Crude oil demand, refinery capacity and the product market: Refining as a bottleneck in the petroleum industry

Wouter Pieterse and Aad Correljé

Clingendael International Energy Programme

Nederlands Instituut voor Internationale Betrekkingen
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Address	: Clingendael 12, 2597 VH The Hague, The Netherlands P.O. Box 93080, 2509 AB The Hague, The Netherlands
Telephone	: +31 70 374 66 16
Telefax	: +31 70 374 66 88
E-mail	: ciep@clingendael.nl

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Abbreviations

API°	American Petroleum Institute; measure for the specific weight of crude using the equation: API gravity = (141.5/ specific weight) – 131.5
CPC Pipeline	Caspian Pipeline Consortium; oil pipeline from the Tengiz field to Novorossiysk terminal at the Black Sea
E&P	Exploration and Production
FCC	Fluid Catalytic Cracker
FSU	Former Soviet Union
HCC	Hydro Catalytic Cracker
MTBE	Methyl Tert-butyl ether; additive in gasoline which enhances the octane number
NGL	Natural Gas Liquids
NIMBY	Not in my backyard
OECD	Organisation for Economic Co-operation and Development
RFCC	Residual Fluid Catalytic Cracker
RHCC	Residual Catalytic Hydro Cracker
TAN	Total Acidity Number
WTI	West Texas Intermediate; US benchmark crude

Summary

In this paper, an analysis is made of the impact of changes in the three sub-systems of the petroleum value chain: the crude market, the refinery industry and the product market. We compare the evolution of product demand in the main geographical consumption regions with refinery output, using two parameters, namely the residual fuel production share and the conversion ratio. By incorporating the utilisation rate of primary distillation capacity into the calculation method of the conversion ratio, the accuracy of the conversion ratio, as an indication of the actual refinery complexity at any given point in time, was improved. The model for the comparison is supported by trend analysis. This provided good insight into (expected) developments in the local petroleum products markets and the patterns of crude demand.

It seems likely that the refining industry will face a lack of capacity if sufficient investments are not forthcoming. The increasing demand for lighter products suggests that there will be a shortage of conversion capacity relative to the supply of light crude. If conversion capacity is used in full, this shortage may only be apparent when demand for products is at a peak or when the use of refinery capacity is restricted temporarily. In both of these situations, the capacity of refineries must be used more intensively, increasing the demand for (light) crude so as to meet light product demand. Not much light crude oil is available, however. Moreover, more heavy crude is needed to produce a similar amount of light products and, consequently, more crude production and more primary distillation capacity are needed. As the available crude production and refining capacity are drivers for crude prices, these prices will rise and become even more volatile.

Regarding local product markets, it was concluded that a discrepancy between the supply and the demand of products is increasing. This is due to a shift towards lighter products and shifts from gasoline to more diesel consumption. In the European situation, the refinery industry is slowly changing over from gasoline production to diesel production. The US and the Middle East are adapting to the discrepancy in Europe. The US imports gasoline from Europe to compensate for its own deficits, and the Middle East invests in HCC and diesel desulphurisation capacity to be able to export to Europe and Asia.

The refinery industry has so far not adapted to these regional shifts, but rather is internationalising its supply patterns, with increasing product transport as a result. Transporting products instead of crude has effects on security of supply that need to be assessed carefully. Tankers used for transportation of products are smaller than those used for crude; therefore, the number of ship movements will increase more than when crude is processed for the local market. Transportation bottlenecks will be used more heavily, increasing the likelihood of supply disruptions of crude as well as products. Blocking the bottlenecks could have serious consequences for the energy market. These bottlenecks are already struggling to cope with an increase in the transport of crude, liquefied natural gas and other product goods.

Overall, it can be concluded that the best way to cope with all of these problems is to *increase local conversion capacity*. Not many players in the industry are actually engaging in this way to a sufficient degree, so we should expect problems in the years to come (see also IEA 2007). It is not expected that new refineries will be built in Europe. Demand growth is small. The investment costs are high, due to environmental constraints and the complexity of spatial planning processes. Environmental regulation decreases the chance of obtaining permits, and the NIMBY effect is common.

It would seem more promising to increase the conversion capacity at existing refineries in the EU. This would have the advantages of: 1) increasing the flexibility of crude intake; 2) enhancing the conversion of residual fuel and the production of light products, allowing for the import of excess residual fuel from other regions; 3) reducing vulnerability to product import disruptions; and 4) enhancing the ability to process low quality swing crude during peak demand, reducing dependence on high quality exporting regions. The European Union should consider implementing a policy that reduces the impediments to investing in conversion capacity.

1

Introduction

1.1. The issues at stake

Developments in the oil industry are attracting a lot of attention. Generally, the two foci are on the downstream evolution of the demand for oil products and on the upstream conditions for making sufficient crude oil available to satisfy this demand at a 'reasonable' price. Current wisdom argues that demand is on the rise, particularly in the rapidly expanding economies of China and India, while crude production facilities are already operating at nearly maximum capacity. The oil industry is struggling to gain access to the world's promising oil provinces and invests heavily in exploration and production activities to make the required crude available. Of course, 'Peak Oil' believers stress the fact that the world is close to its maximum capability to produce crude oil. Others maintain faith that the market mechanism will provide for the exploration and production investment required, generating adequate technologies to find and produce the several types of petroleum resources. Many have doubts regarding the geopolitical aspects of the above, especially concerning the industry's access to potentially oil rich areas. In this context, prices for crude are high and volatile, reacting with increased sensitivity to whatever events disturb the current balance between supply and demand.

In this paper we examine an additional complication to the supply-demand outlook for the near future, namely the mid-stream perspective (including the refinery industry), crude and product transport and storage capacity. Commonly, the importance of these activities enters the analysis in terms of the local capacity to refine sufficient crude oil to satisfy rising demand in the various world regions. In addition, reference is sometimes also made to shifts in the composition of demand, from heavy products like fuel oil to lighter fuels like gasoline, diesel and kerosene, driven by economic development and the associated growth in the transport of goods and passengers.[1] The recent study by the IEA (2007) signalled the need for additional investments in the refining industry as a priority in meeting future energy demand.

We believe, however, that the consequences of the above situation are much more complex. This is a consequence of the interrelationships between the several segments of the petroleum value chain which, given the high throughput of the supply system, tend to become much more binding these days. As a consequence, qualitative aspects are becoming increasingly important. The past was characterised by considerable amounts of under-utilised capacity in crude production, refining and storage and distribution. The refining industry, as a joint production process, was thus able to refine the amounts of available crude necessary to supply the fuels demanded. This often happened at the 'cost' of having some excess production of residual fuel oils that were less wanted.[2]

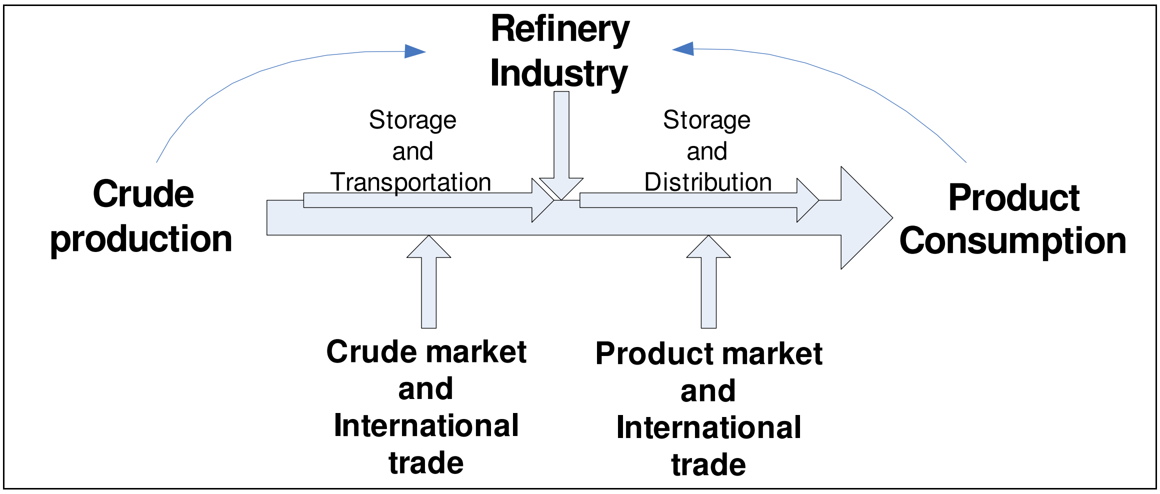
In this paper we take a more integral view of the petroleum value chain, connecting: a) expected developments in the supply of the several types of crude oil, in terms of quantity and quality; b) developments in the structure and size of the refining industry, indicating its ability to supply a particular product yield, given a certain crude intake; and c) the development of demand for the several types of products. In addition, we will employ a regional perspective, examining the balance between these three segments in the main producing and consuming areas. Figure 1.1 illustrates that

[1] Claude Mandil 2006

[2] If the per barrel costs of crude supply plus the variable costs of refining were covered by selling the lighter fuels produced at a higher price, the low revenues on selling residual heavy fuel oil below the crude price were simply accepted (Correljé 1994).

the refinery industry has a central position in the value chain. It supplies the products in demand and purchases the kind of crude oil required, according to the available facilities. Developments in and constraints on the crude supply and the product demand side have an impact on the refinery industry, which is stuck in the middle. At the same time, via the refinery industry, upstream problems are transferred to the downstream product market and vice versa.

Figure 1.1: Value chain of the petroleum industry



Crude oil is not a homogenous product. Many different qualities of crude exist, varying from light to heavy, low sulphur to high sulphur, with or without contaminants, etc. Crude oil is produced, stored and transported to refineries. Before the crude arrives at its destination it is possibly traded in the market. Trade is possible before the crude is produced, during storage at origin, and during transport. Finally, the crude oil is processed in refineries to produce a suitable mix of products for the product market. Many different refinery configurations exist, with different characteristics in terms of product output and required crude and other feedstock. The product mix demanded is determined by the petroleum products needed for transportation (gasoline, diesel and kerosene), heating and industrial purposes, electricity generation and maritime use (gasoil and fuel oil), feedstock for the petrochemical industry (naphthas) and road construction (asphalt and bitumen). Products are traded on (inter)national product markets to balance local commercial requirements, taking advantage of price differentials between markets caused by the relative scarcity of the various products.

Downstream, the worldwide product market is growing. Much of the growth is in the transport sector; consequently, the product mix demanded is becoming increasingly lighter.[3] Moreover, the regulation of transportation fuel quality in a growing number of countries is being tightened step by step.[4] Heavy fuel oil continues to lose ground in the static sector where natural gas is substituted, requiring an ever-growing investment in converting heavy ends of the barrel into light ends.[5]

Because of the changing product market, a number of issues are arising in the refinery industry.[6] First, the vulnerability to disruptions in crude or product supply becomes larger. This is due to the fact that growth in the product market enhances the rate of refinery throughput, which is around 90% in the OECD region, and this reduces the swing capacity for use in case of a peak in product demand or a supply disruption. Second, the lighter product market induces refineries to take measures to satisfy the product market demand. Third, the pressure of product quality regulations forces the refineries to produce suitable products in terms of lead and sulphur content, etc. It is important to realise that the choice by refineries to either invest in the conversion of heavy into light products, or to process lighter

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[3] IEA 2007, Mandil 2006, Stevens 2005

[4] EU 2002, European Parliament 2003, EPA 1999, Stevens 2005

[5] Stevens 2005

[6] Stevens 2005

qualities of crude, will affect the crude market. Moreover, investment in particular processing units will yield a particular product output, influencing the product market.

Five main strategies can be identified to help refiners and traders cope with the changes in the product market. The first strategy implies that refineries do nothing. They export or import finished or semi-finished products to balance the market. The feasibility of exporting or importing products depends on the state of the international product market. Wholesale prices of products at different locations are main determinants, with the transport of derivates and products causing additional costs. A growth in inter-regional product transport places extra pressure on densely used sea lanes, transport routes and ports, with obvious consequences for safety and security of supply.

A second strategy involves changing refineries' crude intake, as a short-term solution. The crude diet to refineries can be gradually changed without additional capital investments. This will also influence transportation costs, as crude will have to be imported from new origins, possibly further away. Though crucially important to producing suitable products in specific refineries, quality aspects of crude are not often taken into consideration. The world produces and trades more than 160 varieties of crude oil, varying widely in price, and there is a growing price difference between heavy and light qualities of crude, reflecting the scarcity of the latter.

Marker crudes, like Brent and West Texas Intermediate (WTI), set the price for the various types of oil, each with a different quality and availability. The pricing formulas incorporate quality differentials with the marker crude, yielding a premium or a discount. These include parameters such as the contents of sulphur, heavy metals and other contaminants, and the viscosity and specific weight of the oil. The availability and demand for different qualities of crude differs from place to place, so similar types of crude can have different local prices. The density and weight of the crude produced is increasing,[7] and a lot of the crude is produced in instable regions and countries.[8] While the price for Brent Blend averaged US$43.04 in August 2004, the price for Syrian Heavy was US$29.97.[9] Supply of crude is tight,[10] and it is argued that the quality of crude supplied does not accommodate the demand. As a consequence, the price of crude is volatile and small incidents have a disproportionate effect on crude prices.

The third, and short-term, strategy involves changing refineries' operating schemes. Different qualities of crude require different schemes for processing and treatment, as well as different operating schemes. These operating schemes can be changed by using different catalysts in different amounts, changing the pressure in the conversion processes, adding more or less hydrogen, changing the boiling points of products, etc.[11]

A fourth strategy and medium-term solution involves the revamping of refinery processes. Revamping a refinery's process may allow for changes in its crude intake and product yield.

Fifth, as a long-term solution, refiners can invest in new equipment. Investments in new equipment may alter the product output and allow changes to the crude quality consumed. Yet these investments are large, involving large amounts of sunk costs with a life cycle of about 30 years. Because of investment cycles and herd behaviour, the refining industry has often not been a profitable business. Future profits cannot be assured and are mutually interdependent, as changes in the output of one refinery have an effect on the profitability of the product yield of others. Also, refiners' shifts in the crude intake influence the overall crude demand and thus input prices. In addition, the product market is increasingly international; therefore, decisions made in other regions have an effect on local crude and product markets. Moreover, environmental regulation and NIMBY effects render investments

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[7] Mandil 2006

[8] Van der Linde, 2006

[9] Bacon 2004

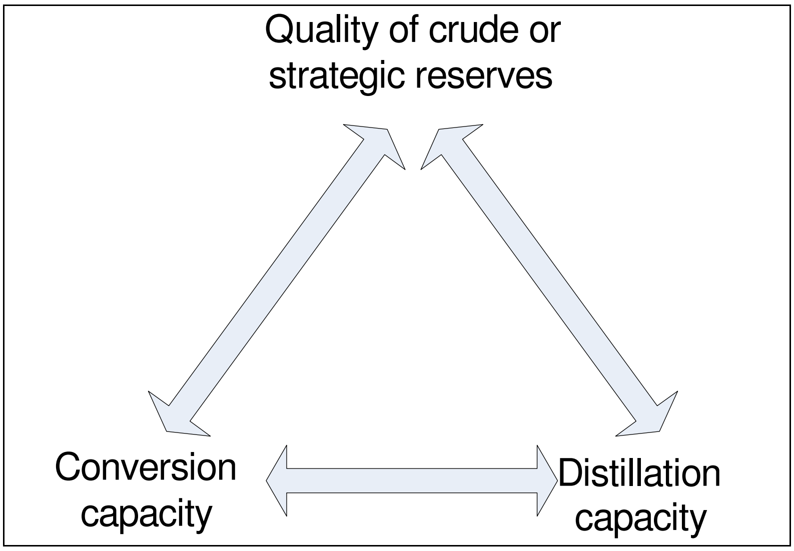
[10] Mandil 2006

[11] Because of the large number of parameters involved, refinery configurations and operating schemes are difficult to assess and are therefore not taken into account in detail in this paper.

difficult, with the obvious consequence that, generally, refiners are hesitant to invest in revamping projects and refinery expansion.

The above five options for changing product output can be summarised into three main actions, as is illustrated in Figure 1.2. All three options influence the operating scheme, with two of them involving investment. First, lighter crudes can be used in processing, which would produce less residual fuel oil and more light products. Second, the refiner might decide to invest in conversion capacity, either by revamping or by purchasing new equipment. As a result, with the same quality crude, less residual fuel is created and more light products are produced. And third, by adding distillation capacity, more crude oil can be processed, resulting in an overall increase of product output but reducing the relative yield of light products. Of course, a combination of these three basic options is possible. It follows that the decision about what option to use depends on the developments of the local and international product and crude oil markets and the economics derived from it.

Figure 1.2: Trade-off between the three basic options for the refinery industry



This paper addresses the effect of changes in the product market on the refinery industry and the crude market. It attempts to provide insight into the way in which refiners may cope with these changes and how this influences product availability, the demand for different types of crude in different regions and the need for transport. To this end, this paper will answer the following question:

How do changes in the product market, given the refinery capacity and its development, influence the demand for crude of different qualities, and how does this match with the quality of crude supplied now and in the future?

A model is constructed to get an indication of the amounts of different qualities of crude oil demanded, on the basis of the evolving product demand structure and the complexity of the refineries in the several main regions of the world. This model allows us to examine the effect of changes in the demand segment of the value chain both on the crude market and in the refinery industry.

1.2. The value chain

The value chain of the petroleum industry, presented in Figure 1.3, shows the main elements considered in this paper. It yields insight into the different relationships within and between the different segments of the value chain, distinguishing between the elements of the system and the associated explanatory indicators applied in the analysis.[12]

The first important element is the issue of crude oil supply. The 'refinery complexity' in part determines the types(s) of crude a refinery is capable of processing into an appropriate product mix according to the local quality criteria. The product market is conceived as the place where the 'product supply mix' and the 'product demand mix' meet, with a special emphasis on regional product balances and international trade. These latter elements are described below.

Crude is essentially nominated as heavy or light, referring to its API degree;[13] and sweet or sour, referring to its sulphur content.[14] For practical reasons, this paper will describe crude quality by these two dominant parameters. At the moment, the increasingly tight low sulphur requirements of transportation fuels are a major concern for the refining industry, requiring huge investments.[15] Other indicators, like the TAN[16] and heavy metal content, are not taken into account in order to avoid too much complexity in the analysis. The quality of the crude determines, via supply and demand relationships, the price of the different types of crude.

If crude prices rise, refiners are more likely to process less expensive crude, which is heavier and contains more sulphur.[17] Lower quality crude, however, is more difficult to process into high quality products, creating higher operating costs and the need for investments in treatment capacity. The primary process for converting high sulphuric crude in diesel fuel is high-pressure hydrotreatment; yet hydrotreatment units, both new and revamped, are expensive.[18]

Conversion facilities and treatment capacities, relative to the primary distillation capacity, determine the refinery complexity. The complexity of a refinery provides us with an indication as to what quality crude it is able to process. The refinery configuration is inflexible[19] due to lead times and the large sunk costs involved. Yet by changing feedstock and the operating scheme, marginal adaptations of the product output are possible. The complexity may be adjusted over the long run, in response to the changing product mix in demand and shifts in product quality requirements.

Given a specific refinery configuration, the operating scheme is adapted to the requirements of both the product market and the crude supply.[20] The operating scheme, together with the crude quality and the refinery configuration, determine what products are produced in which proportions and thus set the product mix in the supply. Light products are generally more valuable. Refiners with high conversion capabilities that are able to process heavy and high-sulphur crude generate the largest refinery margins.[21] Generally, operating schemes aim to use as much conversion capacity as possible to produce a high-yielding product mix, with the lowest-cost crude. At the same time, as is also argued by the IEA (2007), local prices for specific types of crude are influenced by the products yield of the most common refineries in the area. The operation costs are calculated by adding the costs of crude transport to the refining costs. However, this paper focuses on the trends in the quality and products demand mix, with actual operating costs being beyond the scope of this paper.

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[12] The diagram is inspired by the analysis of Bacon *et al* 1990.

[13] APIº describes the specific weight of crude (the higher the APIº the lighter the crude) and was created by the American Petroleum Institute. It is calculated by the following formula: APIº = 141.5/ specific gravity – 131.5.

[14] Stevens 2005, Leffler 2000, Speight 2001

[15] Nakamura 2004

[16] TAN = Total Acidity Number, the measure for acidity of crude

[17] Nakamura 2004

[18] Nakamura 2004

[19] Drevna, 2005

[20] Drevna 2005

[21] Nakamura 2004, Tippee 2005

As stated, the required product quality is influenced by emission legislation and fuels regulation. Motor fuel efficiency is of importance in reducing emissions;[22] the octane number for gasoline and cetane number for diesel are indicators for fuel efficiency in motors. Oxygenates, such as MTBE, enhance the octane number and reduce CO_2 emissions.[23] Still, US legislation is expected to ban MTBE, reducing the production capacity of gasoline[24]. Environmental legislation is focused more on sulphur content and less on oxygenates content[25]. Sulphur is an important contaminant in crude oil and partly determines the value of crude consumed. While the regulation on sulphur content is taken into consideration, the focus of this paper will be on weight in terms of the API degree. Nevertheless, generally, lighter crudes contain less sulphur.

As stated, product quality and the product demand mix require a certain refinery complexity. A demand for lighter product requires a lighter product supply and therefore is more complex for the refinery industry or requires a lighter crude diet. Since the refinery configuration is inflexible, the operating scheme and crude diet are the factors that must change to meet the change in demand. The difference between supply and demand determines the product price, while demand is influenced by the product price and the price elasticity of the specific mode of use of the fuels.

The sum of the revenues of selling the several products in a market, minus the crude acquisition, the refining costs and crude freight, yields the overall netback of refining given qualities of crude in a particular refinery.[26] If the netback is higher than the crude price (fob), a profit is made. The difference between the netback and the crude price is called the margin. Therefore, the expected netback is crucial in the choice of the crude oil to be processed.

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[22] EPA 1999

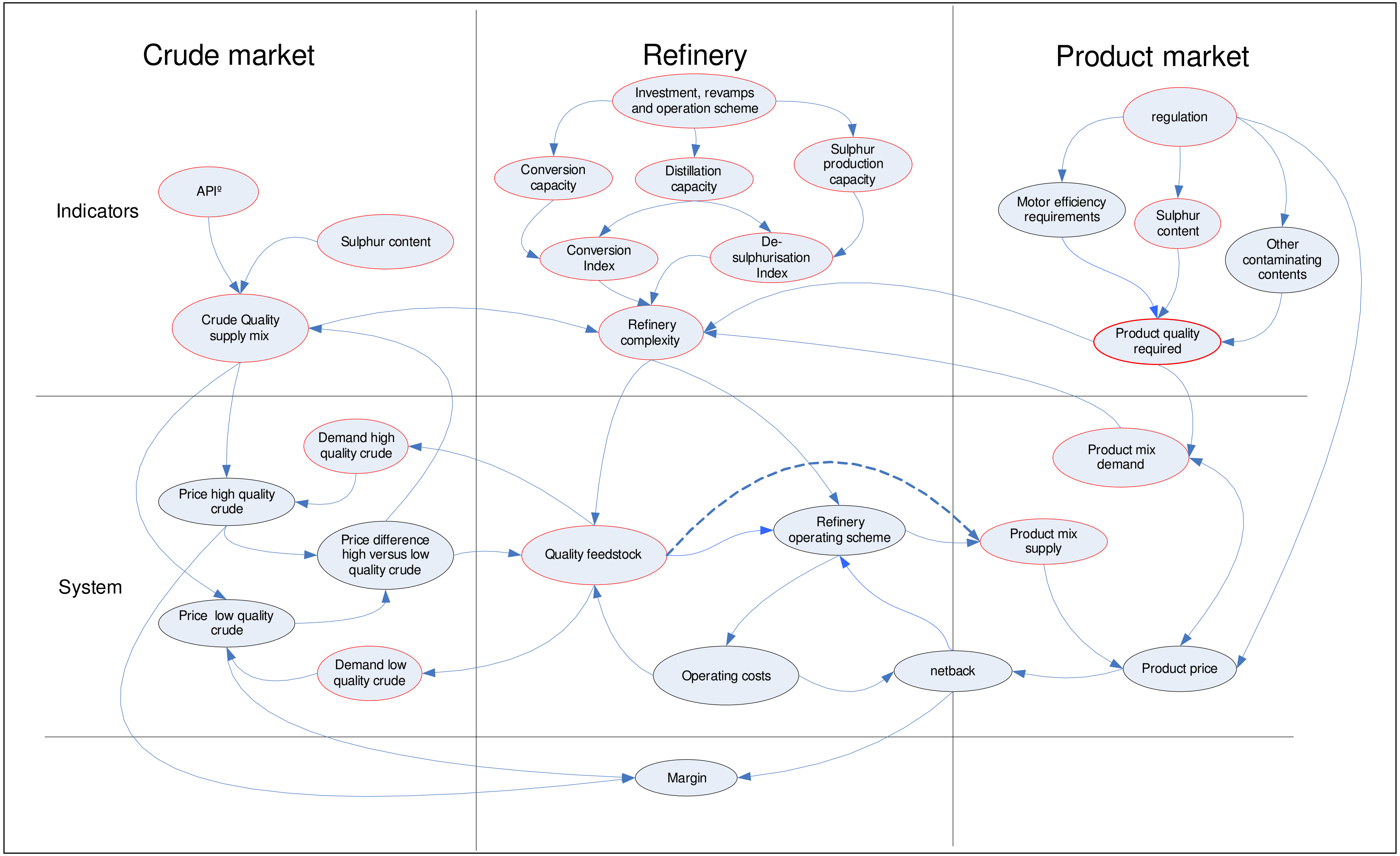
[23] Leffler 2000: 193

[24] MTBE enhances the octane number of gasoline and reduces exhaust fumes, but it contaminates drinking water (Bellamy e.a. 2003).

[25] EPA 1999: European Parliament 2003/17/EC

[26] Favennec 2001: 582

Figure 1.3: Relationships in the petroleum industry: The crude market, refinery and product market

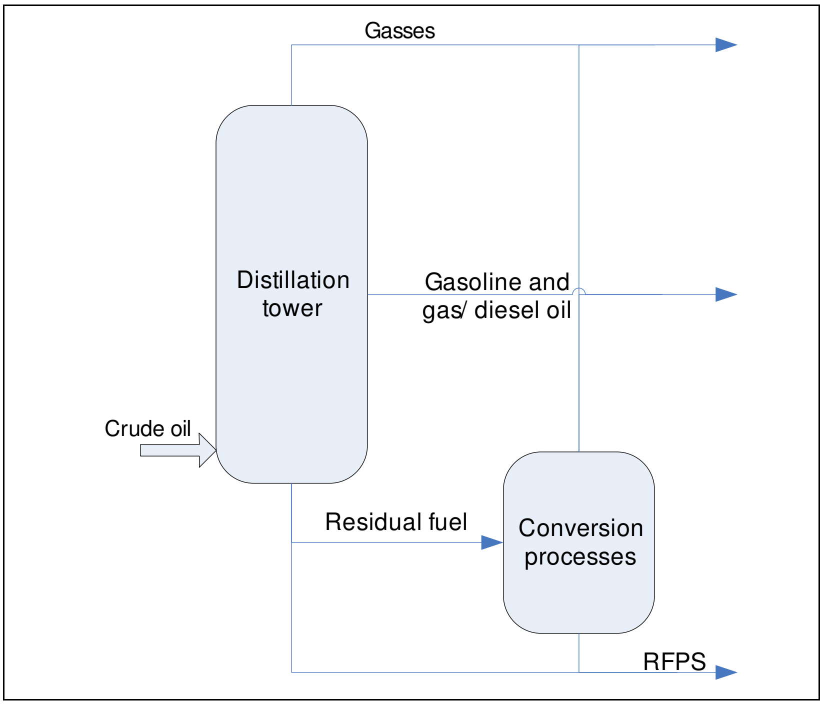


1.3. Assessing patterns of crude demand

In the literature, little analysis is undertaken of the quality of crude consumed in different countries and regions or in individual refineries. Only the US publishes the qualities of the crude it consumes on a regular basis. In this paper a model has been developed to assess the quality of crude consumed in the other regions. With this model, an insight into the qualities demanded is given. In addition, the quality of the crude consumed can be compared with the quality of the crude supplied by the several producers.

The conversion ratio[27] is an indicator of the ability of a refinery to produce light products and reduce residual fuel output (see Figure 1.3). It is assumed that the conversion processes are used to full capacity, converting the crude and the residual fuel into valuable light products as much as possible. The amount of residual fuel the refineries decide to produce while seeking to generate an optimum margin depends on the regional and international product market, the price of the products, the capabilities of the refinery and the availability of crude. Lower quality crude will produce more residual fuel in simple distillation. The conversion ratio determines the amount of residual fuel that can be further converted into light products in 'deeper' processes and therefore the amount of final residue. As stated, we assume that conversion capacity is used in full to yield a maximum volume of light valuable products. So a refiner with a certain conversion ratio looks for an optimal quality of crude. Processing higher quality crude than optimal reduces the amount of residual fuel produced, causing underperformance of the conversion capacity, unless fuel oil is purchased on the market at an acceptable price.

Figure 1.3: Simplification of a refinery plant



Thus, the situation of a refiner can be described by 3 indicators: one indicator for the residual fuel production share in the product market, one for the conversion ratio of the refining industry and one indicating the weight of the crude (API°). The model is based on the following two crucial assumptions:

- The lower the API°, the higher the residual fuel production share (RFPS); and

[27] Conversion ratio = $^{\Sigma\text{(FCC equivalent*conversion capacity)}} / _{\text{(distilling capacity)}}$; see Speight 2001 and ENI 2005 and 2006.

- The higher the conversion ratio, the lower the RFPS.

The average conversion ratio by country, as provided by ENI,[28] is based on distillation capacity. Because this capacity is not used in full and the conversion units need residual fuel, refiners can decide to process heavier low-priced crude in order to produce enough residual fuel to feed the conversion processes. Therefore, the conversion ratio equation is adapted, using the actual crude runs, which give a better indication of the maximum quality of crude a refiner can process in reality.

1.4. Assessed regions

Limited access to information determined the way in which the regions to be examined were selected. The IEA provides a great variety of information on the OECD countries. ENI provides the refinery complexity information divided into countries and regions; however, IEA information has more details about countries. It was therefore easier to adapt the IEA data to those of ENI. These two sources of information are combined carefully here, creating the following regions:

Table 1.1: Regions used to analyse the product and crude streams and crude quality

Consuming regions	Producing regions
North America (US and Canada)	Middle East
Western Europe (EU-15 plus Norway, Switzerland and Turkey)	West Africa
	North Africa
OECD Pacific (Japan, South Korea, Australia and New Zealand)	Latin America (including Mexico)
	FSU (Central Asia, Eastern Europe and Russia)
	North Sea (UK, Norway and Denmark)
	North America (US and Canada)
	Asia Pacific

1.5. Outline

In Chapter 2, the product market is described. Trend analysis, focusing on imbalances between supply and demand and on the quality of the products, is the main research method. The trends found are extrapolated through 2012 to assess changes and to estimate the Residual Fuel Production Share (RFPS), which is used in the model. In addition, quality regulation of fuels is of importance. Regulation influences the investment decisions of the refinery industry, which needs to treat the products to meet product requirements. Through this analysis, more insight into international trade and the trends of product demand and supply is attained, which may have an influence in the development of the refinery industry in different regions.

Chapter 3 assesses the refining industry. The configuration of the refinery sector in the different regions is described in terms of the typical refinery configurations. The configurations indicate the ability of the refinery industry to produce certain products; for example, gasoline and diesel. Future investments are examined to gain insight into the development of the industry and the future product supply capacity. In addition, these investments shed light on the development of the refinery complexity and the ability to treat products. The complexity is used to estimate the future crude quality demand by the model.

[28] ENI 2005, 2006

Chapter 4 describes the crude market from a qualitative perspective. The average quality of crude supply is calculated on the basis of the APIº, and production is extrapolated through 2012. As a result, an estimate of the world crude oil quality supplied in 2012 is given. In addition, the demand for crude by Western Europe, North America and OECD Pacific is calculated by using the import data and the average quality of the imported crude. These averages will be used to construct a model and to estimate the demand for crude quality in the other regions.

Chapter 5 presents a model to predict the quality of crude on the basis of APIº, and conversion ratios and RFPS are described. An equation is given which is able to calculate the average quality of crude consumption of the world and crude demand in the future. Subsequently, on the basis of the model described, an estimate is developed of the quality of crude demanded now and in 2012. The insights from the use of the model are evaluated in the concluding Chapter 7. General conclusions are drawn, and the effects of these conclusions are assessed for the European situation.

2

Product markets

Energy demand is associated with the activities of different segments of users: domestic users, the transport sector, power generation companies and the industry sector.[29] Domestic users consume gasoil and kerosene for heating and cooking purposes; the transport sector consumes LPG, gasoline, kerosene, gas or diesel oil and fuel oil; the power industry uses gas oil and fuel oil; and the industry sector naphtha, gasoil and fuel oil. The relative size of these groups of users influences the consumption of different products, and therefore the product mix demanded.[30] Changes in the relative size of these groups change the patterns of demand and adjustments in product supply. As stated, due to the large sunk costs of refineries, the refinery configurations are relatively fixed and have but a small margin for adapting the product output. Refineries can only adjust the output by using a different crude quality and by altering the refinery processes. This chapter will empirically examine the evolution of demand in the main regions, to clarify the need for adjustment in the refinery sector.

First, the major trends in the product market are described, followed by a description of the development of the product markets in different world regions. This chapter concludes by stating that the product market is getting lighter and that not all refineries can cope with this shift in product demand. To compensate for deficits and surpluses, refineries engage in international trade of petroleum products.

2.1. Changes in the demand for fuels

Recently, there have been significant shifts in the pattern of product demand in the several regions. Natural gas has been introduced into the domestic and industrial sectors, so that it now substitutes fuel oil. In addition, the policy in Europe to stimulate the consumption of diesel has created a shift from gasoline to diesel as the most important fuel in the transportation sector. This pressures the refineries to adapt their refinery processes and configuration.

Economic growth in Asia and South America has changed the relative size of energy consumption in the main market segments. The industrial sector is turning to electricity, and the transport sector is growing rapidly. The industrial sector can diversify its energy portfolio by using coal or natural gas instead of gas oil or fuel oil. Moreover, the consumption of electricity is growing rapidly. Yet expansion of electricity generation is facilitated in some countries by installing small-scale electricity production plants, using gasoil as fuel. The transportation sector is completely dependent on oil products. So the demand for gasoline and diesel is rising rapidly, relative to that of fuel oil. The share of fuel oil is therefore declining in the product balance.

A second important trend is the implementation of increasingly stringent regulations on transportation fuels in order to reduce polluting emissions. Many countries set limits on the octane and cetane number of fuels, to oxygenates or MTBE and the content of lead and other substances. Now that OECD countries have abandoned lead in their gasoline, developing countries are now also regulating lead content. The OECD and even some developing countries are phasing out sulphur in transportation fuels.

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[29] Manners 1967; Schipper et al 1992.

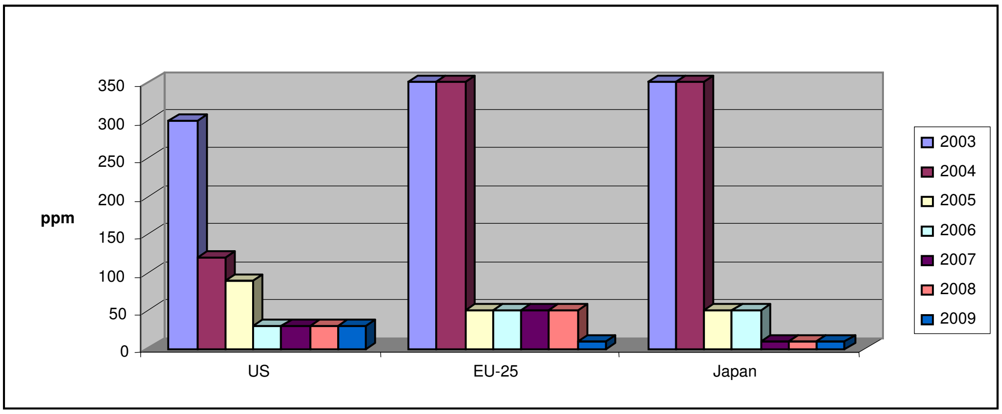
[30] See Leffler 2000, Favannec 2001, Speight 2001, Reinaud 2005, IEA 2006.

Sulphur is not only a pollutant itself; it also reduces the effectiveness and the life span of the catalyst systems in tail pipes[31] which reduce hazardous exhausts. Therefore, reducing sulphur in transportation fuels is seen as an effective policy for achieving environmental goals. Figures 2.1 and 2.2 below show the different sulphur content specifications in different regions and countries.

South Korea, Taiwan, Hong Kong, Australia and New Zealand have or will have regulation similar to that of the EU; most of these countries will start the introduction around 2010. Africa has no regulation on sulphur; Latin America has regulation, but not very stringent, with the exception of Argentina, Chile and Mexico and, to a lesser extent, Brazil.

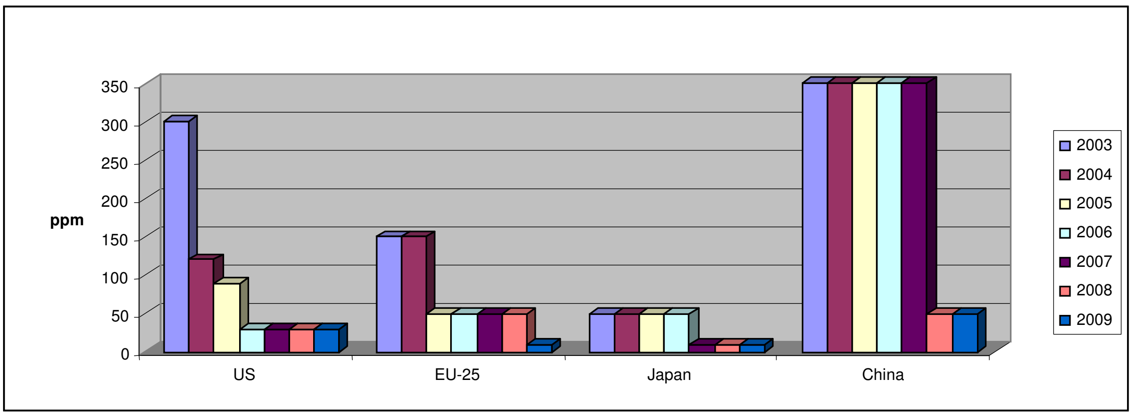
These regulations affect the configuration of refineries. Investments in refineries are needed to desulphurise and treat products to meet product specifications. Hydrotreating is the most commonly used process for removing sulphur from diesel and the heavy ends of gasoline, since sulphur is mostly found in the heavy fractions. This process reduces the octane number and is therefore less suitable for treatment of gasoline. Mild treatment, with a caustic treater, can be used to desulphurise the lighter components of gasoline.

Figure 2.1: Sulphur specification of diesel in the US, EU-25 and Japan



Source: EPA 1999, European Parliament 2003/17/EC, Liisa Kiuru 2002

Figure 2.2: Regulation on sulphur content in gasoline



Source: IEA 2005

[31] European Parliament 2003/17/EC, EPA 1999.

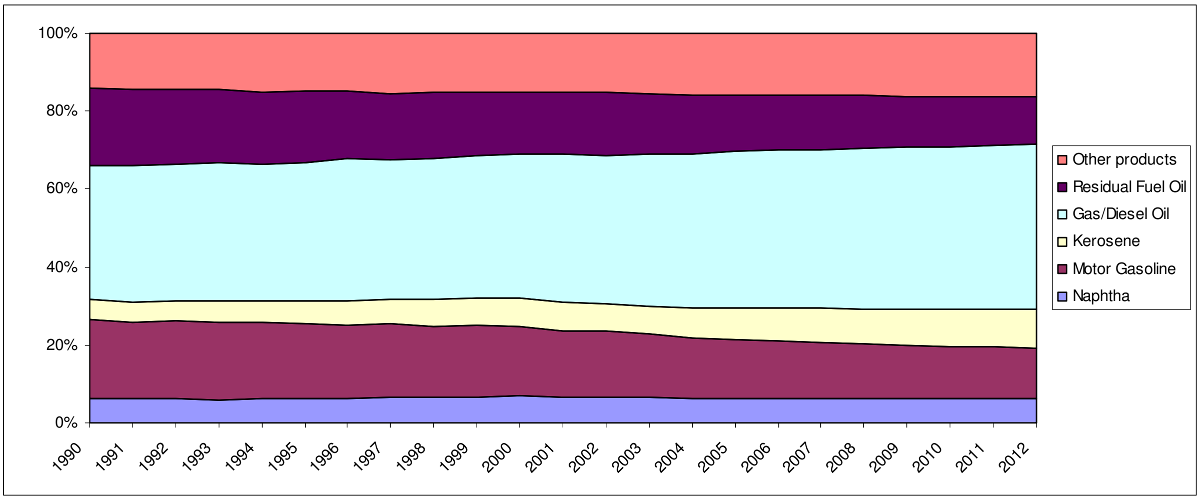
Products produced from low-sulphur crude require less desulphurisation. The heavy products are more contaminated and complex than the light ends, particularly if they contain more sulphur and other contaminants. Generally, processing lower-sulphur crude often means processing lighter crude.

2.2. Demand for fuels extrapolated through 2012 and product balances

2.2.1. Western Europe

In Western Europe, the share of gasoline in oil products consumption has been declining since the beginning of the 1990s, whereas the use of diesel is growing. To reduce overall oil consumption, Europe promotes the use of diesel in transportation, as diesel is generally more efficient than gasoline. This development is expected to continue. The share of gas oil and diesel oil will be 43% and gasoline 13% in 2012, as compared to respectively 40% and 15% in 2005. The demand share of residual fuel is declining slowly, from 16% in 2005 to an estimated 15% in 2012. Figure 2.3 below shows the development of the product market from 1960 to 2012 in Europe.

Figure 2.3: Western European product consumption mix, extrapolated from 2005 through 2012

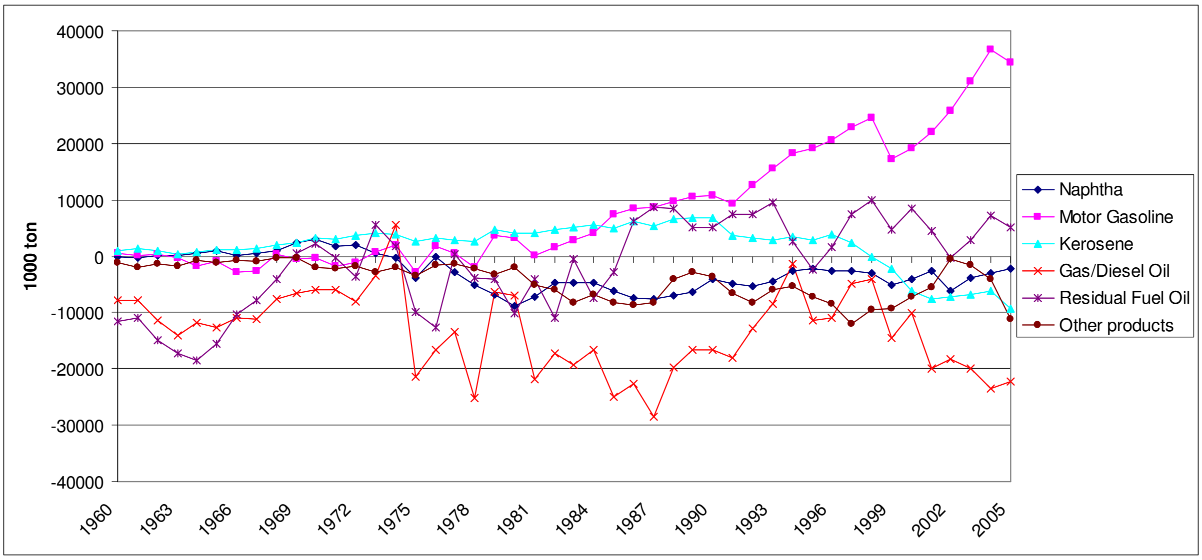


Source: IEA 2006

Figure 2.4 shows that there is an imbalance between production and demand in Europe due to the slow shift from gasoline to diesel as the main transportation fuel. The share of diesel-fuelled passenger cars now is about 30%, which will gradually grow to 45% by 2011.[32] The result is a surplus production of gasoline and deficit of gas/diesel oil. The figure below illustrates this effect; most products are quite balanced except for diesel and gasoline. There has been a surplus of residual fuel since the first half of the 1980s.

Figure 2.4: Western European product balance, 1960-2005

[32] Mandil 2006

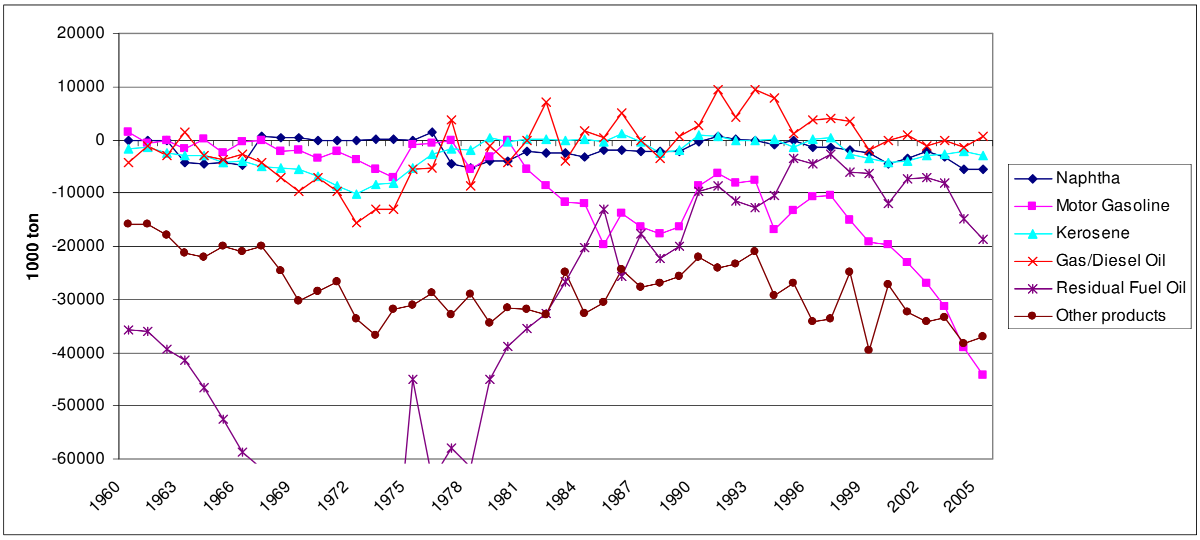


Source: IEA 2006

2.2.2. North America

There have been no dramatic shifts in product demand in North America. The share of demand for residual fuel oil has actually increased since 2003; however, extrapolating the trend from 1990 onward, this share will decrease from 6% in 2005 to 5% in 2012. Gasoline is by far the most important product; it takes a share of 41% of total product consumption in both 2005 and 2012. The growth of gasoline demand is a problem in this region. Refineries are not able or, so far, have chosen not to follow this demand growth. In addition, regulation on gasoline, creating many 'boutique fuels',[33] pressures the production capacity of gasoline, enlarging the problem. Figure 2.5 shows a growing deficit of gasoline. The 'other products' deficit is mostly due to a shortage in LPG and ethane, which are both very light products.

Figure 2.5: North American product balance, 1960-2005



Source: IEA 2006

2.2.3. OECD Pacific

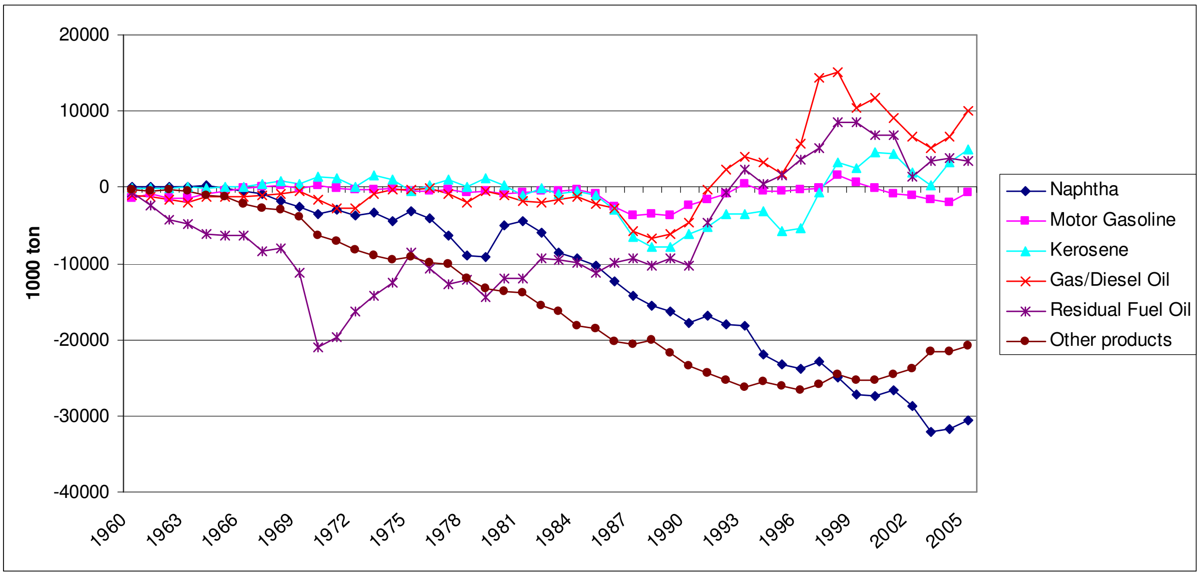
In the OECD Pacific product market, no real dominant product can be found. Gas/diesel oil takes the largest share of demand (23% in 2004), gasoline takes 17%. Most growth in demand is in naphtha, but

---

[33] The US has many different qualities of gasoline; regulation is adapted to the needs of the states which have different problems in pollution. These gasolines are called boutique fuels.

its share of total product demand hasn't changed much. The only proportion changing dramatically is the consumption share of residual fuel, which is expected to fall from 15% in 2003 to 12% in 2012. This may have an impact on the quality of crude demanded, depending on investments in the refinery industry.

Figure 2.6: OECD Pacific product balance, 1960-2005

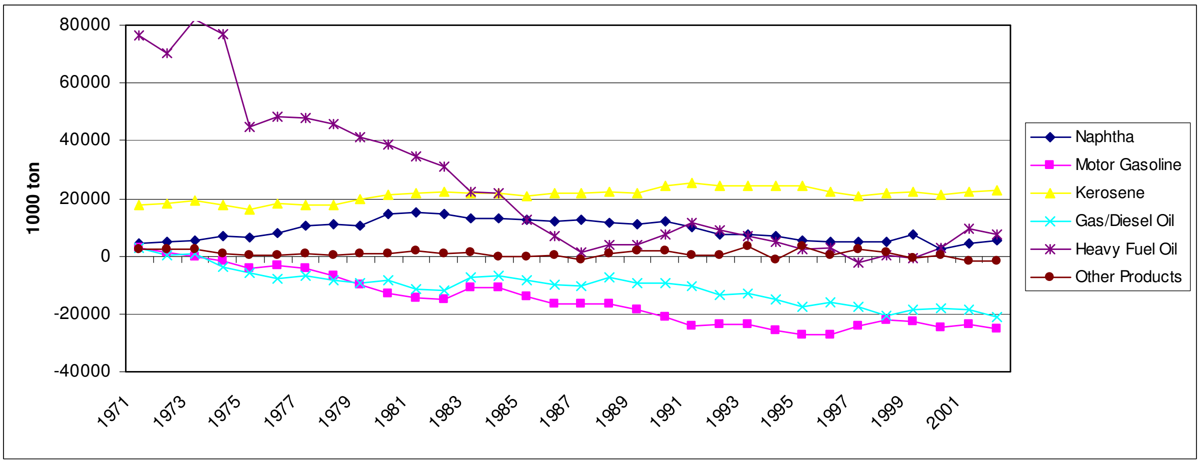


Source: IEA 2006

2.2.4. The rest of the world

Latin America's residual fuel consumption share will drop from 18% in 2003 to 15% in 2012. This region is experiencing a shift from gasoline to diesel that started in the late 1990s. Still, the deficits of these products are growing. Latin America is a net exporter of residual fuel; a small surplus is produced.

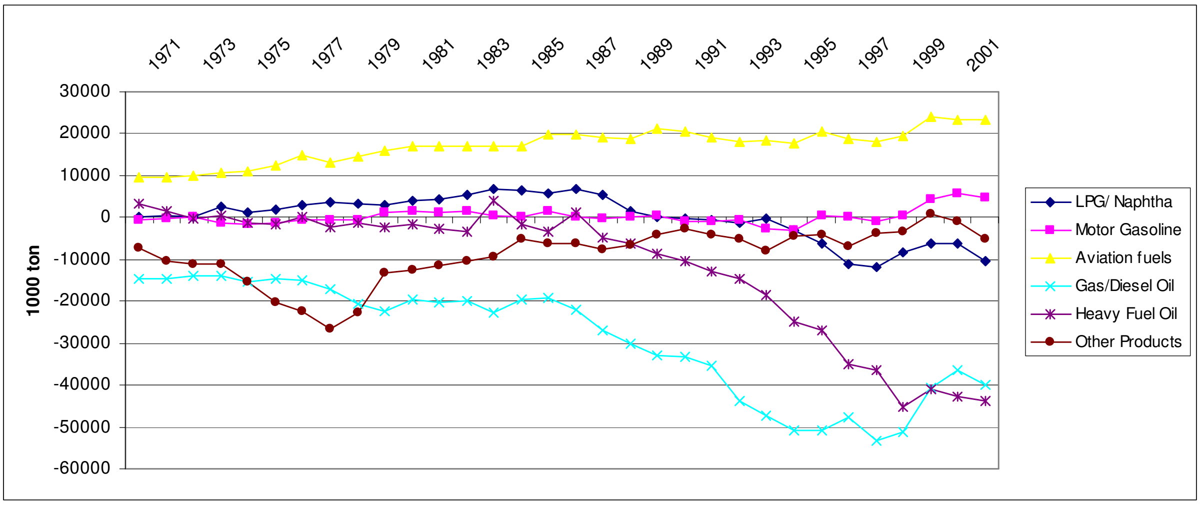
Figure 2.7: Latin American product balance, 1971-2002



Source: IEA 2004

Asia is the most important growth market for petroleum products. China and India have booming economies, and demand there for transportation fuels is exploding. The most important product is gas/diesel oil. Naphtha and LPG are the most important growth products. They are taking an increasing share of the total product consumption. Residual fuel demand share will decrease from 20% in 2003 to 15% in 2012. Overall, Asia is a net importer of residual fuel and gas/diesel oil: 40 million tons of each is imported per year. The deficit of gas/diesel oil decreased somewhat at the end of the 1990s.

Figure 2.8: Asian product balance, 1971-2002



Source: IEA 2004

Africa is only a small consumer of products. The residual demand share will decrease from 18% in 2003 to 15% in 2012. Gas/diesel oil takes the biggest share of demand. The product demand trend in the FSU (Former Soviet Union) and non-OECD Europe is difficult to assess due to a major consumption drop after 1990. Still, a major downward trend of residual fuel oil consumption can be noticed; according to the trend the consumption share will drop from 20% in 2003 to 15% in 2012. Overall, the FSU produces a large surplus of gas/diesel oil (± 80 million tons) and residual fuel. The residual fuel surplus is destined to grow even further.

2.3. Specification of the Residual Fuel Production Share

The Residual Fuel Production Share (RFPS) of the regions is calculated by dividing the total residual fuel production in tons by the total refinery output in tons. To calculate this value for 2012, the trend since 1990 is extrapolated for two parameters: the total refinery output and the residual fuel production. The developed regions are assessed in more country detail in Table 2.1, because these values are used as input in the model in Chapter 5. The general world regions (Latin America, Asia, Africa, etc.) are assessed more roughly in Table 2.2.

The following RFPS are used for the creation of an equation in Chapter 5:

Table 2.1: RFPS of North America, Western Europe and the OECD Pacific

	1993	1994	1995	1996	1997	1998	2000	2001	2002	2004	2005
EU-15	19.4%	17.8%	17.5%	17.2%	17.2%	17.6%	16.8%	16.4%	15.9%	16.0%	15.9%
Western Europe	19.9%	18.3%	18.1%	17.8%	17.7%	18.0%	17.2%	16.9%	16.3%	16.5%	15.9%
Belgium	21.1%	16.9%	17.0%	19.5%	20.3%	21.2%	21.0%	17.6%	16.5%	19.4%	21.7%
France	15.4%	13.3%	13.0%	12.3%	12.1%	13.0%	12.5%	12.5%	12.6%	13.4%	13.6%
Germany	12.3%	11.7%	11.9%	11.6%	11.0%	11.6%	11.3%	11.5%	10.7%	11.7%	10.8%
Italy	23.9%	22.8%	21.4%	20.6%	20.2%	20.5%	20.5%	20.1%	17.9%	17.9%	18.5%

Netherlands	20.3%	16.9%	16.4%	16.7%	16.7%	18.1%	13.9%	13.2%	16.1%	15.7%	14.6%
Spain	27.1%	25.6%	24.7%	23.3%	24.0%	24.4%	21.9%	20.4%	20.9%	15.3%	15.0%
Turkey	36.3%	34.7%	34.7%	34.1%	33.2%	30.0%	33.8%	33.3%	30.6%	30.2%	28.2%
UK	16.2%	14.9%	14.3%	14.3%	14.5%	14.4%	13.5%	14.5%	12.6%	14.5%	13.8%
North America	7.0%	6.8%	6.2%	5.8%	5.6%	5.9%	5.4%	5.5%	4.7%	5.0%	4.8%
US	6.8%	6.7%	6.1%	5.6%	5.3%	5.6%	5.2%	5.3%	4.4%	4.6%	4.4%
Canada	8.2%	7.5%	7.1%	7.3%	7.6%	8.0%	7.0%	7.6%	6.9%	8.3%	8.1%
Pacific	24.3%	24.5%	23.5%	21.9%	21.1%	20.0%	20.2%	19.6%	18.7%	17.9%	18.8%
Japan	21.5%	22.1%	20.6%	19.2%	19.3%	18.8%	17.3%	15.5%	16.3%	15.6%	15.5%
Korea	39.1%	38.7%	36.6%	33.3%	29.0%	27.3%	27.8%	28.0%	25.0%	25.7%	25.8%
Australia	7.7%	6.7%	7.1%	5.7%	4.9%	4.3%	4.8%	5.3%	4.8%	3.1%	2.9%

Source: IEA 2006

The table below presents the RFPS values of the world's regions. To be able to estimate the world consumption of crude in terms of quality, the two parameters – respectively, the conversion ratio and the residual fuel production share – need to be known for the other regions: Latin America, other Asia, FSU, Central Europe, the Middle East and Africa. These regions were chosen on the basis of the data available on the conversion ratio as well as available coverage of the world, together with specific coverage of Western Europe, North America and the OECD Pacific. The values are used to assess the quality of crude demanded in the world by using the model of Chapter 5. The IEA has reports of the production of petroleum products of non-OECD countries through 2002. Therefore, the 2004, 2005 and 2012 are estimates of the RFPS for non-OECD regions. The 2005 and 2012 values of North America, Western Europe and the OECD Pacific are estimates as well.

Table 2.2: RFPS of the world regions, extrapolated through 2012

	1993	1994	1995	1996	1997	1998	2000	2001	2002	2004	2005	2012
Western Europe	18.7%	18.3%	18.4%	17.6%	16.9%	17.0%	16.3%	16.0%	16.0%	16.0%	15.7%	13.3%
North America	7.0%	6.8%	6.2%	5.8%	5.6%	5.9%	5.5%	5.4%	5.5%	4.7%	5.1%	4.1%
OECD Pacific	24.0%	24.3%	23.3%	21.7%	20.9%	19.8%	20.0%	19.4%	18.5%	17.8%	18.6%	15.7%
Asia	28.3%	26.8%	25.4%	23.3%	22.1%	21.5%	19.1%	17.7%	16.5%	15.8%	14.9%	9.9%
Latin America	27.0%	26.8%	25.0%	25.1%	23.6%	24.2%	23.1%	24.7%	25.3%	24.4%	24.1%	21.7%
Africa	30.6%	31.0%	30.1%	30.0%	29.8%	29.8%	31.0%	29.8%	28.0%	28.2%	28.0%	26.5%
Middle East	33.9%	31.7%	32.4%	33.0%	32.8%	32.6%	32.1%	31.7%	31.1%	31.0%	30.7%	28.4%
Central	32.4%	30.2%	29.3%	29.2%	29.4%	28.9%	30.2%	28.9%	28.7%	29.2%	28.8%	26.0%

Europe												
FSU	38.2%	37.8%	37.5%	37.5%	36.5%	35.6%	34.1%	31.5%	31.3%	32.1%	31.5%	27.6%
World	21.9%	21.0%	20.4%	19.7%	19.2%	19.0%	18.4%	17.8%	17.5%	17.0%	16.5%	13.7%

Source: IEA 2004 and 2006

The production of residual fuel may not decrease as expected here; the extrapolations in these tables only follow the trend. No extra analyses have been performed on this matter. Additional analysis on the outlook for consumption of products in these regions could lead to more precise results.

2.4. Product streams

Europe's major import product is gas/diesel oil. Most gas/diesel is imported from the FSU, which produces a large surplus of gas/diesel oil. The Middle East is the second important origin of gas/diesel oil. Diesel from FSU needs to be treated in Europe to meet the EU sulphur standards, due to lack of desulphurisation and treatment facilities in the FSU.

Europe exports most of its surplus gasoline and residual fuel to North America. North America has a deficit of gasoline. Most of this deficit is filled by gasoline from Europe, followed by that from Latin America. Latin America is the US's primary source of residual fuel oil, though it imports light products from Africa as well. The main North American export product is coke, which is exported to the whole world. Latin America is the largest importer of North American products, followed by Europe.

The OECD Pacific requires vast amounts of naphtha, which is imported from the Middle East and Asia. The region's major export products are gas/diesel oil and residual fuel oil, all of it destined for Asia, as Asia has both a deficit of residual fuel (or heavy fuel oil) and gas/diesel oil.

2.5. Conclusion

Focusing on the major consuming regions, OECD Pacific, North America, Europe, Asia and Latin America, a trend towards the use of lighter products is evident. In all 5 regions, the share of residual fuel consumption is declining. In developed countries, consumption is shifting from heavy products to transportation fuels such as gasoline and diesel. In addition to growth in transportation fuels, Asia is experiencing major growth in the consumption of naphtha, which is used in the petrochemical industry. The growth in product demand worldwide is that of transportation fuels; demand of residual fuel and other products has remained approximately the same in absolute numbers, except in the developed regions.

The OECD Pacific might encounter problems in trying to balance its product market through trade with Asia. Asia is both the main importer of residual fuel oil from the OECD Pacific and the main source of naphtha for that region. Knowing that naphtha demand in Asia is growing fast and the residual fuel demand share is lagging in both regions, the OECD Pacific will lose a residual fuel oil outlet as well as a source of naphtha. The OECD Pacific will have to take these developments into account with their investment plans in the refinery sector.

Demand in Europe and Latin America is shifting from gasoline to gas/diesel oil. In the OECD Pacific, North America and Asia, the product demand mix is fairly consistent, except for the decline in the share of residual fuel. In Asia this is due to the faster growth of transportation fuels.

Europe's refinery configuration does not fit its fuel demand. Most of the products produced have either a deficit or a surplus. Europe is able to export gasoline to North America and import diesel from the FSU. Sulphur content regulation requires that diesel from the FSU or other regions undergo treatment or high-sulphur blending.

North America imports gasoline and so far has postponed investment in gasoline production processes. Since the late nineties the deficit has been growing in parallel to the emerging gasoline surplus of Europe. The residual fuel production is balanced, although demand is declining. Supply is also declining, apparently a consequence of the enhanced use of conversion processes, though these are not yet of a high enough quality as to be able to produce gasoline.

The result of the above trends is an expected increase in international product streams: from Europe to North America, from the Middle East to Asia, from the FSU to Europe, and from North America to the rest of the world (coke).

3

The refinery industry: configurations and investment

The configurations of refineries vary widely. The types and size of equipment, the way this equipment is tuned, the operating and processing schemes, together with crude intake, influence the possible yield of products. This implies that, given a certain refinery configuration, the product supply capacity of this refinery varies according to the types of crude or feedstock processed and the processing schemes selected by the refinery management.[34] Due to longer-term changes in markets, the configuration of the refinery industry may no longer correspond with the demand structure. To cope with these changes, different strategies can be followed: first, exporting or importing finished or semi-finished products to balance the market; second, changing the crude intake; third, changing the operating schemes; fourth, revamping the refinery processes as a more thorough solution; or, fifth, investing in new equipment to match the 'new' product demand. Investment costs are high and come with great insecurity regarding return on investments. This chapter will describe the current state of the refinery industry and its expected development in the different world regions, starting with an overview of the most common refinery configurations.

3.1. Configuration of Refineries

There are several types of refineries, each distinguishable on the basis of the possible yields of their different units, as is shown by, among others, Wijetilleke et al (1984), Bacon et al (1990), Leffler (2000), Favennec (2001) and Reinaud (2005). The basis of any refinery is the crude distillation unit (see Fig. 1.2), in which a number of fractions are distilled from the crude oil. These fractions have to be treated further to produce usable fuels. Moreover, to enhance the production of lighter fuels, the heavy fractions can be reprocessed.

The Fluid Catalytic Cracker (FCC) is seen as a basic conversion process; it is applied almost everywhere and is used as benchmark process for the conversion ratio. As it produces high-quality gasoline and low-quality diesel, it follows that this process is mostly used to produce gasoline.

The Hydro Catalytic Cracker (HCC) is a somewhat more expensive, complex and flexible conversion process. It is used to produce high quality diesel, while the gasoline produced through HCC is of low quality. It yields more light products than FCC units do. Therefore, a smaller number of HCC units is needed to produce the same amount of diesel, as compared to the gasoline production of FCC refineries.[35] This should be kept in mind when looking at the tallies performed below.

Generally, thermal crackers are mild conversion units. Yet cokers are able to further reduce the residual fuel output to zero; producing additional volumes of coke, fuel oil, middle distillates like gasoil and diesel oils, and gasoline. This process belongs to the category of 'deep conversion units'. Other examples are the highly complex Residual Fluid Catalytic Cracker (RFCC) and the Residual Hydro Catalytic Cracker (RHCC). These two processes radically reduce residual fuel output and produce high quality products.

On the basis of the presence of these processing units, the following types of refineries are distinguished:[36]

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[34] Correlje 1994: 181

[35] Wijetilleke e.a. 1984

[36] Reinaud 2005, Leffler 2000, Favennec 2001, Bacon 1990: 163-164.

1. Simple refineries, including primary crude distillation and treatment facilities; e.g. catalytic reformers, hydrotreaters and sometimes hydrodesulphurisation plants;
2. Semi-complex refineries, including a simple refinery plus thermal processing units, examples being vacuum distillation, a thermal cracker, a visbreaker or a deasphalter;
3. Complex refineries, including a semi-complex refinery, plus a) Fluid Catalytic Cracker (FCC), b) Hydro Catalytic Cracker (HCC) or c) FCC and HCC; and
4. Very complex refineries, involving deep conversion, like residual FCC/HCC and cokers for minimising the residue, plus a) Fluid Catalytic Cracker (FCC), b) Hydro Catalytic Cracker (HCC) or c) FCC and HCC.

According to this classification, the refinery configuration in the different regions is assessed. Gasoline- and diesel-oriented refinery configurations are distinguished and matched with the product market.

3.2. World refinery configuration

The configuration of the refinery industry in various world regions is assessed in Table 3.1 by counting the typical configurations described in the previous paragraph.

Table 3.1: Regional refinery configurations

Regions	refinery type								
Number			Complex			Very complex			
	Simple	Semi complex	FCC	HCC	FCC & HCC		FCC	HCC	FCC & HCC
Western Europe	7	26	33	10	12	1	4	2	4
OECD Pacific	2	5	22	2	6	0	5	1	2
North America	8	11	48	8	12	4	24	2	32
Africa	18	13	5	1	1	1	0	1	0
Latin America	9	12	17	1	1	1	8	0	0
Other Asia	42	13	18	3	4	5	11	1	7
Other Europe	2	7	5	2	1	3	7	0	1
FSU	19	13	9	1	3	7	7	0	1
Middle East	13	3	5	14	4	1	0	1	0
Total	120	103	172	42	44	23	66	8	47

Source: Oil and Gas Journal, December 2005

Table 3.1 above shows that there is still a large number of simple refineries: 120. African refineries are essentially of the simple type. Asia, the Middle East and the FSU also have a large share of simple refineries, but also a considerable number of semi-complex plants.[37] Other Europe has a fairly complex refinery system. Worldwide, refineries are generally gasoline oriented, with 329 plants using FCC, compared to 141 using HCC. Most of the very complex refineries are situated in North America. This

[37] ENI 2005 and 2006

explains the relatively small share (5%) of residual fuel in the product yield and the relatively low quality of crude oil processed in South and North America. This is also a function of the crude production in those regions. The most common deep conversion capacity is delayed coking.

The refinery industry in Western Europe seems focused on gasoline production. But, as stated, because a smaller amount of HCC is needed to produce similar volumes of diesel as that of gasoline made by FCC units, fewer units are needed to produce more gasoil, assuming both processes have the same average size of measured on possible input. The production of gas/diesel oil and gasoline is actually much the same. In total, 53 refineries are equipped with FCC units, compared to 28 with HCC units, of which 16 also have FCC capacity. The FCC-type refineries added HCC units when the demand for gasoline started shifting towards diesel. Dismantling conversion units is not done until either their life span is surpassed or maintaining them is too expensive.

3.3. Refinery investments

The development of the refinery capacities in the different regions is provided in the tables below. Most investments are made to cope with sulphur regulations and diesel consumption growth. In addition to investments, capacity increases because of 'capacity creep', which is the gradual improvement of control over processing routines. A gradual increase in the optimisation of operation schemes through using different catalysts, pressure, etc., increases the efficiency and the cracking capabilities of the processes, enhancing the product yields. Capacity creep is incorporated into the extrapolation of the trends to estimate the capacity of 2012.

In Western Europe a total of 179,000 b/d of HCC capacity was added in 2005-2006. Four FCC projects are identified. One is very small (France 2,000 b/d). The others are of unknown size. Spain adds most conversion capacity, including coking.

Table 3.2: Distilling and Conversion process additions in Europe (barrels per day)

Country	Crude distillation	HCC (b/d)	FCC (b/d)	Coker (b/d)
Greece				20,000
Spain	90,000 (2010)			20,000 (2008)
Total	90,000			40,000

Source: Oil and Gas Journal 2006

Most investments made are in hydrotreatment facilities, and some in hydrodesulphurisation. Both processes can or are used to reduce the sulphur content in blending stock for both gasoline and diesel. The following table shows the capacity additions per country in Europe:

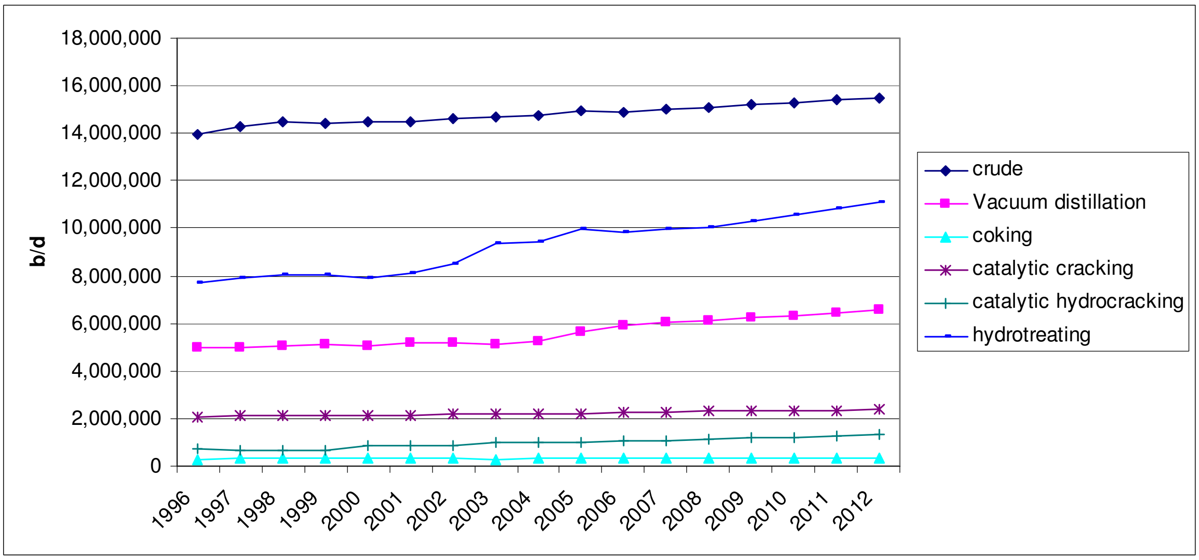
Table 3.3: Treating facilities capacity additions in Europe

Country	Hydrotreater and hydrodesulphurisation (b/d)	
	2007	***2008***
Greece	27,000	
Italy	12,000	
Turkey	28,000	

Spain[38]	36,000 + 85,400	
UK		54,000
Total	188,400	54,000

Source: Oil and Gas Journal 2006

Figure 3.1: Trend lines of refinery configuration Western Europe



Source: Oil and Gas Journal 1996-2006

In other regions, most investments in refinery capacity are in distillation, followed by desulphurisation and HCC. This corresponds with the needs. The utilisation rate of the primary capacity is high, so additional distillation capacity increases the possibility to run more crude. HCC is suitable for satisfying the strong growth in demand for diesel. Overall, it can be expected that the complexity will decrease in most of these regions due to the amount of primary distillation capacity added, assuming current levels of utilisation.

In the OECD Pacific hardly any conversion capacity has been added, just an unknown amount of FCC. There have been capacity expansions in sulphur treatment. In Japan these investments were already made in the late 1990s, in response to the sulphur regulation introduced earlier there than in most other countries. North America has increased deep conversion and HCC capacity, and even some primary distillation capacity. Canada, too, is investing in upgrading facilities to convert unconventional oil into synthetic oil, which is suitable for processing in petroleum refineries. Worldwide sulphur removal capacity has grown by 243% since 1996, with a jump in 2005. This enormous growth is driven by a combination of anti-sulphur regulation and the processing of relative sour crude from South America. It can be expected that North America will increase its conversion ratio, while the conversion ratio of the OECD Pacific will probably fall at higher utilisation rates of the primary distillation units.

Table 3.5: Rest of the world refinery capacity additions

Region (b/d)	Crude distillation (b/d)	HCC (b/d)	FCC (b/d)	Coker (b/d)	Treating (b/d)
North America	532,000	72,000	1,400	218,000	249,000

[38] This figure is actually reported as 4,180,000 tons per year and is converted here to barrels per day by using the characteristics of diesel, which is the most likely product treated. The conversion number of 7.46 barrels per ton is used.

OECD Pacific	35,000	55,000	60,000		67,000
Africa	306,000				
Latin America	1,081,077		19,000	260,314	536,459
Other Asia	2,390,500	146,000	60,000	3,700	306,300
Other Europe	90,000	49,000	15,000		145,534
FSU	183,800		15,000	20,000	58,684
Middle East	2,185,000	61,300			64,080

Source: Oil and Gas Journal 2006

3.4. Specification of the conversion ratio

It is generally assumed that conversion facilities are used at maximum capacity.[39] Yet often primary distillation units are not used at full throughput. To employ conversion processes optimally, refineries that are not using their complete distillation capacity process heavier crude, to make enough heavy feedstock available for the conversion units. To cope with this effect, the conversion ratio is corrected for the utilisation rate of its distillation units, translated from crude runs reported by ENI.[40] The result of this calculation on different world regions is given below:

Table 3.6: Conversion ratio on the basis of crude runs instead of distillation capacity

Conversion ratio	1993	1994	1995	1996	1997	1998	2000	2001	2002	2004	2005
Western Europe	35	35	37	36	35	35	37	39	40	39	39
North America	80	79	79	77	77	77	78	80	82	81	82
Pacific	28	28	29	31	33	35	36	40	43	43	42
Asia	38	42	45	43	49	54	61	63	63	57	61
Latin America	26	38	40	40	43	41	42	45	46	48	48
Africa	14	12	13	15	13	13	16	18	20	15	24
Middle East	19	21	22	22	21	21	23	23	24	25	23
Central Europe	48	48	46	46	47	46	52	55	58	60	60
FSU	23	28	26	33	32	29	31	30	27	30	31
World	42	43	44	44	45	46	48	50	51	51	51

Source: ENI 2005 and 2006

Overall, the conversion ratio rises over time. Only in the mid 1990s did it decline in Europe and North America, which is explained by the higher utilisation rate of primary distillation. The high conversion ratio in Central Asia and Central Europe is due to a low utilisation rate of primary capacity. China has a very complex refinery industry, with a conversion ratio of 84, if the utilisation rate is not taken into

[39] Leffler 2000, de Krom 2006 (interview)

[40] ENI 2005 & 2006

account. It has more than half of the refinery capacity of all Asia; hence, the conversion ratio in other Asia is lower.

To predict the possible conversion ratio in 2012 on the basis of the investments described in the former paragraph, the following method is used:

- It is assumed that the added distillation capacity is used at the utilisation rate of 2005;
- To assess capacity creep, the increase of Western Europe and North America through 2012 is calculated by extrapolating the trend since 1996. An exception is made for the OECD Pacific, because of the fast growth of its refinery capacities in the 1990s and the sudden end of this growth in 2001. Therefore the capacity creep is not as evident as with the other developed countries.
- By using index numbers, with 2005 as the base year, plus the expected capacity additions, the conversion ratio of 2012 is calculated.[41]
- In the other regions, including the OECD Pacific, the 'worldwide refinery update' is used to predict the capacities in 2012, and the possible conversion ratio of 2012 is calculated.[42] Capacity creep is not taken into account here.

These estimated calculations give insight into the quality of the crude that may be demanded in 2012.

Table 3.7: Expected 2012 conversion ratio

	2005	2012	Difference
Western Europe	39	43	4
North America	82	84	2
OECD Pacific	42	44	2
Asia	61	62	1
Latin America	48	49	1
Africa	24	21	-3
Middle East	23	23	0
Central Europe	60	65	5
FSU	31	31	0
World	51	52	1

Source: ENI 2006, OGJ 1996-2006

Overall, the refinery industry is becoming increasingly complex. Only Africa's refinery complexity is less than it used to be, due to additions to primary distillation capacity. The Middle East and the FSU refinery complexity are expected to stay the same.

3.5. Conclusion

[41] 2005 is 100, as well as for the distilling capacity as for the conversion capacity. The index number of the distillation capacity and the conversion capacity of 2012 are calculated. These are then divided to find the conversion ratio index number. Via a cross table with the actual conversion ratio of 2005, the conversion ratio of 2012 can be estimated.

[42] Using the FCC equivalents and formula as described by ENI 2006

The world refinery industry is gasoline oriented. The domination of FCC units over HCC and the total capacity of both units underline this. Gasoline production takes the lion's share of total production. The shift in demand from gasoline to gasoil in Europe is boosting the number of refineries with both FCC and HCC capacity. FCC units are not being dismantled; rather HCC units are being added. This explains, in part, the surplus of gasoline now produced in Europe.

As stated in Chapter 2, the product market is getting lighter, and refineries need to produce a light product mix to satisfy the changing product market. There are two possible options available to achieve this. They should either use lighter crude or invest in conversion; apparently, though, most regions enhance the complexity of their refineries.

North America is investing in diesel production facilities, despite the shortages of gasoline. It seems that this region is taking advantage of the structural surplus of gasoline produced in Europe. This was already noted in Chapter 2, and can be confirmed with this analysis with a high level of certainty.

Most new refineries are being built in the developing regions of Latin America, Asia and the Middle East. Also HCC, FCC and coker capacity is being added in Asia, and coker and FCC capacity in Latin America. Taking into consideration the heavily sulphurous Latin American crude, reducing the residual fuel production and cleaning the products is important.

Given the FSU utilisation rate of 66%, it is surprising that the FSU is adding distillation capacity. But the geopolitical structure of this region has changed dramatically over the past 20 years. The Soviet countries were used to buying their requirements from Russia, but now importing from other locations might be more efficient. The geographical location of the existing refineries in Russia might not be adequate any more, and therefore new distillation capacity is being built in better locations.

The Middle East seems to adapt to the surrounding product markets by adding distillation, HCC and (diesel) desulphurisation capacity. The diesel produced can be exported to Europe as well as to Asia. As a result, less investment in diesel producing units is needed in Europe and Asia. The Middle East, to an increasing extent, chooses to produce products for export to foreign markets, instead of just crude oil.

The impact of sulphur regulation on refiners is reflected in the investments in hydrotreatment facilities. The relation between the time capacities are added and the introduction of regulation underpins this. More investment in treatment and sulphur plant capacity can be expected around 2007 in North America and 2010 in Europe and Asia. The investments in treatment facilities will take place around the time of introduction. Therefore, it can be expected that after the adjustment of the regulations, the crude consumed will become somewhat sweeter, or will at least not grow sourer.

4

The Crude market: quality of supply and demand

The specific weight of crude, denoted in APIº, is a good indicator for the amount of heavy and light products it yields. In this chapter the crude production of the various regions is discussed. By trend analysis, a prediction is made about the crude that will be produced in different countries and regions by 2012. This is done in great detail to assess the crude quality produced in 2012. The average crude quality produced in these countries/regions, as published by the IEA, is used in this paper to calculate the weighted average of the quality of crude produced in the world. The import and export figures of OECD countries are used to calculate the weighted average of the quality consumed in the importing countries.

4.1. Crude supply, quality and outlook through 2012

The crude production regions distinguished are: the Middle East, Africa, the Former Soviet Union (FSU), the North Sea, South and North America, and Asia Pacific. All predictions about the production in 2012 are based on the trends from 1990 onwards. The IEA Energy Outlook and other references are used to check the values, and, when necessary, correct the outcome. Most outlooks use barrel per day as a production unit. In this study we use tons. The quality parameters used, APIº and sulphur content, are taken from the Key World Statistics 2006 published by the IEA.

These values represent the average quality of crude of the different producing countries in 2006. It is assumed that the average quality of crude within a country stays constant. Economics would suggest that the quality of crude produced within a country will decline over time, especially in countries where production is already declining. First the high value crude will be produced, later being substituted by crude of lower quality and value. The sulphur content is estimated through the use of the Haverly database[43] from the Internet and values reported in publications of the IEA and other sources.

4.1.1. The Middle East

It is generally expected that the Middle East will be able to increase its role as oil production centre for the world. In extrapolating the trend from 1990 through 2012, the following aspects should be noted:

- 'Oil production in Iraq is expected to reach around 3 mb/d in 2010 and 8 mb/d in 2030, provided that stability and security are restored.' (IEA 2005) Because of the great uncertainty of prospects, due to the instability of Iraq, this analysis will presume a constant production through 2012.
- The Kuwaiti trend is taken after production recovered from the Iraqi invasion in 1990.
- Saudi Arabia's 1990 growth percentage is not taken into account because it doesn't seem to be representative of the growth rate over the complete period (1990-2005).
- 'By the decade-end Qatar plans to boost its oil production capacity to one million barrels per day (bpd) from the existing 750,000 bpd.'[44] The growth of production in Qatar will be 250,000 b/d. This amount will be added to the production reported by BP in 2004, 990,000 b/d, or 44 million tons per year.

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[43] http://www.haverly.com/crulibs.htm. This website contains crude oil assays with information on the sulphur content of many different crude oils from different countries. The average sulphur content of all the different qualities of crude reported is taken per producing country.

[44] Global Research 2005

On average, Middle East crude is light and sour. Most production from Saudi Arabia is light, almost medium heavy, and sour. Only Yemen produces high-quality crude with a low sulphur content and high APIº. However, the quality of crude from the Middle East will stay approximately the same until 2012, assuming that the quality produced by individual countries remains the same.[45]

Table 4.1: Crude production and quality in the Middle East

Country	Production 2004 (1000 tons)		Percentage of total production		APIº	Sulphur (wt%)
	2005	2012	2005	2012	'05/ '12	'05/ '12
Saudi Arabia	518,767	567,208	44%	44%	33	2.1
Iran	205,107	232,813	18%	18%	34	1.7
UAE	130,604	154,462	11%	12%	39	1.0
Kuwait	126,780	147,383	11%	11%	32	3.0
Iraq	90,504	90,504	8%	7%	36	2.2
Other Middle East	95,098	95,105	8%	7%	34	1.9
Total/ weighted average	1,166,858	1,251,473			34	1.9

Source: BP 2005, Haverly 2005, IEA 2006

Middle East production is growing. The IEA (2005) predicts a production of 26.6 million b/d by 2010, without natural gas liquids (NGL). (BP includes NGL production where it is produced separately.) Our estimate for 2012 production is 1.25 billion tons a year.

4.1.2. Africa

Overall crude quality in Africa is light and sweet and very suitable for production of light products with low sulphur content. The main producing countries in Africa (Algeria, Libya, Angola, and Sudan) are, according to BP and the IEA, under-explored; therefore, many E&P opportunities remain available. The following observations are important:

- Libyan crude production costs are low, exploration has been minimal over the past decades and an infrastructure is available. So "Libya is considered a highly attractive oil province […] Libya plans to increase its production from 1.6 mb/d now to 2 mb/d by 2010. Further increases are possible in the longer term."[46]
- It is assumed that in Sudan an increase in reserves may occur, because the country is still under-explored. In this report it is assumed that production will grow by 10% per year.
- Nigerian production is high, but social unrest jeopardises production, making predictions difficult. The Nigerian government is ambitious, aiming to boost production to 4.1 mb/d in 2006.[47] However, this goal is unlikely to be reached. Production grew by an average of 2.3% annually from 1990-2004, and is projected to do so until 2012, to 156 million tons.

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[45] This could differ due to new oil field production of different quality and the decline of production by older fields. However, these differences can only be marginal and are therefore not taken into account. Still, over time, the quality could change.

[46] IEA 2004

[47] IEA 2004

Table 4.2 shows the African crude oil production in 2004 and 2012, together with the average qualities of the crude produced in the main producing countries. The weighted average of the crude quality is light and sweet: 39º API and 0.5% sulphur content.

Table 4.2: Crude production and quality in Africa

Country	Production 2004 (1000 ton)		Percentage of total production		APIº		Sulphur (wt%)	
	2005	2012	2005	2012	'05	'12	'05	'12
Nigeria	133,094	156,059	28%	24%	37			0.1
Algeria	90,733	111,004	19%	17%	41			0.2
Angola	62,505	98,416	13%	15%	35			1.2
Libya	82,878	11,1885	17%	17%	39			2.2
Egypt	32,871	28,687	7%	4%	32			0.1
Sudan	16,275	31,715	3%	5%	32-34			0.1
Other Africa	79,274	120,238	16%	18%	38			0.5
Total/ weighted average	497,630	658,004			37	37	0.5	0.5

Source: BP 2005, Haverly 2005, IEA 2006

The crude reserves and exploration opportunities are increasing the production potential. The investment climate is improving,[48] as is illustrated by the opening of the Libyan market. Moreover, crude oil quality is very good and will yield a high price. Finally, the geographical position at the Mediterranean and West Coast of Africa is good for exports to Europe, the United States and Asia. A prosperous future can therefore be expected for African crude production, possibly compensating for the decrease in the volumes and quality of crude produced elsewhere.

4.1.3. Former Soviet Union

The FSU is the world's second largest crude exporter. The growth in Russia's production capacity is predicted to slow, reaching a level of 10.7 million b/d in 2010.[49] Kazakh crude production had an average growth of 6.8% annually from 1990-2004, and it is assumed that this growth will continue through 2012.

FSU crude is of medium quality. The Russian Federation produces the bulk of crude, exported as Ural blend (mixture of Ural, Siberian crude and some Caspian grades such as Tengiz) which is transported via the Druzbha pipeline system to Europe and the Black and Baltic Seas.

Production from the Caspian Sea region has other export routes: the CPC pipeline (to the Black Sea) and the Baku-Ceyhan (Mediterranean) pipeline. Tengiz and Kashagan fields are examples of crude reservoirs in this region. Overall, Caspian crude is light and medium sweet.

Table 4.3: Crude production and quality in the FSU

[48] Simmons 2004

[49] IEA 2005

Country	Production 2004 (1000 ton)		Percentage of total production		API°		Sulphur (wt%)	
	2005	2012	2005	2012	‘05	‘12	‘05	‘12
Russia	469,857	514,282	81%	75%	31			1.3
Kazakhstan	62,067	102,541	11%	15%	41			0.6
Azerbaijan	22,401	33,971	4%	5%	32			0.2
Turkmenistan	9,860	15,119	2%	2%	33			>1.3
Uzbekistan	6,004	8,951	1%	1%				
Other FSU	6,646	7,060	0%	1%	33		1.2	
Total/ weighted average	576,835	681,923			33	33	1.2	1.2

Source: BP 2005, Haverly 2005, IEA 2006

4.1.4. Europe

A decline in crude production is the trend foreseen in Europe. The decline started in 1999 for the UK and in 2001 for Norway. New deposits and investment could induce a slower rate of decline in production than the expected 7% per year for the UK and 2% for Norway. Denmark’s production is increasing, being an estimated 31 million tons/year in 2012.

Overall, the quality will stay above world average, the production will decline, and the API° will drop from 36° to an average of 35°. The sulphur content will stay approximately the same.

Table 4.4: Crude production and quality in Europe

Country	Production 2004 (1000 ton)		Percentage of total production		API°		Sulphur (wt%)	
	2005	2012	2005	2012	‘05	‘12	‘05	‘12
Norway	138,766	120,466	54%	55%	37			0.2
UK	84,627	50,920	33%	23%	39			0.5
Denmark	18,518	31,006	7%	14%	35			0.3
Italy	6,427	7,640	2%	3%	22			>0.5
Other Europe	9,547	8,376	4%	4%				
Total/ weighted average	257,885	218,409			36	35	0.3	0.3

Source: BP 2005, Haverly 2005, IEA 2006

4.1.5. South America

The major crude producers in Latin America are Venezuela, Mexico, Brazil, Argentina, Colombia, and Ecuador. For Mexico, the IEA predicts a slow increase of production through 2010 of 1.8%; after 2010 the production is not expected to grow further. Venezuelan production will increase by 2.5% per year. Brazilian production will grow by 6.5% per year through 2012, which has been the trend since 1990. The other Latin American countries are able to moderately increase production. Overall, a great production potential for low-quality crude is found in this region. Table 4.5 below shows the production of 2004, 2012 and the crude quality of the assessed countries.

Table 4.5: Crude production and quality in Latin America

Country	Production (1000 tons)		Percentage of total production		API°		Sulphur (wt%)	
	2005	2012	2005	2012	'05	'12	'05	'12
Mexico	191,697	212,588	36%	31%	28			2.1
Venezuela	152,950	191,976	29%	28%	26			1.9
Brazil	77,319	133,616	14%	20%	30			0.5
Argentina	38,124	45,610	7%	7%	29			0.2
Colombia	27,402	30,445	5%	4%	28			0.7
Ecuador	27,376	37,232	5%	5%	27			1.2
Other	21,554	26,864	4%	4%	25			1.5
Total/ weighted average	536,422	678,331	100%	100%	25	25	1.5	1.4

Source: Haverly 2005, IEA 2006

4.1.6. North America

Canada has great potential for increasing its crude production, as large amounts of oil sands and bitumen have recently been found. Canada is adding large amounts of upgrading capacity, as described in Chapter 3, to process oil sands and bitumen into synthetic crude. For the US, declining petroleum production and increasing consumption has lead to growing crude imports from Canada and Latin America.

The high-quality crude production in the United States is declining and is being replaced by low-quality crude from Canada, mostly Alberta tar sands. Therefore, the quality of the crude produced in this region will decline over the coming years. Nevertheless, the reserves of the United States grew in 2005.[50]

Table 4.6: North American crude production and quality

Country	Production (1000 tons)		Percentage of total production		API°		Sulphur (wt%)
	2005	2012	2005	2012	'05	'12	'05/ '12
USA	143,364	174,829	32%	39%	35		1.1
Canada	306,637	269,366	68%	61%	30		1.1
Total/ weighted average	450,001	444,195			33	33	1.1

[50] IEA 2006

Source: BP 2005, Haverly 2005, IEA 2006

4.1.7. Asia Pacific

On average, Asian Pacific crude production is of good quality. It has a low sulphur content and above average API°. The table below presents the different quantities and qualities of crude produced in the countries of this region. The quality of crude will stay the same through at least 2012.

Asia petroleum production is projected to remain constant through 2012. Some new fields will come into production, while production of other fields will diminish. It is difficult to find any consistent projections of the crude production in 2012 of the individual countries. The following observations are of importance:

- China's production levels are at about 3.5 mb/d (IEA 2005);
- Malaysian, Vietnamese and Thai production is calculated by adding the average absolute growth between 1990 and 2012. This is done because production growth estimates are realistic and on the careful side.

Table 4.7: Crude production and quality in Asia Pacific

Country	Production 2004	(1000 ton)	Percentage of total production		API°	Sulphur (wt%)
	2005	2012	2005	2012	'05/ '12	'05/ '12
China	183,336	207,548	52%	54%	33	0.2
Indonesia	53,572	47,191	15%	12%	34	0.2
Malaysia	35,660	37,393	10%	10%	43	0.1
Australia	24,678	24,623	7%	6%	46	0.1
Vietnam	18,220	25,010	5%	6%	36	0.2
Other Asia	36,210	44,105	10%	11%	43	0.1
Total/ weighted average	351,677	385,871			35	0.1

Source: BP 2005, Haverly 2005, IEA 2006

4.2. Crude streams to the consuming regions

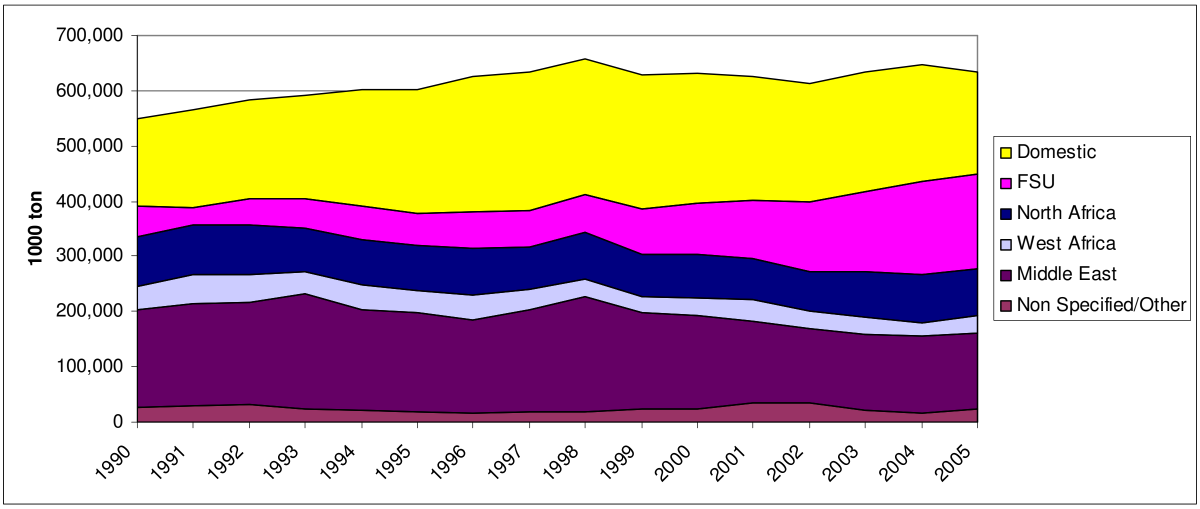
This section will analyse the crude streams to the different consuming regions. The method of the weighted average will be used to calculate the average weight and sulphur content of the crude imported. The API° of the country of origin is used, and when this is unknown, the average of the region of origin is used. Firstly, the streams and quality of crude imported to Europe are described, followed by North America and the OECD Pacific. These regions are assessed because of the availability of data; the model in the next chapter is used to calculate the crude quality consumed in the other regions.

4.2.1. Crude streams to Western Europe

Since 1999, actual domestic crude consumption has declined from 2.3 to 1.9 million tons. Overall consumption decreased from 1999-2003 and recovered to above 6 million tons in 2004. Overall, the trend is that of more imports of crude from outside the region.

In the early nineties, Europe was mostly dependent on Middle Eastern oil, mostly from Saudi Arabia and Iran. This dependence has shifted to crude from the FSU, which now provides the biggest proportion of crude supplies after domestic crude. Most regions have declining shares in the crude imports of Europe. This was due at first to increasing domestic production, and after production peaked, the imports shifted to the FSU, which was able to increase its exports and has targeted its main exports routes at Europe. Overall, there are four different sources of crude for Europe: domestic, FSU, Middle Eastern and North African.

Figure 4.1: European crude consumption per region of origin



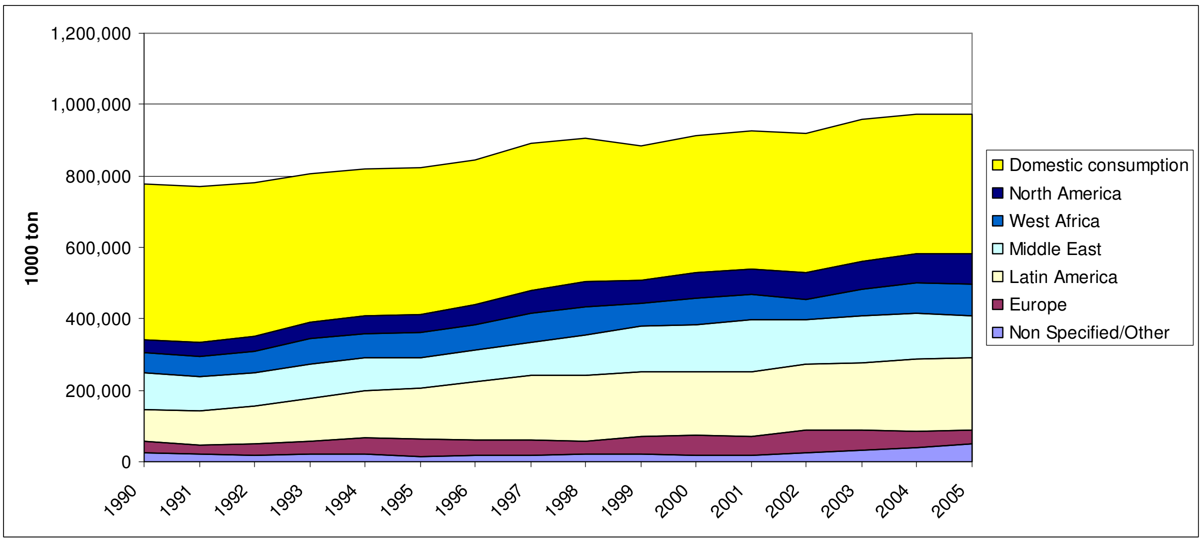
Source: IEA 2006

Consumption grew by an average of 1.22% per year from 1990 to 2004 (distillation capacity grew by 0.8% yearly as of 1990). Extrapolating this trend, the consumption in 2012 will be around 700 million tons. This is 50 million tons more than was consumed in 2004.

4.2.2. Crude streams to North America

North American consumption of domestic crude is slowly declining, due to declining production in the US. Canada is able to increase its crude production. A growing percentage of crude is imported from Latin America, mostly from Venezuela and Mexico. Overall consumption is increasing, with small dips in 1999 and 2002. It is expected that by 2012 even more crude will have to be imported because of declining domestic crude production and a growing demand for oil products.

Figure 4.2: Crude consumption per origin region North America

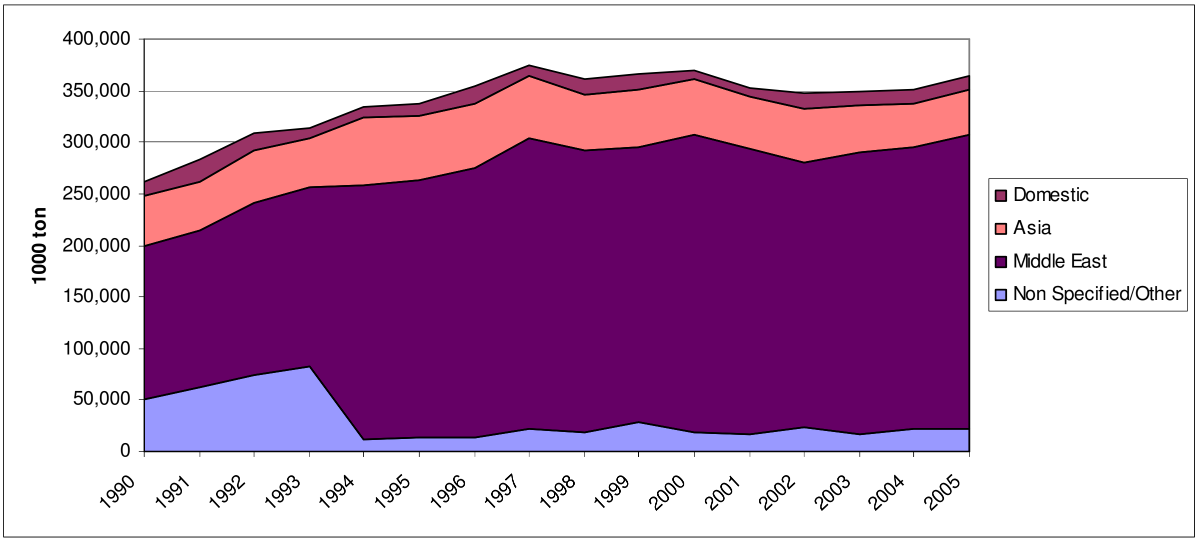


Source: IEA 2006

4.2.3. Crude streams to OECD Pacific

The OECD Pacific countries are increasingly dependent on imports of Middle Eastern crude, this comprising 56% of consumption in 1990 and 80% in 2004. Asia, particularly Indonesia, provides another 12%. If we look at the non-specified/other category at the beginning of the 1990s, it seems logical that the lion's share of these imports is from the Middle East. Overall consumption has been declining over the last decade.

Figure 4.3: OECD Pacific crude consumption



Source: IEA 2006

4.3. Quality of crude by importing regions

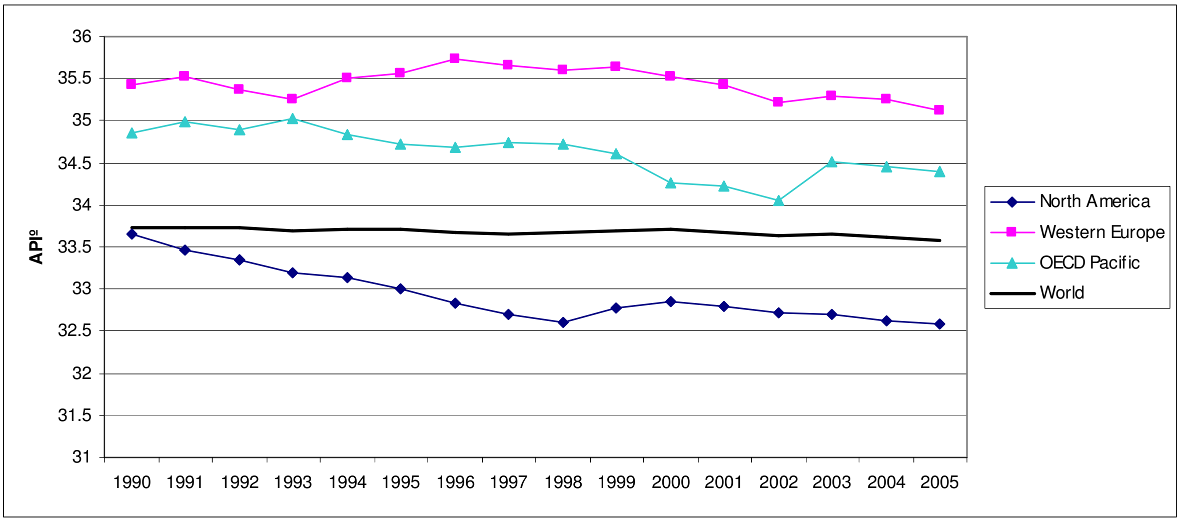
Average quality of the crude used as refinery feedstock in Europe is relatively high compared to average world production. The average weight of crude processed in Pacific refineries is somewhat heavier, ranging from 34.74° in 1997 to 34.23° API in 2001. The API° of crude consumed in North America declined between 1990 and 1998, recovered a bit in 1999 and 2000, and than declined again at a slower rate to around 32.5° API.

Table 4.3: Crude quality consumed in the measured regions

	1993	1994	1995	1996	1997	1998	2000	2001	2002	2004	2005
Western Europe	35.3	35.5	35.6	35.7	35.7	35.6	35.1	34.7	34.6	35.2	34.9
North America	33.2	33.2	33.0	32.8	32.7	32.6	32.9	32.8	32.7	32.6	32.6
OECD Pacific	35.0	34.8	34.7	34.7	34.7	34.7	34.3	34.2	34.1	34.4	34.4
World production	33.7	33.7	33.7	33.7	33.7	33.7	33.7	33.7	33.6	33.6	33.6

Source: IEA 2006

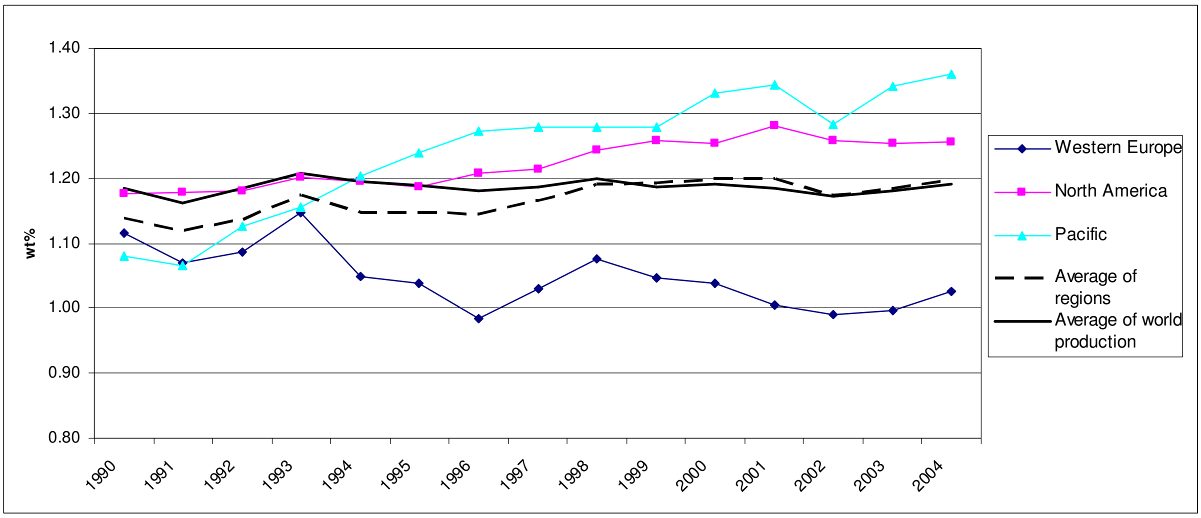
Figure 4.4: Average API° consumed in the regions, calculated by use of the weighted average



Source: IEA 2006

Based on 2004 figures, 50 % of the crude processed in Europe is sweet; the other half tends to be medium sour (FSU crude) to sour (Middle East crude). The crude consumption turns sweeter together with growing domestic crude consumption and vice versa, sourer with domestic crude production decline. Overall, the sulphur content has remained between 1.1% and 1.0%, with a primarily downward trend (toward sweeter crude). North American crude consumption has tended to become more sour, but has seemed stable since 2001/2002. OECD Pacific sulphur content is increasing the most.

Figure 4.5: Average sulphur content of crude consumed



Source: IEA 2005

4.4. Conclusion

The quality of world crude supply is declining slowly. African and Caspian Sea crude production will be able to compensate for some of this decline. These two regions still have a large potential for exploration and production. Yet Caspian Sea crude has transport constraints. Europe is the most likely user of FSU crude, since most export routes are through Europe.

In Europe and the US, domestic production is in decline. The domestic crude supplies are of above average quality. To replace domestic crude with imports, Africa and the Caspian Sea region are the most likely suppliers, since they produce comparable types of crude and have the potential to increase their production. To cope with a heavier crude slate, investments in refineries are needed, especially in conversion and treatment processes. It seems that North America is adapting more than Europe to this challenge, as was shown in Chapter 3.

North America has the most diverse supply, with imports from all production regions, even the high-consuming regions. Asia and the OECD Pacific, on the other hand, are almost completely dependent on imports from the Middle East. For security of supply reasons, diversification of supply is important. FSU crude may be a solution; new pipelines from Eastern Siberia could relieve dependence on the Middle East. But so far, no transportation routes are available.

5

Model to assess the quality of crude demand in 2012

In the previous chapters the emphasis has been on the OECD regions: the OECD Pacific, North America and Western Europe, for which sufficient data is available. To asses the quality of the crude used in the other regions, a model is needed, which will be presented in this chapter. By using this model, new insights are generated on the quality of world crude demand.

Section 1.5 already presented the conceptual framework for such a model. The model starts from the following two critical assumptions:

- The lower the APIº, the higher the Residual Fuel Production Share (RFPS); and
- The higher the conversion ratio, the lower the RFPS.

The crude quality or the conversion ratio can be changed (or both) to produce either more or fewer light products. To find a relationship between the crude quality consumed and refinery complexity, the product market must be incorporated. Producing more or less valuable - mostly light - products implies producing relatively low-value products, like residual fuel oil. Therefore, the RFPS is taken as an indicator for the state of the product market.

The crude oil qualities consumed by the OECD countries, calculated in Chapter 3, need to be in proportion with the RFPS and the conversion ratio. This is tested by comparing the different proportions: crude quality-conversion ratio. In addition, the calculated crude qualities are evaluated in respect to their development, in proportion with the development of the other two parameters. First, these three parameters are compared with each other separately, to assess the quality of the data used as input. Subsequently, these parameters are incorporated in a model. A relation is sought between the conversion ratio and the quality of crude, by incorporating the product market represented by a single variable, the RFPS. Below, the basic relations are given, followed by the method of normalising the APIº, and eventually the complete model is presented.

5.1. Conversion ratio and crude quality: testing the crude quality

The conversion ratio is set against the APIº of the crude used by refineries in the countries and regions assessed in the previous chapter.

Table 5.1: The quality of crude consumed in APIº

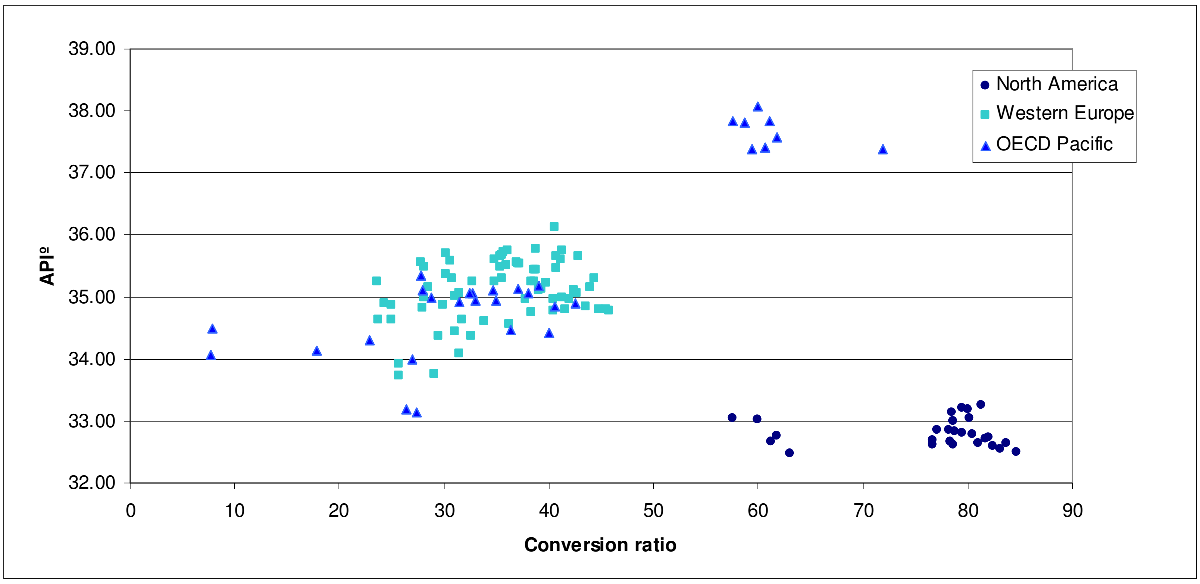
	1993	1994	1995	1996	1997	1998	2000	2001	2002	2004	2005
North America	33.2	33.2	33.0	32.8	32.7	32.6	32.9	32.8	32.7	32.6	32.6
US	33.3	33.2	33.1	32.8	32.7	32.6	32.8	32.7	32.6	32.5	32.5
Canada	32.7	32.8	32.5	33.0	33.0	32.6	33.6	33.6	33.5	33.5	33.6
EU-15	35.3	35.5	35.6	35.7	35.7	35.6	35.2	34.8	34.6	35.2	34.9
Western Europe	35.3	35.5	35.6	35.7	35.7	35.6	35.1	34.7	34.6	35.2	34.9
Belgium	34.6	35.1	34.4	34.9	34.9	34.6	35.3	35.0	34.8	33.9	33.7

France	34.4	34.9	35.0	35.4	35.5	35.6	35.6	35.7	35.3	35.3	35.1
Germany	35.5	35.6	35.7	35.7	36.1	35.8	35.6	35.3	35.2	35.1	35.1
Italy	34.8	34.8	34.8	35.0	35.0	35.0	35.0	34.8	34.8	34.8	34.8
Netherlands	33.7	34.1	34.4	34.6	34.6	34.4	34.7	34.9	34.9	34.1	33.9
Spain	33.4	33.2	34.4	34.4	34.4	34.1	34.1	33.8	33.1	34.1	33.9
UK	33.1	33.7	33.6	34.0	33.9	33.7	31.6	30.2	32.1	34.0	33.8
Turkey	36.5	36.8	37.0	37.2	37.2	37.2	34.5	31.7	31.8	36.7	35.0
OECD Pacific	35.0	34.8	34.7	34.7	34.7	34.7	34.3	34.2	34.1	34.4	34.4
Japan	34.9	34.9	35.0	35.0	35.0	35.1	34.8	34.8	34.7	35.1	34.9
Korea		34.4	34.0	34.0	34.2	33.9	33.1	33.0	32.5	33.3	33.4
Australia	36.1	36.4	36.2	35.8	36.5	36.0	35.9	35.9	35.8	35.6	35.5

Source: IEA 2006

The following scatter plot illustrates the relationship between the refinery complexity and the quality of the crude consumed. The sample size is 187.

Figure 5.1: Scatter plot of the conversion ratio and API°



Source: IEA 2006, ENI 2005, 2006 and 2007

The scatter plot of the conversion ratio against the API° of crude consumed shows a rather weak relationship. Knowing that a different product market requires a different output structure from the refinery sector and/or a different quality of feedstock, adding the product market through an indicator should increase the correlation between the two. Thus, the values are standardised according to the structure of the regional product markets. This relationship will be used in the next section.

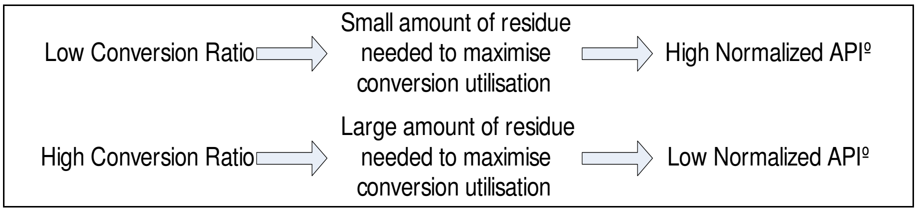
5.2. Standardised APIº

Two ways of incorporating the product market are possible. The first one corrects the conversion ratio according to the product market, while the second option corrects the crude quality measured in API° according the products demanded. Here we chose to correct the API° factor. The residual fuel production share (RFPS) is suitable as an indicator because it is a low-value product, is difficult to transport and store, due to high viscosity and the many contaminants, and it is expensive to dispose of through conversion. Refineries will therefore try to serve their local market, avoiding high-cost transport of low-value products and converting fuel oil as much as possible to other products. In addition, the following rules apply:

- The heavier the crude (the lower the API°), the higher the RFPS;
- The higher the conversion ratio the lower the RFPS; and
- The conversion facilities are run at maximum capacity.

Knowing that conversion capacity is used in full, refineries need to produce enough vacuum gasoil through the vacuum distillation of residual fuel, as vacuum gasoil is a main feed for HCC and FCC processes. They must also produce residual fuel for RFCC and RHCC processes to keep the conversion capacity running at maximum throughput. Hence, the quality of the crude should be such that it yields sufficient amounts of residual fuel and/or vacuum gasoil to feed the conversion facilities at full capacity.

Figure 5.4: Relation between conversion ratio, residual fuel production and standardised API°



To correct the API° on the amount of residual fuel produced, the following formula is introduced:

Standardised API° = API° * RFPS + API°

This formula standardises the API° in relation to the amount of residual fuel produced. The standardised API° represents the upper limit of the API° of the crude consumed by a refinery with a certain conversion ratio, yielding enough feedstock for the conversion facilities to be used in full, as well as eliminating residual fuel oil production. By introducing this new parameter, the residual fuel and the quality of crude are combined, so that a relation can be sought with the conversion ratio. In the table below the standardised API° is given.

Table 5.2: Standardised API° of the regions and countries used to create a model

Standardised API°	1993	1994	1995	1996	1997	1998	2000	2001	2002	2004	2005
North America	35.5	35.4	35.1	34.7	34.5	34.5	34.6	34.6	34.3	34.3	34.2
US	35.5	35.4	35.1	34.7	34.4	34.5	34.5	34.5	34.1	34.1	33.9
Canada	35.3	35.2	34.8	35.4	35.6	35.2	36.0	36.2	35.9	36.2	36.3
EU-15	42.1	41.8	41.8	41.9	41.8	41.9	41.1	40.5	40.1	40.9	40.4
Western Europe	42.3	42.0	42.0	42.1	41.9	42.0	41.2	40.5	40.2	41.1	40.4
Belgium	41.9	41.1	40.3	41.6	42.0	42.0	42.6	41.2	40.6	40.5	41.0
France	39.7	39.5	39.6	39.7	39.8	40.2	40.0	40.1	39.7	40.0	39.8
Germany	39.8	39.8	39.9	39.9	40.1	39.9	39.6	39.4	38.9	39.2	38.9

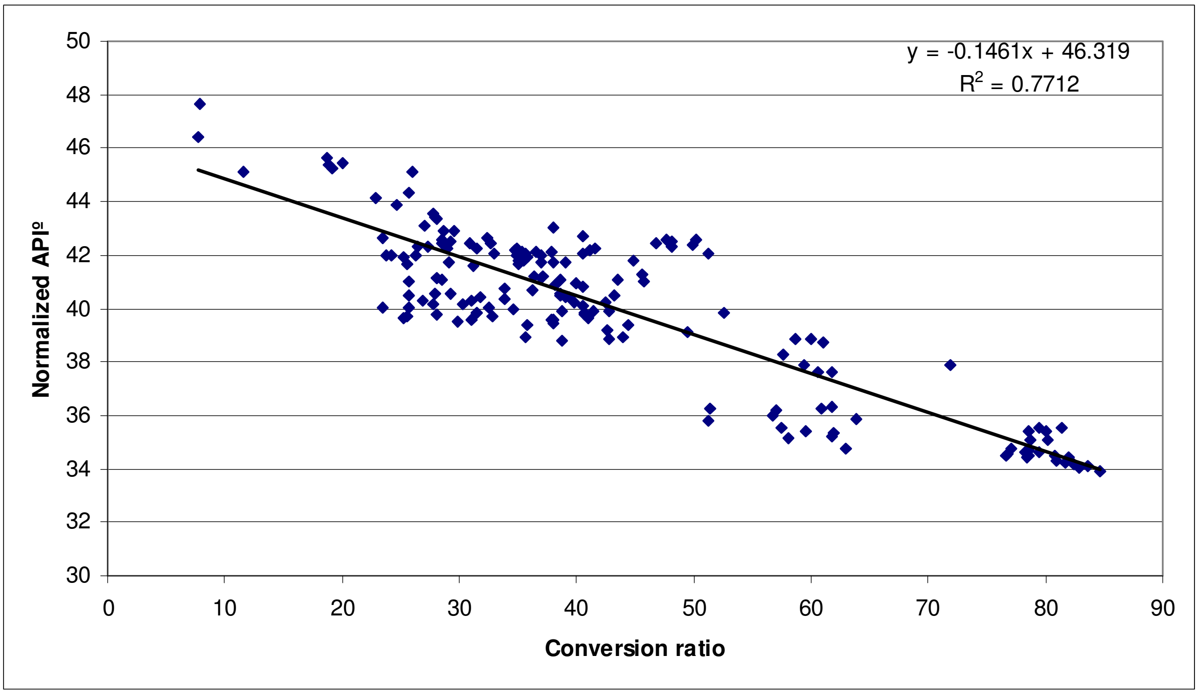
Italy	43.0	42.7	42.3	42.2	42.0	42.1	42.1	41.8	41.0	41.1	41.2
Netherlands	40.6	39.8	40.0	40.4	40.4	40.7	39.6	39.5	40.5	39.5	38.8
Spain	42.4	41.7	42.9	42.5	42.6	42.4	41.6	40.7	40.0	39.4	38.9
UK	45.1	45.4	45.3	45.7	45.1	43.9	42.3	40.3	42.0	44.3	43.4
Turkey	42.4	42.3	42.3	42.5	42.6	42.6	39.1	36.3	35.8	42.1	39.9
OECD Pacific	43.5	43.4	42.9	42.3	42.1	41.7	41.2	40.9	40.4	40.6	40.9
Japan	42.4	42.7	42.2	41.7	41.7	41.7	40.8	40.3	40.4	40.6	40.3
Korea	0.0	47.7	46.4	45.3	44.1	43.1	42.3	42.3	40.6	41.8	42.0
Australia	38.8	38.9	38.8	37.9	38.3	37.6	37.7	37.9	37.5	36.7	36.6

Source: IEA 2006

5.3. The correlation between the standardised APIº and the conversion ratio

Using the standardised APIº, the effect of different configurations of product markets is corrected. There is a clear correlation between the conversion ratio and the standardised APIº:

Figure 5.5: Conversion ratio – Standardised APIº



Source: IEA 2005, ENI 2005 and 2006

Combining the equation factors derived from the trend line in Figure 5.5 with the formula for the standardised APIº, the following formula denotes the relationship between the conversion ratio and RFPS, and the APIº of the feedstock:

$$API^{\circ} = \frac{(-0.1461 * \text{conversion ratio} + 46.319)}{(RFPS + 1)}$$

5.4. Future world crude quality consumption

5.4.1. The crude quality consumed

With the equation given in section 5.3, and the values of the RFPS and the conversion ratio, the qualities of crude demanded can be calculated. The RFPS given in section 2.3 and the conversion ratio given in section 3.4 are used as input for the model. The table below presents the result of these calculations:

Table 6.1: Crude quality as estimated by the model (API°)

	1993	1994	1995	1996	1997	1998	2000	2001	2002	2004	2005	2006	2012
Western Europe	34.7	34.8	34.6	34.9	35.2	35.2	35.2	35.1	34.9	35.1	35.1	35.3	35.8
North America	32.4	32.6	32.8	33.2	33.3	33.2	33.1	32.9	32.6	32.9	32.6	32.6	32.9
Pacific	34.1	34.0	34.2	34.3	34.3	34.4	34.2	33.9	33.7	34.0	33.9	34.2	34.8
Asia	31.8	31.7	31.7	32.5	32.1	31.6	31.8	31.9	32.0	33.3	33.0	32.9	34.0
Latin America	32.8	31.5	31.6	31.6	31.5	31.6	31.5	31.1	31.0	31.0	31.0	31.1	31.5
Africa	33.9	34.0	34.1	34.0	34.2	34.2	33.9	34.1	33.9	34.6	33.5	33.6	34.3
Middle East	32.5	32.9	32.5	32.4	32.6	32.6	32.7	32.8	32.7	32.7	33.1	33.1	33.4
Central Europe	29.7	30.2	30.6	30.7	30.5	30.7	30.0	29.7	29.3	29.3	29.3	29.8	30.4
FSU	31.0	30.6	30.9	30.2	30.5	31.0	31.8	32.0	32.1	32.1	32.1	32.6	32.8
World	33.0	33.1	33.1	33.3	33.3	33.3	33.3	33.2	33.2	33.5	33.6	33.5	33.9
World production	33.7	33.7	33.7	33.7	33.7	33.7	33.7	33.7	33.6	33.6	33.6	33.6	33.5

Source: IEA 2005 and 2004, ENI 2005 and 2006

5.4.2. The desired and expected conversion ratio

The desired conversion ratio, satisfying the RFPS in 2012 (as given in section 2.3) with demand for the same quality crude as at present, can be calculated by using the equation of the model of Chapter 5. The crude quality as consumed in 2005 is used for the year 2012.

Table 6.2: The desired and expected conversion ratio

Conversion ratio	2005	Desired in 2012	Expected in 2012	Difference
Western Europe	39	42	43	1
North America	82	84	84	0
OECD Pacific	42	45	44	-1
Asia	61	71	62	-9
Latin America	49	53	49	-4
Africa	24	28	21	-7
Middle East	23	28	23	-5
Central Europe	60	66	65	-1

FSU	31	39	31	-8
World	**51**	**57**	**52**	**-5**

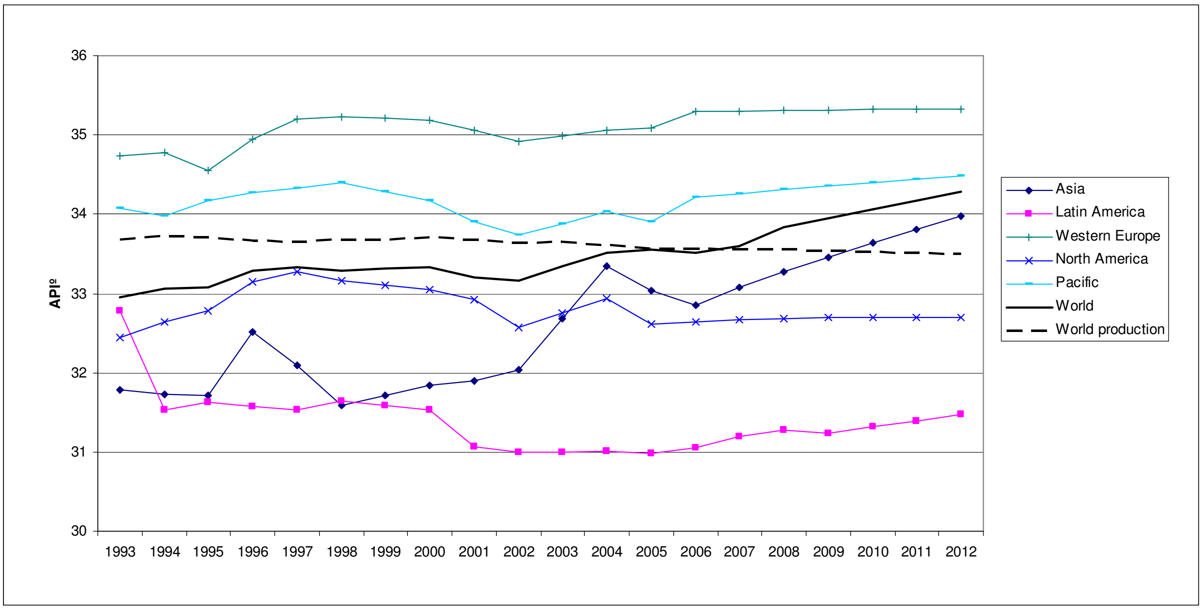
Source: ENI 2006, IEA 2003 and 2005

The desired growth of conversion ratio does not correspond with the expected increase of conversion ratio calculated in Chapter 3. Consequently, the crude quality demanded towards 2012 will be higher, especially due to Asia and Latin America; and also to the FSU, Middle East and Africa, though their influence will be less, due to their smaller demand of crude. The expected world conversion capacity in 2012 is different from that which could be expected from the regional figures. This can be explained by the methods used. The conversion ratio of the regions OECD Pacific, Asia, Latin America, Africa, Central Europe and the FSU are estimated by using data from the refinery construction update, leaving out capacity creep and unreported capacity additions. North America, Western Europe and the world as a whole are estimated using trend analysis, extrapolating the trend from 1996-2006 through 2012. This last method takes the capacity creep and unreported capacity additions, in a way, into account. Hence, it can be assumed that the conversion ratio in the first group of regions will be higher in 2012 than reported here.

5.4.3. Crude quality demand, from 1990 - 2012

It follows that a conversion capacity shortage can be expected, implying higher crude quality demand and/or a higher RFPS. This is illustrated with the figure below:

Figure 6.1: World crude quality demand in the most important consuming regions



The exporting regions Latin America, Africa, and the FSU will have to consume lighter crude than they do now, because of the relatively decreasing conversion ratio and a declining RFPS in demand. Therefore, the average quality of crude exported by these regions will probably decrease, as the lighter crude available will be needed to satisfy their own market.

In addition, the crude swing production will not yield the lighter grades, since they are sold at a premium price and are exported first because of high demand. The heavier grades are more difficult to sell and will therefore be used as swing capacity. Consequently, when demand for light products peak, the demand for light crude will increase by only the additional heavy crude available. This may have serious implication for security of supply issues as well as geopolitical consequences for the light crude consumers and suppliers.

5.5. Consequences of the misfit of crude quality demand and supply

The most important effect that can be expected from the increase in the quality of crude demanded and the limited amounts of light crude available is a surplus of residual fuel. This will be all the more true as the amounts of crude demanded will grow faster, as compared to the situation in which light crude had been used to produce the required amount of light products to satisfy the product markets. As a result, more crude production and distillation capacity is needed, to produce and process the additional crude necessary to satisfy the product market.

As a consequence, it can be concluded that three measures are conceivable for refiners to cope with product demand and crude supply:

- Increasing conversion capacity,
- Increasing distilling capacity with a surplus of residual fuel as a result, and
- Processing lighter crude.

Considering these three alternatives, it can be stated with good level of certainty that processing lighter crude will not be possible. Of course, it is possible for one region to process lighter crude, but always at the expense of another and at a high price. Therefore, two structural options remain open: increasing the primary distillation capacity, as a result of which the residual fuel production will eventually increase due to the relative lack of conversion capacity; and increasing the conversion capacity, reducing residual fuel production and/or crude oil quality demanded, while using less primary distillation capacity.

Due to the high demand for high quality crude, the crude surplus capacity is of poor quality. High-quality crude is easily sold at a high price, while demand for heavy crude is slacking and is sold at a relatively low price. Therefore, the swing capacity in crude supply will be of low quality. The crux of this situation is that, when demand for light products is at a peak, for example, during the US driving season, the demand for light crude is even higher than in the normal situation. As stated before, the conversion capacity is already used in full, leaving no additional capacity to convert heavy into light products. Indeed, the availability of light crude is more important at the peak, but it is not available at that time. The result is an increase in the demand for crude, which is higher than strictly necessary due to the heavy characteristic of swing crude production, needing more swing crude and distillation capacity. Assuming that heavier crude contain more contaminants, additional treatment is needed to increase the quality of the products. As a result, the crude price is more vulnerable to peak demands, and is therefore volatile.

5.6. Conclusions

The average API° of the feedstock demanded is lighter, but it is constrained by the quality of crude produced. As yet, the conversion capacity additions expected will not be enough to cope with the trend of lower residual fuel demand and the decreasing crude quality produced.

With the constraints on the possible crude quality demanded and the moderate increase of conversion ratio, it can be expected that the residual fuel production will grow, or at least be higher than demand requires. This will drive the price of residual fuel down and increase problems of disposal of what can be termed as ‘waste’. Solutions need to be found to cope with the surplus of residual fuel to avoid environmental hazards and the wasting of scarce resources.

The difference between the demand for low- and high-quality crude will increase the price differential between different types of crude. This difference will give an incentive to sell high-quality crude first, and use low-quality crude as swing production to take care of peaks in demand. Because of the low quality of swing production, more swing production is needed to satisfy the light product market, just as more swing distillation capacity is needed.

There is lack of conversion capacity relative to the quality of the crude produced and the product market. The crude demanded in the future will probably be of a higher quality than what is currently demanded. The tight distillation capacity increases these difficulties. The swing distillation capacity available is mostly found in the FSU, but these areas are not well connected to the main transportation routes. Therefore, extra attention should be given to investments in conversion capacity to temper crude demand growth, avoiding a surplus of residual fuel on the market and increasing the quality of products supplied.

The European and OECD Pacific demand is for higher quality crude than the average of that currently supplied. For security of supply reasons, an increase of the conversion ratio will decrease the quality of crude demanded and therefore increase the amount of crude suitable to these markets. As a result of such investments, more possibilities arise for diversification of supply, reducing the dependency on the few regions with high quality crude production and lessening the rivalry for scarce high-quality resources.

6

Implications for the petroleum industry

The conclusions of the preceding chapter may have serious implications for the future of the world oil and oil products market. Main aspects are the security of supply, the structure of the product market, the refinery industry, the crude market and the associated patterns of international trade, transportation of fuels, energy policy and geopolitics. This chapter sketches some of these implications and the consequences they could have for Europe. Finally, some general conclusions drawn from the developments of the value chain in the different regions are provided.

6.1. Patterns of crude demand

Most of the developments described in the above chapters have implications for the refinery industry. It can be claimed, by and large, that the issues are structural. It seems that the industry will face a lack of capacity if sufficient investments are not forthcoming. Until recently, these investments have been lacking. The processing capacity available does not always match the local product market, and thus the market will get tighter. Moreover, as shown, crude supply quality is decreasing, while the products demanded are increasingly those that are light and of low sulphur content.

The problems, in the context of a lighter product market and heavier crude supply, can be summarised as follows:

1. More demand for light crude, due to a lighter product market and lack of investment in conversion; and
2. No additional light crude available, due to heavier supply and lighter demand.

Figure 1.2 showed the trade-offs involved in the refinery industry relative to the product and crude oil markets. Subsequently, the increasing demand for lighter crude indicates a shortage of conversion capacity relative to the lighter product market. Yet because the conversion capacity is used in full, this will be more apparent when demand for products is at a peak or when the use of refinery capacity is temporarily restricted. In both situations, to compensate for the momentary disruption of refinery capacity including conversion facilities, the capacity of remaining refineries must be used more intensively, increasing the demand for light crude to meet light product demand. As stated in Chapter 6, not much light swing crude oil is available; consequently, heavy crude is used instead. As more heavy crude is needed to produce the same amount of light products, more swing production and more primary distillation capacity are becoming necessary.

Crude swing production capacity, as a way to cope with fluctuations in demand, is a driver for the short-term crude prices on oil markets. As indicated in the introduction, the crude price is very volatile. Given the patterns identified in previous chapters, the following effects can be expected:

- Low quality crude swing capacity[51] and the full use of conversion capacity will lead to more demand for crude to satisfy product demand,[52] requiring more swing crude and distillation capacity;
- Low availability of high-quality crude, high levels of refinery throughput of around 95% and low quality of crude swing capacity will lead to high crude and product prices;

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[51] Stevens 2005
[52] See also Watson 2006

- Bilateral agreements and contracts to secure higher quality crude for diet balancing with heavy crude[53] will become more important; and
- Because of the mismatch between the crude supplied and the crude demanded, a surplus of residual fuel and a decline in the quality of products may arise.

To address these implications, different options exist, as illustrated in Figure 1.2:

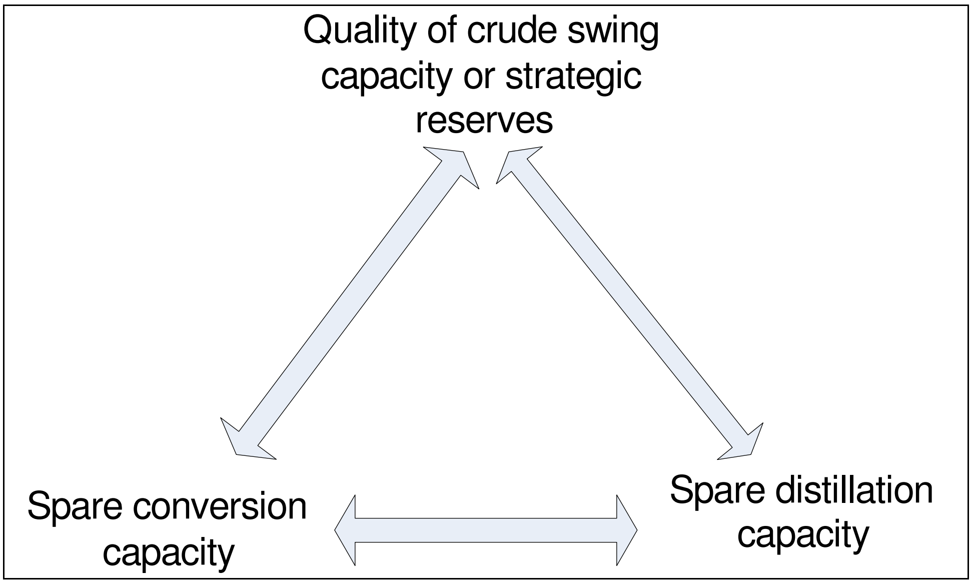
- The quality of swing crude could be enhanced in the various regions. For example, high-quality crude produced in the North Sea may be reserved for peak demand moments, or the quality of strategic reserves could be enhanced. These options, however, invoke a huge number of practical impediments, such as the question as to how such arrangements would look, institutionally, and how the costs of such measures would be covered. Moreover, it would take light crude away from the market at normal times.

- The primary distillation capacity can be expanded to process more crude and, thus, increase the output of light products. Yet a side effect would be an increase in the yield of residual fuel and a possible decline in the overall refining margin per unit processed.

- The conversion capacity can be increased by investment in HCC, FCC, and deep conversion processes like coking and RFCC. The investment costs are high, but it may resolve the mismatch between the supply and demand of products, and could reduce the demand for scarce light crude. Moreover, more conversion facilitates the production of more light products and less residual fuel, as a result of which less crude would be needed to meet the lighter product market. Thus, more distillation capacity could be reserved for fluctuations in demand. Deficits of residual fuel might be able to be resolved by imports from, for example, Russia.

Overall, to secure energy supply and stabilise the petroleum industry, a balanced choice needs to be made on the different measures possible. Taking the implications made above and in Figure 1.2, it can be concluded that the measures are a trade-off between three parameters, as illustrated below in Figure 7.1.

Figure 7.1: Trade-off between distillation and conversion capacity and the quality of crude swing capacity



[53] One part of the crude diet of refineries is fixed, via fixed contracts with suppliers with a more or less fixed quality. The rest is filled up with crudes from spot and mid-term future markets to balance the barrel. About every month a 'shopping list' is produced, with price indications and qualities, for the purchase of crude for next month.

In addition to the problems in the crude market, problems were identified in the local product markets. It was concluded that a mismatch between the supply and the demand of products is increasing. This is due to a shift towards lighter products and from gasoline to diesel consumption. In the European situation, the refinery industry is slowly adapting from gasoline production to diesel production. The US and the Middle East are adapting to the mismatch in Europe; the US imports gasoline from Europe to compensate for its own deficits and the Middle East invests in HCC and diesel desulphurisation to export to Europe and Asia.

The European and North American refinery industry is well adapted to the regional crude supply quality. Europe consumes a relatively high quality of crude, which is regionally available in (North) Africa, the Caspian Sea and the North Sea, while North America consumes relatively heavy crude, with heavy Latin American and Canadian oil in the vicinity. This pattern is changing in part due to emerging markets in Asia. Asia used to consume the regional crude, which is generally of high quality, in combination with Middle Eastern crude. Currently, crude oil is imported from other origins as well, like North Africa and the Caspian Sea region, but also Venezuela and even Canada. This threatens the traditional supply pattern of Europe and North America.

As concluded in Chapter 6, the quality of crude consumed in Europe is high, due to the historically high availability of light crudes from domestic production and from the nearby producing regions in Africa and, to a lesser extent, the FSU. Much of the refinery industry is historically designed to process these high-quality crudes. The recent change from a relatively relaxed crude market with low prices to a volatile crude market with high prices raises questions in respect of the supply, especially of high quality crudes. Moreover, the crude supply is getting increasingly heavy.

It can be stated with some certainty that the current state of the crude market will not change dramatically in the coming years. The uncertainties currently dominating the market will not disappear, and will result in a highly volatile crude price and large price differentials between qualities of crude. As investment in refinery capacity is lagging, different strategies are being applied to cope with the changing crude and product markets:

Europe and North America tend to increase the conversion ratio to increase the output of light products and decrease the quality of crude consumed. Europe has had a very small increase of crude consumption, North America somewhat larger. Investment in new refineries is not very likely in these regions due to the relatively low consumption growth.

It is not to be expected, however, that the European refinery industry will be able to change its conversion capacity dramatically in the short term. Disinvestments are not very likely due to the large sunk costs, while investment in new equipment is increasingly expensive. Therefore, the configuration of the refinery industry and the conversion ratio will change only slowly over time. Through 2012, Europe may be able to stabilise the quality of crude consumed, although the residual fuel demand will decline. Eventually, though, to be able to accept a lower quality of crude, more investments are needed in conversion processes.

Asia and Latin America invest in primary distillation capacity, which is logical due to a large growth of the local product market. Use of this capacity will increase the total amount of crude to be processed. Assuming that the utilisation rate does not fall, the crude demanded will get lighter.

As concluded in Chapter 6, Asia will demand more light crude and will therefore compete with Europe. The main high-quality crude exporting countries are in Africa and the Caspian Sea area. The pressure will be on these regions, where Europe possibly has a geographic advantage over Asia. It can be observed that Asian countries will try to increase their influence in Africa and the Caspian Sea region. Indeed, China is prepared to go a long way in investing in crude production and refineries in remote places.

China and India use their national oil companies to gain influence over crude production, in addition to said governments using bilateral agreements to secure the supply of crude. Europe has no national oil companies and, therefore, has a competitive disadvantage. 'Given the dynamics of international political and economic relations, a static singular approach to energy security may not suffice.'[54] To secure the quality of crude supplied, Europe will need to adjust its foreign policy to the changing geopolitical environment.

It can be concluded that emerging markets choose to increase distillation capacity over conversion capacity, in contrast with the developed markets of Europe and North America. Indeed, investment in conversion capacity is much more important in the latter regions. This is partly due to a difference in product quality regulation – which products needs treatment and conversion – but also due to the differences in market growth.[55]

The refinery industry, so far, is not adapting to regional changes, but is internationalising its supply patterns, resulting in increased product transport. Tankers used for transportation of products are smaller than those used for crude; therefore, the number of ship movements will increase more than when crude is processed for the local market. Transportation bottlenecks will be used more extensively, increasing vulnerability to supply disruptions of crude as well as of products.

Transportation of products instead of crude has effects on the security of supply that need to be assessed carefully. Transportation of products will increase the complexity of 'traffic control' and increases the concern of terrorism – for example, in the Straights of Hormuz and Malacca. Blocking these bottlenecks could have disastrous results on the energy market, as they are already coping with an increase in the transport of crude, liquefied natural gas and other products goods.

Overall, it can be concluded that the best way to cope with all of the above-mentioned problems is to *increase the local conversion capacity*. Not many players in the industry are actually engaging in this way to a sufficient degree, so we should expect problems in the years to come (see also IEA 2007). It is not expected that new refineries will be built in Europe. Demand growth is small. The investment costs are high due to environmental constraints and the complexity of spatial planning processes. Environmental regulation decreases the chance of obtaining permits and the NIMBY effect is common.

Given this situation, it is more promising to increase the conversion capacity at the existing refinery sites. There are many reasons for this: 1) it increases the flexibility of crude intake; 2) it enhances the conversion of residual fuel and the production of light products, allowing for the import of excess residual fuel from other regions; 3) it reduces the vulnerability to import disruptions of diesel; 4) it enhances the ability to process low-quality swing crude during peak demand or drop-outs without producing much more residual fuel; 5) it reduces the vulnerability to supply from high-quality exporting regions such as Africa and the Caspian Sea; 6) it increases the ability to replace high-quality domestic production with lower qualities of crude from elsewhere; and 7) it enhances Europe's competitive position vis á vis North America and Asia.

The European Union should consider reducing the impediments to investment in conversion capacity. Moreover, securing *light* crude supply is of more importance than gaining access to heavier crudes, which are still widely available. Foreign policy initiatives should focus on the high-quality crude suppliers. Europe could stimulate the light crude production by providing, for example, investment and security of demand for crude producers.[56] Lack of decision-making in the EU will probably induce security of supply problems.

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[54] Correljé and Van der Linde 2005

[55] Monaghan 2005

[56] Correljé and Van der Linde 2005; Commission of the European Communities 2006.

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