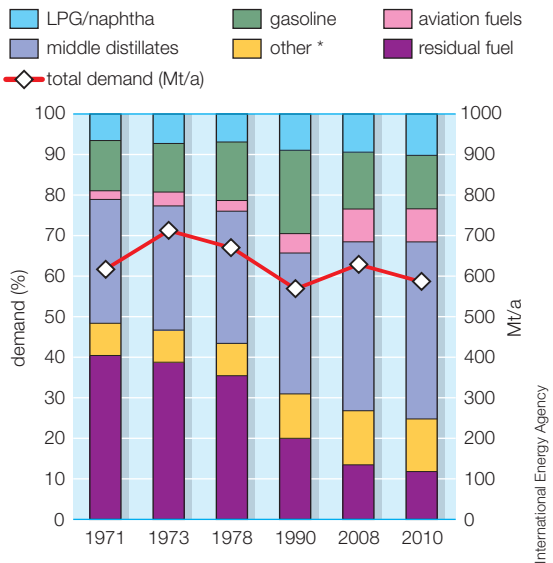
European petroleum product demand and crude supply

Figure 1 shows the evolution of petroleum product demand in what was to become the EU-15 over the past 40 years.

After a peak in 1973, total European demand for petroleum products has been on a slow decline. Crucially, the proportion of the various product groups has changed markedly. As demand for transport fuels soared, the market has demanded ever-increasing volumes of light products. At the same time the traditional markets for heavy fuel oil in power generation and heavy industries dwindled, a situation only partially offset by the buoyant marine bunker market. Today residual fuels account for just over 10% of the product barrel versus 40% in 1971, and so-called 'white' products (gas oils and lighter) now represent more than 70% (this is often referred to as the 'whitening of the barrel'). While this pattern has been repeated worldwide, Europe has also seen a specific trend: the widespread consumer uptake of the diesel passenger car from the early 1990s caused the demand for gasoline to decline while, also as a result of strong road freight growth, demand for diesel fuel soared. This is illustrated in

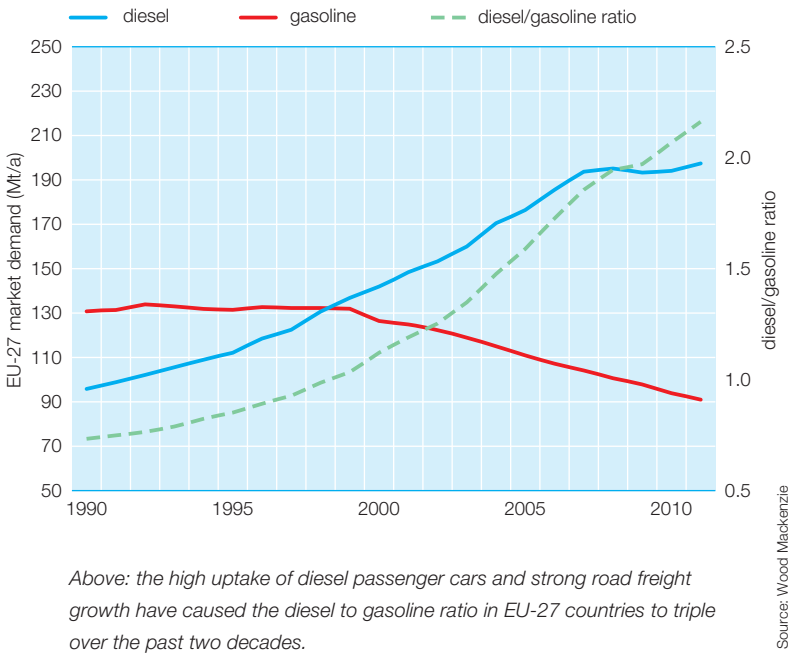
Below: after a peak in 1973, total demand for petroleum products in the EU-15 has been on a slow decline while the proportion of residual fuel decreased four-fold.

Figure 1 The evolution of petroleum product demand in what was to become the EU-15 over the past 40 years



* The 'other' category mostly consists of speciality products such as lube oils, bitumens, solvents, etc.

Figure 2 The diesel to gasoline ratio in EU-27 countries, 1990–2011



Above: the high uptake of diesel passenger cars and strong road freight growth have caused the diesel to gasoline ratio in EU-27 countries to triple over the past two decades.

Figure 2 which shows that the EU-27 diesel to gasoline ratio has virtually tripled in the past two decades.

During the same period, major changes were introduced to fuel specifications, both to satisfy engine performance requirements and to comply with increasingly stringent emission regulations. Until the late 1980s, fuel quality specifications were primarily an industry matter guided by engine requirements and storage transport and handling imperatives. Only a few key properties such as gasoline octane were regulated and, in Europe, this was done independently by each national government. From the early 1990s, as a result of progress in the implementation of the EU single market and the development of EU-wide environmental laws, fuel specifications were gradually harmonised across the EU and came under the jurisdiction of the EU Commission. Responding to concerns about the impact of road transport on air quality, the EU Commission set out on an ambitious programme to drastically reduce vehicle emissions, triggering the introduction of new technologies such as the three-way catalyst for gasoline vehicle exhaust and later the particulate filter for diesel vehicles. In turn, these technologies placed new constraints on fuel quality, while other associated legislation directly required adaptations of specific quality parameters. The so-called Fuel Quality Directive was first promulgated in 1993[2] and has been updated several times since then. Table 1 summarises the evolution of the most crucial quality parameters in Europe for the main transport fuels, as stipulated by European standards EN228 (gasoline) and EN590 (diesel fuel). The phase out of lead in the early 1990s was the first major quality challenge faced by refiners, requiring a complete rethink of the way gasoline was made. The problem was later further complicated by additional restrictions on a number of traditional gasoline components (aromatics, olefins, etc.). Arguably though, the biggest issue for refiners was the almost total removal of sulphur in road fuels, with sulphur content reduced by two orders of magnitude.

[2] Directive 93/12/EEC relating to the sulphur content of certain liquid fuels, dated 23 March 1993

Table 1 The quality requirements of EU road fuels have been fundamentally changed in the past two decades

		Year	1994	1995	1996	2000	2005	2009
Unleaded gasoline (standard grade)					**EN228**			
Sulphur	ppm m/m	max	1000	500		150	50/10	10
Benzene	% v/v	max	5			1		
Aromatics	% v/v	max	Not specified			42	35	
Olefins	% v/v	max	Not specified			18		
Oxygen	% m/m	max	2.5[a]			2.7		
Vapour pressure (summer)	kPa	max	up to 80			60[b]		
Diesel (standard grade)					**EN590**			
Cetane Index		min	46					
Cetane Number		min	49			51		
Sulphur	ppm m/m	max	2000		500	350	50/50	10
Density	kg/m	min	820					
		max	860			845		
T95	degrees C	max	370			360		
Polyaromatic hydrocarbons	% m/m	max	Not specified			11		
Lubricity	µm @ 60°C	max	Not specified		460			

[a] Up to 3.7% at Member State discretion. Individual limits apply to specific compounds.

[b] 70 kPa maximum allowed in Member States with arctic or severe winter conditions.

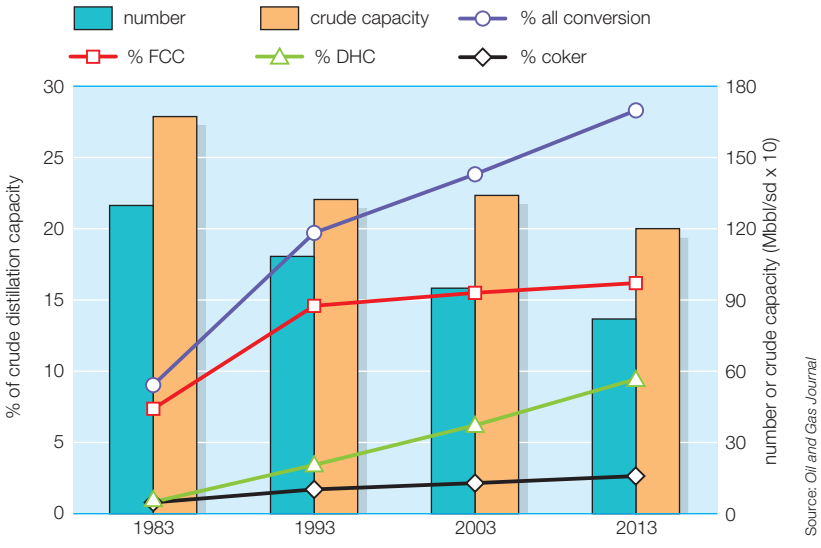
During the period, there were also major changes to the crude oil production and supply routes. Until the late 1960s there were relatively few producing countries and production was mostly handled by large international integrated oil companies operating concessions in the host countries. The oil companies would also transport and refine crude oil mostly in their own refineries.

From the early 1970s oil producing countries increasingly took direct charge through national oil companies. At the same time rising demand led to growth in the number of oil producing regions. This resulted in the gradual separation of crude production from refining and distribution and the creation of an open crude market. From virtually complete reliance on the Middle East, European supply was gradually diversified to include the North Sea, North and West Africa and the Commonwealth of Independent States. The availability of relatively light, low sulphur crudes from these regions helped in meeting the growing demand for lighter products.

Although the recent worldwide trend is towards a marginally heavier crude mix, Europe still has and is expected to retain good logistic access to major light crudes, the declining North Sea supply being replaced by new resources from West Africa and the Caspian area.

Below: the number of EU-15 refineries has decreased over the years while the remaining sites became increasingly complex.

Figure 3 Population, capacity and complexity trends of EU-15 refineries, 1983-2013



Refining challenges

In order to continue to supply the market, the refining industry, both globally and in Europe, has had to respond and adapt to the momentous changes in the composition of the demand barrel and the more stringent product specifications, while also reducing direct emissions to air and water from the refining sites. This has required large capital expenditures in refineries.

Over the years many, mostly smaller sites gradually closed down while larger ones, where investments could be justified, were being modernised, upgraded and expanded. To respond to the 'whitening of the barrel' refiners have had to build 'conversion' facilities to convert residual material to distillates. Figure 3 shows the evolution in the past 30 years of the number of refineries in the EU-15, their crude oil processing capacity and the ratios of different types of conversion capacity to crude capacity. From 130 in 1983, there are now 82 active refineries in the EU-15 (including specialist bitumen and lube-oil refineries). In line with the total demand, crude capacity decreased at first but has been stable since the early 1990s, although recent refinery closures have resulted in a capacity reduction of 11% over the decade from 2003–2013. However, the conversion intensity showed a very large increase at first with the addition of mostly catalytic cracking capacity and, more recently of hydrocracking capacity (a technology that allows production of more middle distillates and less gasoline). Coking also makes a growing contribution although it is not as widespread in Europe as in, for example, North America where the market for heavy fuel oil is small.

Lead removal, sulphur reduction and other quality changes required investment in additional facilities, further increasing the complexity of refineries.

CONCAWE's contribution

CONCAWE's role and contribution to these matters is relatively recent. The fuels and emissions activity started in the mid 1980s to investigate issues at the interface between fuels and vehicles. When comprehensive, game-changing EU fuel legislation came to pass in the early 1990s, it became clear that, in addition to investments in additional conversion capacity required to meet light product demand, the EU refining industry would

face significant additional investments to meet the new specifications notably with regard to sulphur content.

Against this background the Refinery Planning Advisory Group (RPAG), later renamed as Refinery Technology Support Group (RTSG), was instituted with the task of developing and maintaining tools to evaluate the potential cost of fuel quality legislation on the refining industry. A single refinery can be complex and there are often many ways in which it can respond to a given challenge. This is even truer at the level of a country or indeed of the whole EU. The RPAG therefore set out to develop an EU-wide refining model, based on the linear programming (LP) methodology, which would identify the least-cost investment options for EU refineries to meet anticipated market demand in terms of both quality and quantity.

LP models are commonly used to programme and optimise refineries in the short term, and are normally driven by a combination of supply and demand constraints and prices. For the CONCAWE model the objective was more to understand how the total EU refining 'system' needed to evolve in order to meet demand. For that reason the model was run in an over-constrained manner with fixed demands and a virtually fixed crude supply representative of the European slate, the main degree of freedom being investment in new facilities. This made the outcome insensitive to prices which, for such medium-term studies, are extremely speculative.

The model became operational in 1993 and supported many studies and reports, particularly on the impact of the specifications that resulted from the Auto/Oil programmes, such as the April 1999 report (no. 99/56), *EU oil refining industry costs of changing gasoline and diesel fuel characteristics*.

By the early 2000s, although investment costs remained a crucial consideration, the focus shifted towards energy efficiency and carbon emissions, the latter having become a major element of the overall impact of a particular legislative initiative. The EU-refining model could be put to task to quantify the changes in refinery CO_2 emissions to be expected as a result of general product demand and specific fuel quality changes, but it first needed a major revamp to ensure that it was 'carbon-balanced', i.e. that the conservation of carbon was respected in all sub-sections of the model. This proved to be a delicate but eventually successful task and resulted in, to our knowledge, the first such carbon-balanced model.

In the course of the past decade, the RTSG has conducted a series of studies to estimate the potential impact of various legislative packages on EU refineries' investment costs, energy consumption and CO_2 emissions, in the expected supply and demand environment. The most recent of these studies was published in 2009 as CONCAWE Report 3/09, *Impact of marine fuels quality legislation on EU refineries at the 2020 horizon*.

In the context of the 'Well-to-Wheels' analysis of vehicle fuels and powertrains in Europe[3], the EU refining model was also used to estimate the marginal energy and CO_2 emissions associated with the production of gasoline and diesel in Europe.

Since 2009 the activities of the RTSG fall under the Refinery Management Group (RMG), which includes task forces that have recently been called upon to investigate other technology-related refinery issues such as the potential for application of CO_2 capture and storage in EU oil refineries (Report 7/11), EU refinery energy systems and efficiency (Report 3/12) and developing a methodology for an EU refining industry CO_2 emissions benchmark (Report 9/12).

Many technological and economic challenges lie ahead for the EU refining industry, mainly driven by the growing imbalance between diesel and gasoline demand and the reduction of marine fuel sulphur content in 2015 and 2020. CONCAWE's RMG will continue to use its unique EU refinery modelling capabilities to provide insightful analysis and reporting on the impact of such legislative and demand-related changes on the EU refining industry.

[3] The 'Well-to-Wheels analysis of automotive fuels and powertrains in the European context' is a joint initiative of the EU Commission's Joint Research Centre (JRC), the European Council for Automotive Research (EUCAR) and CONCAWE.