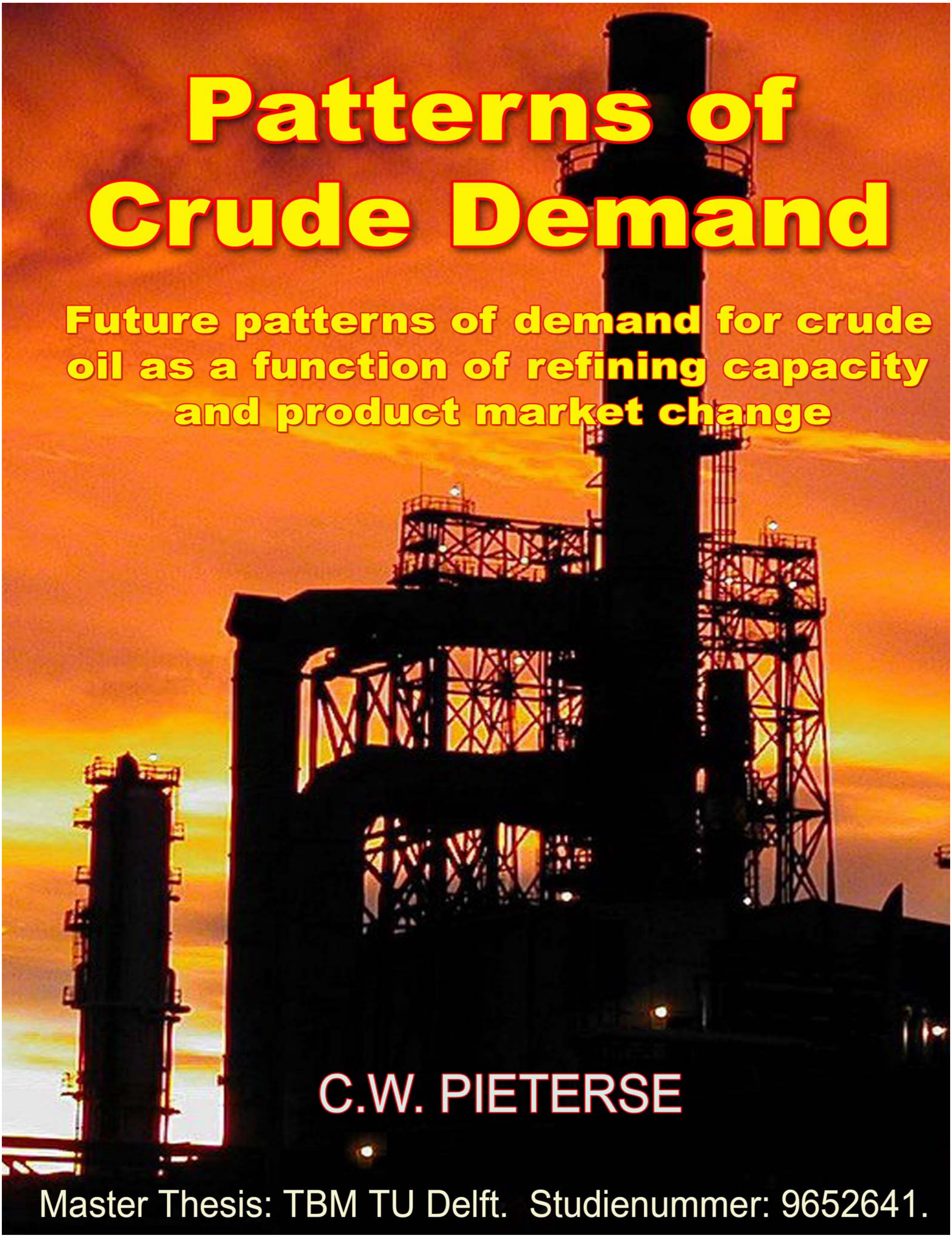
Patterns of Crude Demand

Future patterns of demand for crude oil as a function of refining capacity and product market change



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Patterns of crude demand:

Future patterns of demand for crude oil as a function of refining capacity and product market change

Master Thesis

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Preface

The petroleum market is actually experiencing dramatic changes on a world wide scale. These changes initiate problems, which can be found back in the whole petroleum industry value chain. This thesis covers the complete value chain from a demand perspective. It starts with a description of the product market, advances to the refinery industry, and finally the crude market. Quality aspects of products and crude and complexity of the refinery sector are key notions. At the end a complete oversight is given on the problems within the value chain, with an explanation of the reasons why the price of oil is high and volatile.

The problems will be identified, explained and brought into connection with each other. This thesis will show that there is a strong causality within the complete value chain, and that problems in one sub-section of the chain could well be the problem of another subsection.

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I like to thank my first advisor, Aad Correljé, for his readings and good advices steps on the complex problem which was subject to this thesis; Lucia van Geuns for her support and providing the needed data for research; Marcel Ludema for asking why with every step I toke, made me think twice several times and motivated me to explain better; and John Groenewegen for his support on the methods used and ideas. And last, the support I got from the members of the section of Economics of Infrastructure.

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My girlfriend Hanna and my parents, Cor and Lize, for making it all possible and their patience,

And all the other people who have contributed to my studies.

Wouter Pieterse
October 2006

Summary

The crude oil market is actually experiencing dramatic changes on a world wide scale. Most of the analysts of this industry are concerned with the developments in demand and regulation of products, the state of the refinery industry, and the crude market. It is a matter of fact that the price of crude is high, and, at the same time, that the capacity of the refinery industry is limited. In addition, demand of products shifts to lighter products pressuring the refinery industry to investment, change operating schemes, and/or change quality of the feedstock (crude). Demand for crude oil is growing, especially in Asia. In fine, the tight crude market drives up the price of crude.

Crude market is often described from the perspective of 'peak oil', that is from the perspective of the supply of crude, and price of high quality crude, as Brent. Thus, it is interesting to research the crude market from a demand side perspective. This thesis aims precisely at understanding the quality of oil from a demand side perspective. The demand of crude is defined by the refinery industry, which supply the product market by processing crude. Changes in demand of crude are initiated by developments in the product market. It follows that this dissertation addresses the complete value chain from products demand to crude supply.

The goal of this thesis is:

Giving insight in what causal implication developments in the product market have on patterns of crude demand.

The dissertation is organized around one central problem and three subsidiary questions:

What patterns of change can be identified in the regional petroleum product markets and how will this affect the future capability of the refining industry to provide the products in demand and regional crude demand with emphasis on crude quality?

1. What is the current relation between the demand structure of the products markets, the production capabilities of the refinery industry, and the supply of crude oil?
2. What trends can be identified in the product market, refinery industry, and the crude market?
3. What challenges do these trends pose to the operations of the petroleum industry in the different world regions?

Answers to these questions are provided by dividing the value chain up in sub-systems—product market, refinery industry, and crude market—to analyze them separately. The most appropriate method is trend analysis, which consists of analyzing data taken from previous period of time to predict future trend in the industry. Data sets from the International Energy Agency (IEA), Oil and Gas Journal (OGJ), and the ENI World Review are taken for this analysis. In addition, a theoretical explanatory model was build up and used

to assess the quality of crude demanded in the regions under investigations and, eventually, the world. The regions the dissertation is looking at are Western Europe, North America, and the OECD Pacific.

According to our model, the quality of crude demand depends on the refinery complexity and the products the refineries want to produce. The conversion ratio can then be used to measure the refinery complexity. To be able to compare the different regions, the product markets need to be made comparable. The indicator taken to compare different product markets is the amount of residual fuel produced relative to the other products. Residual fuel production share of the regions is normalized by incorporating it into the known quality of feedstock of Western Europe, North America, and the OECD Pacific. With the normalized crude quality, of these regions, a correlation with the conversion ratio was found.

Now, taking the conversion ratio and the residual fuel production share, the quality of the feedstock of countries, regions, and the world can be calculated. In addition, this model illustrates the high value of the three parameters—API°, conversion ratio, and the residual fuel production share—as indicators on the state of the petroleum industry.

The product market is shifting to lighter products world wide, and regulation on sulphur content change the context of the refinery industry in Western Europe, North America, and the OECD Pacific. Both these aspects pressure the refinery industry which has five basic strategies to cope with these changes:

1. Do nothing and export or import products to balance the market.
2. Change crude diet (a short term solution).
3. Change operating schemes (a short term solution).
4. Revamp refinery processes (a medium term solution).
5. Investment in new equipment (a long term solution), whether they are early or late investments.

The first solution is used by Europe and North America. Europe has a high gasoline surplus due to a product market shift of less gasoline demand and more diesel demand. European refineries are designed to produce more gasoline than that demanded right now. To use the conversion processes on maximum capacity the surplus gasoline needs to be exported, to North America in this case. North America seems to adapt to the surplus of Europe with low incentive to invest in gasoline production processes.

The second strategy has a direct influence on the demand of crude. To produce more light products, lighter crude can be processed. Another advantage of lighter crude is low sulphur content. Using trend analysis and the model, this strategy is (willingly or unwillingly) used by Asia, Europe and the Former Soviet Union. These regions will demand lighter crude by 2010.

Regulation on sulphur content in transportation fuels has an effect on the sulphur content of the crude consumed. Overall the crude consumption is growing sourer, but at the point of time of regulation introduction the crude consumed is some what sweeter than former years. This is corrected in the years following. This corresponds with early investment and late investment strategy. Eventually the refinery industry adapts by investment in treating processes. It can be said that sulphur regulation has little effect on the crude quality consumed.

The average crude quality is getting heavier. The average quality of crude demanded in the future will probably get higher than the average quality of the crude produced. Therefore, to suffice the light product market, the market needs to satisfy with heavier quality crude which yield less light products. The ability to convert heavy ends is limited; and heavier crude than light crude need to be processed to produce the same amount of light products. This will increase the demand for crude and the production of residual fuel, more than it is necessary.

The volatility of the crude price can be explained by the reason in the former paragraph. When demand for light products is peaking, extra capacity in the refinery industry and the crude supply is needed. The only spare capacity the refinery industry has is distilling capacity, which is limited. To be able to avoid increase of residual fuel production, and to use the limited refinery swing capacity optimally, lighter crude needs to be processed. However the problem is that the lighter crude is not available. Therefore heavy crude is processed, needing more distilling capacity and crude, both scarce, to produce the amount of light products needed. Therefore, the petroleum industry is sensitive to peak demand and drop outs of refinery capacity and crude production.

The main solution bring forth by this thesis is increasing the conversion capacity. The residual fuel production is reduced in advantage of light products and/or heavier crude can be processed. Thus more light crude can be made available for swing production to cope with peak demand and drop outs. In addition more spare distilling capacity due to less crude runs need to be made available.

There are specific solutions to different world regions. For almost all regions it is important to increase conversion capacity. The problem, however, is that only North America and the Middle East do so sufficiently the coming years. In addition, Asia needs to increase its overall capacity, and in a lesser extend this count for North and Latin America. The regions with sulphur regulation need to invest in treating facilities to increase the quality of the product output. Moreover pressure will rise on the regions which produce light crude. The regions Africa and Central Asia will play a central role. These two regions have great potential in increasing the light crude production.

It is expected that the coming years the problems in the petroleum industry will not vanish. Crude price will stay volatile due to swing capacity and complexity problems in the refinery industry, and therefore on the crude market. The refinery industry can’t handle the quality of the crude supply and the crude supply can’t handle the demand. The refinery industry can be changed by investment; there is only a limited influence on the quality of crude supply.

Content

1 Introduction

The assignment for this thesis is: research aspects of oil reserves. Oil reserves as a subject is not straight forward and has a lot of aspects within. Therefore a selection on what aspect of oil reserves is addressed to here, is useful. An internship at VOPAK under supervision of Joop Jonkers, conversations with Lucia van Geuns, Aad Correljé and two other thesis writers on the subject, Reinier van Berge Henegouwe en Wouter de Haan made me decide to write my thesis on crude quality. The goal of this thesis is to give insight on what causal implications changes in the product market have on the demand of different qualities of crude and the petroleum industry as a whole.
This introduction will start with a problem description by first describing the value chain from crude to products. The value chain will be explained by addressing the different sub-systems (product market, refinery industry and the crude market) separately. In the second paragraph the research objective and research questions will be given. Then the system will be described by a causal diagram, followed by the research methods used and demarcation. Last, a chapter division is given.

1.1 Problem description

Crude oil, and therefore oil reserves, is not an homogenous product, quality parameters are of importance. Refiners demand certain qualities of crude to produce products of good quality to serve the product demand. Changes in product demand could lead to changes in crude demand via the refinery industry demanding certain qualities of crude which need to be available. Therefore the value chain from crude oil to petroleum products is of interest.
First the value chain will be presented, than the product market/ refinery industry and the crude market is described in more detail. Emphasis is on changes and the impact these changes have on the complete chain.

1.1.1 The value chain

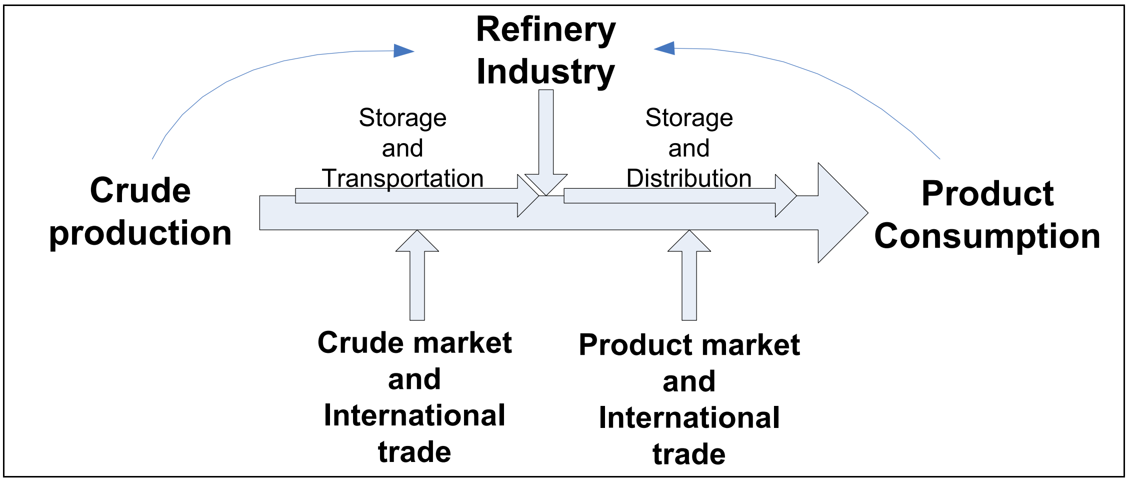


Figure 1: Value chain of the petroleum industry

It all starts with the production of crude oil. Crude oil is not a homogenous product, many different qualities are produced. Crude is stored before transported to the area where it is stored and processed to suitable products by the refinery industry. Before the load arrives at its destination, it is possible to trade the crude with third parties on the international crude market, this can be done during storage at origin and transportation and even before it is produced, paper markets they are often called (Horsnel 1993). The crude is processed in refineries, to produce suitable products for the product market. Also in the refinery sector many different configurations with different characteristics are found. The product market consists of players from the petrochemical industry, electricity generation, transportation, heating and energy use in all sorts of industry.
Before the products are consumed these are stored, traded on the international market such as Rotterdam and Singapore, and distributed to end consumers. Eventually the transportation fuels will be distributed over the stations for final consumption.

1.1.2 Product market changes

The product market is essentially changing on three aspects:

1. Overall growth of demand
2. Increasingly lighter product demand (more diesel and gasoline and heavy fuel oil)
3. Product quality requirements

These developments differ per region, just as its influence on the refinery industry and the crude market. This will be described further below.

Refiners in Europe and the US are running close to their maximum capacity (ENI World Review 2005), while product demand is growing and specifications on the products are tightened by regulation (EU 2002 & 2003, EPA 1999). Investments in the refining industry are necessary to meet the regulatory constraints and growing demand of light products and decreasing demand of heavy products (Stevens 2005). Asia is taking a bigger proportion of total petroleum demand. ‘Much of the growth is in the transport sector. Heavy fuel oil continues to loose ground in the static sector, which require ever growing investment to convert heavy ends of the barrel into light ends, where demand growth will come.’ (Stevens 2005)

Due to environmental legislation problems emerge in production and treatment of products; this troubles the refinery industry in Europe and the US, but also international trade of these products. Environmental regulation prevents refiners to invest in polluting equipment (CO_2) needed to convert heavy to light products and treat them to the appropriate quality.

1.1.3 The refinery industry

Due to product market changes the refinery industry is forced to adapt and change refinery output. This has repercussions on refinery investment strategies and industry processes. Because of the high complexity of the processes and the chemistry of the refinery industry, the refinery industry is seen as black box. First the black-box (figure 2) is described, than a discussion on the strategies is given.

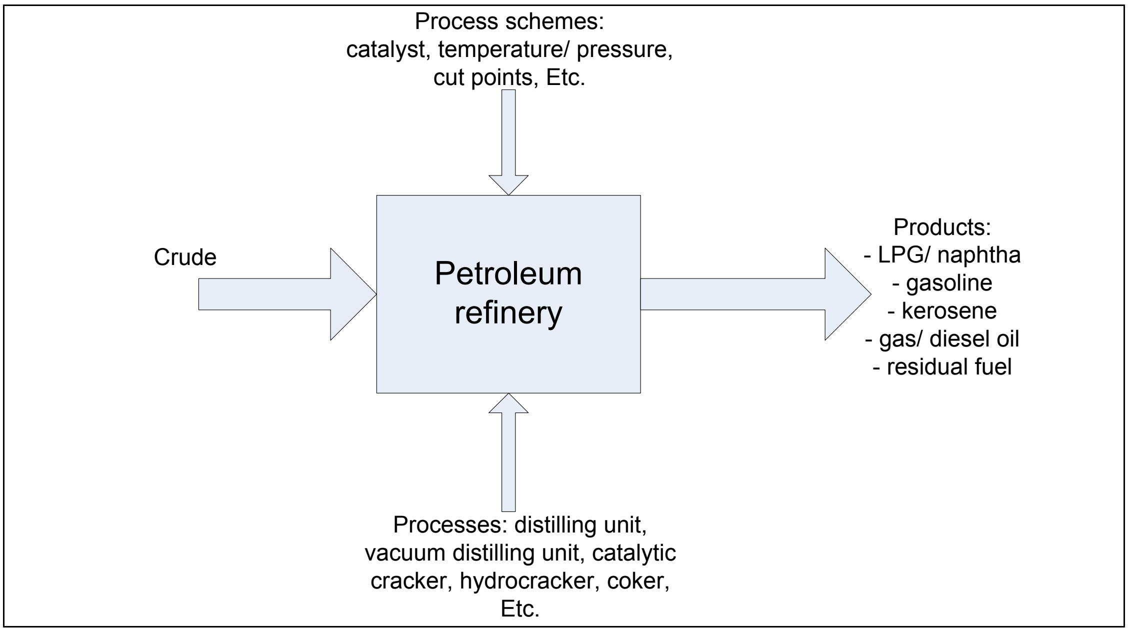


Figure 2: Input, output controls and mechanism of a petroleum refinery

The input is crude oil, sometimes vacuum gas oil or residual fuel/ heavy fuel oil. By processing crude, products are produced which can be sold on the product market. The mechanisms to process the crude starts with a distilling unit which separates the different products from crude, called straight run products. The conversion processes convert heavy into lighter products as gasoline, kerosene and diesel. These processes are explained in chapter 4.

The controls to produce a certain product mix are more complex. Different catalysts, temperature and pressure, cut points etc. lead to other product mixtures.

The combination of input, controls and mechanism yield a certain output which needs to be economically feasible compared to the costs of the input and refinery processes.

Overall, five strategies can be found to cope with the product market changes and/ or crude supply:

1. Do nothing and export or import products to balance the market
2. Change crude diet (short term solution)
3. Change operating schemes (short term solution)
4. Revamp refinery processes (medium term solution)
5. Investment in new equipment (long term solution)
    a. Early investment
    b. Late investment

Exporting and importing products instead of adapting output is another option for a refiner. Taking that the refinery is originally built to serve the local market, these other markets would relatively be farther away. Therefore transportation over bigger distances is needed, implying extra costs. The price difference of products between the exporting and the importing regions need to be bigger than the transportation costs. This is not assessed. Transporting products is more expensive than transporting crude because products need more caution to preserve quality.

Changing crude diet (pool of crude taken in by a refinery) is an option which is relatively easy to apply. Different crudes yield a different product output, and the other way around; different refineries give a different product output with the same crude. So, a refiner needs to use a crude fit to its configuration and the product market it is serving. For these purposes refineries use linear programming models to calculate there optimal input (diet) and capacity use to derive at the optimal output. Since these crudes may be different from the crude's the refinery was designed for, some capacity may not be used optimally. This could not be beneficial to the goals of the refinery.
Refineries are designed to use the local crude (or crude found relatively close by) for the production of products to serve the local product demand, implying a certain kind of capacity and configuration. If the refiner wants to adapt to the product market by changing crude feedstock, it can be presumed that the feedstock is taken from places farther away, implying extra transport costs.

The changing product demand mix challenges the abilities of refineries to adapt and to increase their flexibility to differ their output. There are three options for changing output by changing process schemes to optimize refinery processes:
(http://www.aip.com.au/issues/security.htm)

1. Use different catalysts in the catalytic cracker or hydro-cracker to produce more or less diesel or gasoline (catalysts are expensive, and such a change is only interesting if it would hold longer than a year)
2. Change settings of the catalytic cracker or hydrocracker
3. Alter the cut points for different products

These measures could increase production, this increase is called '*capacity creep'*.

Midlife upgrades (revamps), for example adaptations to withstand higher pressures, are good options to adapt to changes of the product market in the medium term. Capacities are enhanced by better knowledge of the equipment and a more efficient use of the capacity at hand.

The last option (addressed here) for coping with changing demand, or supply (crude) is investment in capacity, either distilling (primary) capacity or conversion capacity (converting heavy to light products). Changing the refinery configuration is difficult in the short run, big investments are needed and it takes years before the capacity is operational. Therefore it can be presumed that the refinery configuration is constant, except for marginal changes in output by using the above described options and for investments which come into utility because of earlier made decisions.

To adapt to, for example, regulation, the choice of early investment or late investment is of importance. Early investment has the advantage of early high prices, late investments yield less risk because the market may be more settled and forecasts are easier to make. In the case of sulphur regulation, profit can be made on using less expensive high sulphur crude when early investments are done.

1.1.4 Crude market

Recent events on the crude market raised doubts on the availability of crude in the future. The market is tight and the predictions on the crude price vary widely, from \$55 to a striking \$262 (Schwartz, 2006). This underlines the insecurities within the crude market. But the problem is not as simple as presented here. Quality aspects are not addressed.
Problems with the crude market are mostly described as a supply problem. Peak oil leads to high oil prices is the main argument. Demand aspects are described only as growing or declining, therefore the choice was made to address crude quality in this thesis.

Mostly the prices of crude published are of benchmark crudes, like Brent, WTI and Dubai. These crudes are of relative high quality and price. But ‘the world produces and trades more than 160 varieties of crude oil, which range widely in price: while the United Kingdom’s Brent Blend averaged US\$43.04 in August 2004, Syrian Heavy averaged US\$29.97. Such large price differentials show why a single price cannot serve as a forecast for all crudes.’ (Bacon 2004) These price differences are mostly due to crude quality differences, but also allocation and possible product yield (strongly relates to quality). As described in paragraph 1.1.2 the refinery industry can alter its output by using different qualities crude.

Three quality properties are used most:

1. the specific weight, denoted in API^{o},
2. sulphur content, recently getting more important
3. the Total Acidity Number (for corrosion reasons of refining equipment) (Bacon 2004, Chafizadeh 2003).

Next to these three quality indicators, the ability to produce certain products from crude (boiling point curve) and the location of the crude does matter. Some crudes are more suitable for the production of gasoline than of diesel. The choice of crude depends, in this context, on the structure of the refinery industry and the product market. This, among other things, will be assessed in this thesis.
Transportation costs rises the price of crude at arrival relative to the origin. The same quality crude will yield a higher price when it is closer to a refinery center which can handle the quality. Therefore the allocation of crude is of importance.
Additional parameters are the metal content and the amount of paraffin’s (waxes) and naphtenes.

In the developed regions of the world, production of crude is mostly declining because most of the crude is extracted already. Nowadays, North Sea production is declining, leaving the UK as net importer, just like the US production has passed its peak leading to import reliabilities. Declining domestic production and increasing consumption leads to increasing reliability on imports and therefore more vulnerability of supply disruptions. Already Europe imports about 75% of its crude, of which 43% from OPEC countries and 30% is from the Persian Gulf region. It is expected in 2020 that the Persian Gulf crude production will be 40% of total world production (Commission of the European Communities 2000). Also centralization of crude production, refining and storage at the Gulf of Mexico increase vulnerability by for example tropical storms. Still, oil consumption is growing in the regions where crude production declines; IEA predictions show about 2 percent annual growth of consumption. Security of supply issues are back on the agenda (Stevens 2005, Helm 2005).

Another problem with declining indigenous production, for example in Europe, is that the refinery industry designed there refineries to process specific qualities of crude (local grades). When local crude is produced less, refiners need to adapt and process other qualities from elsewhere. Close import locations with similar crude characteristics are not always available, leading to additional transportation costs. Therefore dedicated (to particular qualities of crude) refiners need investments to make them more flexible to process different grades of crude. As a side effect, flexibility creates possibilities for refiners to diversify there crude feedstock, making them less vulnerable for supply disruptions. All in all, 'the oil must travel ever greater distances to reach markets, which raises issues of the adequacy of the transportation infrastructure and the security of sea lanes and transit pipelines (ESMAP, 2003)' (Stevens 2005)

The Chinese and Indian economies are growing rapidly, boosting there energy demand. These two countries attract vast quantities of crude to their areas, leaving less for the rest of the world. Production seems to have problems keeping up the growth, tightening the crude market. Social unrests in producing countries like Nigeria don't help, and increases insecurity.

Also the events around oil companies resituating their reserves, and mostly correcting them downwards, are a source of insecurity. Shell got the kick off; a more recent case is REPSOL, who needs to cut their reserves in Latin America. These events raised questions on the ways of predicting the available reserves which companies are able to produce, and more importantly, the reliability of data.

1.1.5 The identified problems

Several aspects in the petroleum industry are or are going to change. The context is of importance in this respect. Researching the petroleum industry from a product market and refinery industry perspective will need to incorporate the quality of crude. The following problems were identified above and will be addressed in the thesis:

1. new rules on product composition lead to pressure on the capacities of refineries, because the quality of the refinery output needs to be enhanced (OPEC 2004, Featherstone 2005, IEA 2005, Stevens 2005).
2. the regional refinery production capacities do not match with the regional product demand mix, leading to export and import of products (IEA 2005). In Europe, for example, gasoline demand is declining and diesel demand is increasing. These

kinds of shifts lead to a need of altering refinery schemes, crude feedstock or configurations which are more suitable to produce the new evolving product mix.

3. pressure on refineries and lack of capacity for producing light products may lead to an increasingly lighter feedstock used, resulting in a higher high-low quality crude price differential (OPEC 2004). High investments are needed to convert more heavy to light products (Stevens 2005). 'The share of light products and middle distillates in global oil consumption has risen from 65% in 1980 to 80% today.' (IEA 2005)
4. there may be an imbalance of the quality of crude demanded and supplied: 'The price rise [$50 autumn 2004] was not the result of an overall shortage of crude, but a lack of light, sweet crude for gasoline in China. There's a lot of sour crude in the world, more than anyone can use. More than anyone wants right now.' (Featherstone 2005)
5. the share of production of light low-sulphur crude is declining relative to more heavy sour crude (IEA 2005), this could mean feedstock change for refiners which will probably need to adapt their capacities.
6. when oil reserves or prices are described, not much is told about the quality of crude, while the quality is an important property for producing suitable products (Leffler 2001, Featherstone 2005, Favennec 2001). The crude price revered to most is of a high quality (Brent and WTI), which is only a small part in the crude spectrum, forgetting the majority of crude of less quality. There is a knowledge gap of the influence of the quality crude on the refinery industry and the product market.
7. the petroleum industry is not often described from a demand and supply perspective, underlying crude oil and product prices.

All these aspects are addressed in one way or another in this thesis.

1.1.6 Industry change and strategy

The petroleum industry is at the brink of changes, as described above. Industries adapt or initiate changes by using strategies. The following box denotes the three '*dimensions of strategy*' described by Bob de Wit (1999):

- *Strategy Process*. The manner in which strategies come about is referred to as the strategy process. Stated in terms of a number of questions, strategy process is concerned with the *how, who* and *when* of strategy – how is, and should, strategy be made, analyzed, dreamt-up, formulated, implemented, changed and controlled; who is involved; and when do the necessary activities take place?

- *Strategy Content*. The product of a strategy process is referred to as the strategy content. Stated in terms of a question, strategy content is concerned with the *what* of strategy – what is, and should be, the strategy for the company and each of its constituents units?

- *Strategy Context*. The set of circumstances under which both the strategy process and the strategy content are determined is referred to as the strategy context. Stated in terms of a question, strategy is concerned with the *where* of strategy – where, that is in which firm and which environment, are the strategy process and the strategy content embedded?

‘[Industries] do not change in a piecemeal fashion, because an industry is an *interrelated system*.’ (de Wit, 1999 p347) As noticed above, the environment of the petroleum industry is changing, new regulation on products and a changing product demand mix. Because industry is an *interrelated system* these changes have effect on the whole value chain. To understand what changes can be expected, this thesis is focused on the third dimension, the strategy context. From the strategy context insight can be given on what strategies are followed.
The context influence the industry to change its structure or to influence the context it self. De Wit (1999 p333) presents two perspectives: the industry *evolution* and the industry *creation* perspective. The evolution perspective assumes the industry needs to adapt to their environment (context), ‘industries evolve because some forces are in motion that create incentives or pressure to change.’ (de Wit, 1999 p346).
The second refers to an industry which attempts to shape the context to its liking. ‘In the *industry creation* perspective, both the strictness and the rigidity of the industry rules can be challenged.’ (de Wit, 1999 p334) To be able to challenge the rules and alter them ‘a significant amount of creativity’ (de Wit, 1999 p334) is needed.

1.2 Research objective and Research questions

This thesis will describe the context of the petroleum industry from an evolutionary perspective. By describing the context insights in the possible strategies of the industry can be assessed. Therefore the questions asked are inspired by the question: where are the strategy process and the strategy content embedded? Porter gives a basic concept on how the context can be described from industry evolution perspective, but also gives a framework for forecasting evolution.
The frame work of forecasting evolution of the context starts by the initial structure of the industry. In this case the initial structure chosen is not in the beginning of the industry life cycle (Porter, 1980) but the present situation. The position of the industries life cycle depends on the region. The Asian industry for example seems more in the development stage (with fast growing product demand) than the European industry which is more consolidated. Therefore a description of the present situation needs to be done regionally, depending on the development of the assessed nations.

The goal of this thesis is:

Giving insight in what causal implication developments in the product market have on patterns of crude demand.

To enquire this goal, questions are formed to divide this thesis into manageable pieces. First the main question will be given, followed by questions underlying this question. The focus will be on the quality of the feedstock.

The main question is:

What patterns of change can be identified in the regional petroleum product markets and how will this affect the future capability of the refining industry to provide the products in demand and regional crude demand with emphasis on crude quality?

To answer this question, these sub-questions need to be answered first:

1. What is the current relation between the demand structure of the products markets, the production capabilities of the refinery industry and the supply of crude oil?
2. What trends can be identified in the product market, refinery industry and the crude market?
3. What challenges do these trends pose to the operations of the petroleum industry in the different world regions?

The first two sub-questions are analysis questions which help answering the third question which addresses the main question.

1.3 System analysis and demarcation

The three sub-systems, the crude market, refinery industry and the product market, were described in short in the introduction. The methods used to describe the interactions between the three will be described here. First the guidelines used for this researched will be given, than a division of regions assessed. In paragraph 3 a causal diagram will be described. The causal diagram is used to build a demarcation and methods for researching the three systems separately. Paragraph 5 will present the framework which will be used to overview the complete system and paragraph 6 will describe the major demarcations and research methods described in this chapter (conclusion).

1.3.1 Guidelines for research

This thesis captures the complete chain within the petroleum industry. For the structure of this thesis, the book: *Demand, Prices and the Refining Industry* of Robert Bacon e.a. is used. ‘This book of essays analyses the bevaviour of demand of petroleum products in Europe, the structure of the European refining and patterns of investment and disinvestment in refining, the characteristics of capacity utilization in refining and of the refining yield, the determinants of product price movements and their relationship to crude oil price behaviour and finally the characteristics and changed over time of product taxation in Europe.’ (Bacon 1990) Bacon addresses the three systems and tries to give an oversight. The complete value chain is addressed by Bacon e.a., but focused on finding correlations between prizes of crude and products via econometrical models. This report is focused on finding correlations between the qualities of products and the quality of crude and will not use econometric models.

Bacon addresses the following subjects (selection, econometric and product prize subjects are left out):

- ‘behaviour of demand’, ‘the supply of products from European refineries’ and the international trade of petroleum products
- ‘the industrial structure of European refining’ and the ‘patterns of investment and disinvestments and
- ‘the acquisition of crude oil by refiners’.

This order is suitable for the structure of this thesis and is therefore a guide for the analysis performed here. This thesis will analyze the patterns in crude demand and supply on the basis of the refinery structure and the product demand. It will not go into economic values as prizes, investment costs and operation costs (and therefore margins etc.).
These subjects are all addressed in this report and presented in separate chapters, which can be read separately as essays. At the end the interactions between the systems are analyzed to find an indicator for the quality of crude demand.

There are almost no papers or books which try to capture the complete chain, but often take one or two parts. The research methods for every part use different references which have the best result for reaching the goal of this report.

1.3.2 Division of regions

The world is divided in different regions. Geographical location, consuming or producing and regulatory state are important properties for forming these regions. First a geographical division is made, which resemble the world continents. The exporting and importing regions are separated within these continents. Countries with similarities on regulation are separated from the other importing countries. The crude exporting regions are divided in geographical location and by the quality of crude it produces. The availability of data (IEA Data 2005 and ENI 2005 and 2006) is of great importance. Regions are checked on the resemblance of regions used by the major data providers.

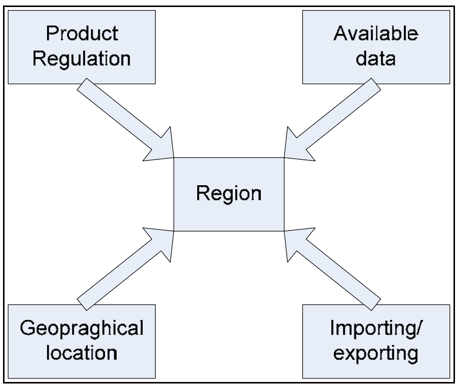


Figure 3: Construction of regions

Geographically division: Europe, Asia Pacific, Africa, North and South America. The main importing regions are:

- Europe
- Asia Pacific
- North America

The producing regions are:

- the Middle East
- Africa
    - West Africa
    - North Africa
- Latin America
- FSU
- North Sea (UK, Norway, Denmark)
- North America
- Asia Pacific

The level of regulation divides the world in developed and developing countries. Primarily the OECD countries have more regulation and are mostly working on sulphur reductions. Next to similarities in level of regulation, the OECD countries are major consumers of petroleum. The OECD regions North America, Pacific and Europe are consistent with geographical location and consuming.
The refinery complexity is of importance. ENI World Review 2005 and 2006 uses regions which are quite similar. The ENI information is much less compliant than the IEA information, mainly because the IEA describes a great diversity of countries and regions of which the regions can be changed with a minimum of effort. The consuming regions are therefore divided in the regions as used by ENI.
In addition, to construct a framework to combine the product market, refinery industry and crude market parameters need to be known. The problem lies with crude quality. To link the conversion ratio to crude quality the crude quality consumed needs to be known. As later on will be decribed, the crude quality can be assessed on the basis of the import origins. The import origins of the OECD countries are known, therefore focus is on these countries and regions. By using the model the crude qualities consumed in the other regions will be calculated.

Incorporating the quality crude produced, the following regions can be made: North Africa, mainly light sweet crude, West Africa, mainly medium heavy and sweet, Middle East, FSU and Latin America (Heavy) (p19 Reinaud, 2005). Consuming regions also have production. The following regions are identified: North Sea area or Western Europe (UK, Norway, Denmark), OECD Pacific (Australia) and North America.
The following regions will be assessed:

Consuming regions	Producing regions
North America (US and Canada)	Middle East
Western Europe (EU-15 plus[1])	West Africa
OECD Pacific	North Africa
	Latin America (including Mexico)
	FSU
	North Sea
	North America
	Asia Pacific

Table 1: Regions used to analyze the product and crude streams and crude quality.

The following regions will be used to calculate the average quality of demand of crude oil. The regions with the same name used above include the same countries. Asia is taken without the OECD Pacific (to prevent double counting). This division is made providing the complete world was covered and the complexity ratio is known. Different data is used with another goal and therefore these regions do not need to resemble the regions given above.

- Asia
- Latin America
- Africa
- Middle East
- Central Europe
- FSU
- Western Europe
- North America
- OECD Pacific

1.3.3 Causal diagram of the petroleum industry

The goal of the causal diagram is finding ways to research the quality of the crude demand. First the diagram will be described as a whole, than it will be described per important parameter for this thesis. These parameters are inspired by the aspects (between the brackets) researched by Bacon described in paragraph 2.1. The most important parameters in the causal diagram presented in Figure 4 are:

- Crude quality supply mix
- Quality feedstock (‘the acquisition of crude oil by refiners’)
- Refinery complexity (‘industrial structure of European refining’)
- Product quality required (‘behaviour of demand’)
- Product mix demand (the international trade of petroleum products, ‘behaviour of demand’)
- Product mix supply (‘the supply of products from European refineries’, the international trade of petroleum products)

[1] EU-15 plus Norway, Switzerland and Turkey (ENI 2005)

Overall description of the causal diagram
The causal diagram will address the most important notions for my thesis. They will be brought in connection so that the system will become clearer. The diagram will be used as basis for the rest of my studies, therefore it plays a central role. This chapter paragraph will describe the causal diagram in an orderly fashion.
This diagram will be described from right to left: beginning with the crude market ending with the product market. These three aspects will be described from up to down consequently.

Crude market
The crude market is, in this report, dominated by the quality of crude oil. The quality of crude is determined by two indicators: API° and Sulphur content. There are other indicators as well, but API° and sulphur are the most important properties (Leffler 2000, Speight 2001). Crude's are often revert to as heavy or light and sweet or sour, revering to API° and sulphur (ENI 2005, Leffler 2000, Speight 2001 etc.). At the moment sulphur specifications for product is the major concern for refiners, using most of the capital (Nakamura 2004). The crude quality determines, through demand and supply, the price of different qualities of crude. If crude prices rise, 'refiners are more likely to process less expensive crudes, which are heavier and contain more sulfur.' (Nakamura, 18-10-2004) Lower quality crude is more difficult to process into high quality products, leading to higher operating costs and need of investment. 'The primary process for converting the hard-to-remove sulfur species in diesel fuel is high-pressure hydrotreating. These units, both new and revamped, are expensive.' (Nakamura, 18-10-2004) Crude's containing less sulphur need less treatment and is therefore from the refining cost perspective more attractive.

Refinery
The refinery complexity is determined by the facilities it possesses. Conversion possibilities and sulphur production capacity relative to the primary capacity determine the complexity. The complexity of a refinery gives an indication on what quality crude it is able to process to produce suitable products. The refinery configuration is mostly inflexible (Drevna, 2005), by changing feedstock and the operating scheme marginal adaptations are possible. The complexity is, on the long run, influenced by the product quality and the product mix demand. The configuration of the refinery industry is historically set (Reinaud 2005) by the regional situation of the product and the crude market.

The quality feedstock used determines the amount of processing needed to produce suitable products and therefore it influences the operating scheme (see: Drevna 2005). The operating scheme determines what products are produced and in what quantity, and therefore determines product mix supply. The scope of the refinery operating schemes and the crude qualities used is limited by the refinery complexity.
Refiners able to treat heavy and high sulphur crude are able to make the biggest refinery margins (Nakamura 2004, Tippee 2005). According to O'Malley (chairman of refiner Premcor Inc), 'high conversion refineries make twice to three times as much money running heavy crude than it does on higher quality crude.' (Tippee 2005) This illustrates that complex (taking high conversion means more complex) refineries should use its capabili-

ties to make high profits and therefore feed with qualities of crude appropriate with refiner's complexity. Therefore the operating scheme is dictated by using as much capacity as possible to produce a product mix with crude most suitable to attain the highest possible netback.

The operation costs are calculated by adding the costs for crude freight with the refinery costs. The operation costs are determined by the operation scheme used. The operation costs determine the possible height of the netback, and therefore indirectly the refinery operating scheme. The decision on the feedstock used is partly determined by the operating costs.

The product market

For the product market, quality has the primary focus. The product quality is influenced by emission legislation, leading to fuel regulation. Motor fuel efficiency is of importance to reduce exhausting (EPA 1999), the octane number for gasolines and cetane number for diesels are indicators for fuel efficiency in motors. Oxygenates (like MTBE) enhances octane number and reduces CO emissions (Leffler 2000; 193), but in the US legislation is at hand for banning this substance leading to less producing capacity. Environmental legislation is focused on sulphur content, and less focused on oxygenates content (EPA Tier 2 1999; Directive 2003/17/EC). Because this report focuses on sulphur content, the other contaminations are not taken into account.

The product quality required requires a certain refinery complexity. Product quality required changes product demand, through the use of alternatives like for shipping. Since the refinery configuration is inflexible, the operating scheme is the first to change to meet changing demand. Supply and demand determine the product price; the demand is influenced by the product price. Product price is part of the calculation of the netback.

The product mix demand also influences the refinery complexity. Changing demand, for example, to more light products leads to more need of conversion (or operating scheme for that matter).

'The netback value of a crude oil is calculated from the values of its product yield, less refining costs and crude freight.' (Favennec, 2001; 582) If the netback is higher than the crude price (fob), a profit can be made called. The difference between the netback and the crude price (fob) is called the margin. There for the possible netback is important for the crude choice made.

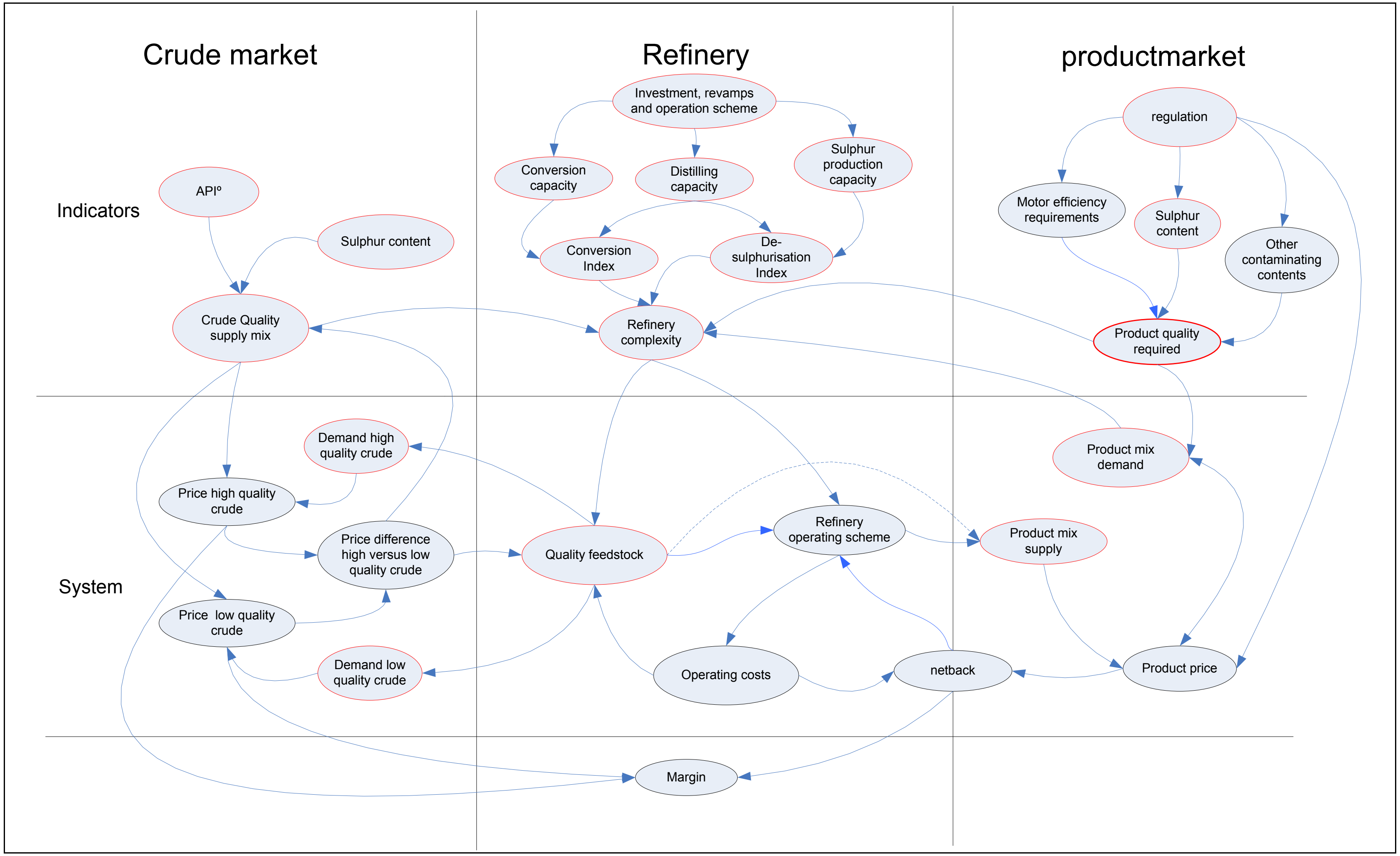


Figure 4: Causal Diagram, crude market, refinery and product market

1.4 Research methods

1.4.1 Product market, supply and demand

The product market is one of the initiators of problems within the refinery industry and crude market. Change in product mix and change in regulation on contents of products asks of refiners to be more flexible on their outputs. Therefore, the first focus will be on changes in this segment.
A look into regulation on quality of products needed. Changes in regulation are currently on sulphur content. Regulation in the OECD regions may have influence on the product streams between regions; some traditional importing origins may not be able to comply with new regulation. This could also change crude supply, towards low sulphur crude.

To be able to analyze the product market on a world level, prioritizing different products to reduce the amount of products analyzed is needed. This is partly set by the regulated products, mostly transportation fuels, and by the relative importance within the product market in the sense of volume or mass traded. The products are also chosen on the basis of available data.
The following products are taken on the basis of regulation, amounts traded and the available data from IEA:

Products analyzed	**Other Products**
Naphtha	Refinery Gas
Gasoline	Ethane
Kerosene	Liquefied Petroleum Gases
Gas/ diesel oil	Aviation Gasoline
Residual fuel oil/ heavy fuel oil (HFO)	Gasoline type Jet Fuel
Other Products	White Spirit & SBP
	Lubricants
	Bitumen
	Paraffin Waxes
	Petroleum Coke
	Other Petroleum Products

Table 2: Products analyzed in this thesis

Because the goal of this report is giving insight in demand of certain qualities of crude, the look into the product market can be restrained to trend analyses on the basis of time series and trends in regulation on products, which can be described on a qualitative basis. The product market is often described by trend analyses and econometrical methods on price elasticities (Bacon e.a. 1990; 65-67). Often a relation between the price of products with the price of crude is assessed.

Because not a relationship in price between products and crude is of importance, but physical demand and supply with quality aspects, trend analysis on supply and demand will suffice in this thesis.

Time series are often used next to growth percentages of different periods (see Bacon e.a. 1990, Reinaud 2005, IEA 2005, ENI 2005 etc.). These trends can be used to assess future demand of products. Trends do not take into account sudden changes in markets. Shocks in the demand for products, influenced by different external factors like the state of the crude market and the refinery industry, are feasible to happen in the future. Trend analyses are suitable for predictions in the short run rather than in the long run, because it is more likely that a trend break happens in the long run rather than in the short run. The trends will mostly address demand for products and it is taken that the refinery industry needs to follow. Differences in consumption and regional refinery output are calculated to begin an assessment on the product flows between regions.

Next to supply and demand, product streams between regions may be of importance for dissolving shortages and surpluses. Trend analysis is possible, but requires a lot of work because four dimensions are involved in this analysis: products, time, regions of destination and origin. The analysis is based on the consuming region, of which the im- and exports are assessed per product. To prevent extensive analysis, only two years are taken into account, 2000 and 2004. This way, recent changes can be assessed and the current situation is known, regression on the basis of time series will not be performed.

1.4.2 Industrial structure of refining

The configurations of refineries vary widely. The types and size of equipment influences the possible yield of products. The way this equipment is tuned, and, to make it even more complex, the type of crude used influence the possible yield. '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.' (Correlje, 1994: 181). Analyzing the refinery capacity worldwide is a very complex business when all parameters are taken into account. The second problem, next to the huge complexity, is the amount of information needed to predict the possible product yield, which is not always available. That is why a simplification of configurations, capacities, yields and generalizations on the feedstock and capacities in certain refining regions are needed. Regions are already formed in paragraph 2.2.

There are different ways of modeling the refinery industry, mostly dominated by linear programming (LP). The major oil companies have a very wide range of models, which are very sophisticated and have been developed over a long time period. The problem with these models is that they are confidential, very complex and need vast amounts of information (Babusiaux, 1970). Therefore LP modeling is not used in this thesis.

The analysis on the structure of refining will start with a description of the refinery processes, their typical feedstock and yields. The ability to convert heavy into light products and the type of yield (for example mainly diesel or gasoline) can be used to classify the different sorts of refineries (Reinaud 2005, Wijetilleke e.a. 1984, Bacon e.a. 1990 etc.).
The complexity of a refinery can be described by a single index. Several authors tried to do so. A selection is made on the most suitable index. A choice between the conversion

ratio and the Nelson index is made. The complexity index can be used for correlation with quality indicators of crude. It is presumed that the lower the quality of crude demanded the higher the complexity of the refinery (taking that the product market is comparable).

To get more is insight in the configuration of the refinery industry, typical refinery configurations need to be created. To create a suitable classification, different classification schemes used by several authors, knowingly Margaret Chadwick (Bacon e.a. 1990), Julia Reinaud (Reinaud 2005), Favennec (2001) and William Leffler (2000). These classifications are a like, and the best features (for this report) of the structure of these methods will be used. The features are tested on the suitability and information available for this thesis.

A tally will be performed on the different types of refineries. Together with information on the different kind of product yields of the equipment tallied, an idea of the possible product yield can be formed. Comparable tally is performed by EC-IPPC in 2001.

A trend analysis is performed to assess the capacity growth of the refinery industry, focused on the different kinds of conversion equipment. In combination with the typical yield of these different processes, insight in the ability of producing certain products in the future can be created. The trend seen from 1996-2004 will be extrapolated to 2010. A approximation of the development of the complexity can be made. This can be used to assess the future quality of crude demanded. The year 1996 is chosen because of the available data. The capacity addition reported by Oil and Gas journal refinery investment update will be added.

1.4.3 The acquisition of crude oil by refiners, the quality of crude

'Petroleum is a naturally occurring mixture of hydrocarbons, generally in a liquid state, that may also include compounds of sulphur, nitrogen, oxygen, metals, and other elements.' (ASTM D-4175, from JG Speight, 2001) There is a wide variation of compositions of petroleum, this is mainly site specific, and the composition differs per oil field. That is why making an easy sheet with the possible qualities is not possible unless simplifications are made. There are indicators which give a good idea about the quality.

There are heavy and light crude's. Light crude's are mostly referred to as conventional and (very) heavy crude's mostly as unconventional. Heavy oil is more viscous than light and has a bigger high boiling point fraction (heavy products). 'The most important properties of a whole crude oil are its boiling-point distribution, its density (or API gravity), and its viscosity.' Viscosity is an indication on the content of 'undesirable residual material', which resists the crude to flow. The boiling point distribution is often denoted in a graph and gives an indication on the amounts of different products produced after simple distillation of crude. The density is an indicator for both, lighter crudes contain products with low boiling points (light products) and is less resistant to flow, and vice versa. Sulphur content is a crucial characteristic for crude (JG Speight, 2001) Therefore the analysis will start with setting up a good classification of the notion crude on what is heavy or light and sweet (low sulphur) or sour (high sulphur). Several references will used to classify the crude qualities.

After this first step the actual production and consumption is analyzed, starting with the quality of crude:

- The quality of crude in the producing countries is taken from IEA data cd-rom, Haverly site (with a great amount of crude assays).
- It is taken that within the regions the crude quality produced is approximately the same. The weighted average of the countries with known API° and sulphur content from the same region will be used for countries with unknown quality.
- The production of 2010 is predicted by extrapolation of the growth from 1990 until 2004.
- In addition, predictions from the IEA will be used to check and to sometimes correct trends and the outlook to 2010. The IEA outlook does not present their predictions in great detail, therefore this analysis is performed. Different sources use different definitions of their data, while trying to describe the same. For example, BP includes condensates and natural gas liquids, but the IEA Outlook excludes them from the crude production. These differences are taken into account.
- The quality of crude in regions and the world are calculated by the weighted average. By using the extrapolation of production the average quality from 1990 until 2010 can be calculated.

Second step taken, is describing the crude streams. The origin of imports into OECD countries is mapped (these import figures are made available by the IEA), and adapted to be able to calculate the imports of the regions described above. In addition, the shares of imports per origin will be given in 1993, 1994, 1996, 1997, 2000, 2001 and 2004. Of these years there is information available on the refinery complexity.

Finally, quality of crude processed in refineries in different regions will be analyzed by calculating the weighted average of the quality of the import and domestic crude. The import streams and the quality of crude per production country will be used. No trend analysis will be performed here; it is unknown what the future import origins will be. The model described in chapter 6 will estimate the future quality of crude processed.

The qualities imported from export countries could be of a different quality than the average used in this report. It must be noted that countries produce different qualities of crude, which can be imported separately. All though this influences the average quality of crude processed in different countries, this is not taken into account. The data needed to incorporate this is not available. Oil refiners keep there feedstock quality secret, and the import figures do not include the type of crude imported.

It is taken that the average quality of crude produced in the countries stays the same over the years, from 1993-2010. The individual fields differ in quality. New oil fields come on stream and old fields decline in production, therefore the average quality produced changes over time. This change is not taken into account.

1.5 Demarcation

This paragraph is divided into four sections: the three segments of the system (product market, refinery industry and the product market) and a demarcation for the model in chapter 5.

1.5.1 Product market

1. The focus will be on the OECD regions (chapter 2.1)
2. Regulation on sulphur content in products are taken into account in this report, other regulated contaminants are not taken into account. Sulphur is a quality indicator of crude.
3. When the product demand mix shifts to lighter products, less heavy products are demanded. This seems straight forward but is of importance for the model in chapter 5.
4. The product price is beyond the scope of this thesis, which is about supply and demand.
5. The following products will be assessed (see chapter 2.1 for more details):
   a. Naphtha
   b. Gasoline
   c. Kerosene
   d. Gas/ diesel oil
   e. Residual fuel oil
   f. Other petroleum products
6. The higher the API^{o} of the crude the less residual fuel is produced by the distilling unit.

1.5.2 Refinery industry

7. The refinery complexity is summarized into one indicator: the conversion index (for the reason see chapter 4.2).
8. The 'do nothing' strategy is not assessed.
9. The operating costs are determined by the refinery scheme, quality of the feedstock and the netback. The refinery scheme is difficult to determine (Correlje 1994), and is influenced indirectly by the operating costs (via the netback). Therefore operating costs, refinery operating scheme, the netback and therefore the margin are not taken into account. Prices, costs etc. are beyond the scope of this report.
10. Demarcation 7 implies that the strategy of altering operation scheme to adapt to the product market is not further assessed.
11. The strategy of revamping existing units is incorporated in the investments and not assessed separately.
12. The configuration of the refinery determines the production of products together with the quality of feedstock. HCC refiners are best suit for the production of diesel, FCC refineries are best suit to produce gasoline (see chapter 4.1).
13. The historical demand of gasoline and diesel (product mix demand) determine the configuration of the refinery industry now and therefore the product mix supply. This fits with the industry evolution perspective.

14. Based on the possibilities of refineries to produce different products with different processes the following classes of refineries are defined (chapter 4.2):
    a. Simple refinery: distillation and treating units
    b. Semi complex refinery: includes thermal processing and treating units
    c. Complex refinery:
        i. FCC
        ii. HCC
        iii. FCC and HCC
    d. Very complex refineries: deep conversion:
        i. FCC
        ii. HCC
        iii. FCC and HCC
15. Because investment in conversion capacity is high and the gains are large (Leffler 2001), it is taken that the conversion capacity is used in full, in contrary to the distilling capacity. This was underlined by Han de Krom of Shell global solutions.
16. It is taken that refineries demand a quality of crude appropriate to the capabilities of processing them (relates to the maximum use of its conversion possibilities) and the state of the product market (heavy – light products balance).
17. The refinery industry has four different possibilities to cope with changing crude and product market:
    a. Alter operating scheme (beyond the scope of this report) (short term)
    b. Change crude quality (short term)
    c. Revamp old equipment (medium term)
    d. Invest in new equipment (long term)

1.5.3 Crude market

18. Crude quality is determined by the API° and the sulphur content.
19. The price difference between different qualities of crude are not taken into account, this thesis uses the physical trade as basis for its analysis, not price.
20. Crude is classified according the following table (chapter 5.1):

Crude	Sweet <0,5 wt%	Intermediate sweet	Intermediate sour	Sour >1,5 wt%
Heavy 10-22° API	Heavy-Sweet	Heavy-Inter. Sweet	Heavy-Inter. Sour	Heavy-Sour
Medium 22-33° API	Medium-sweet	Medium-Inter. Sweet	Medium-Inter Sour	Medium-Sour
Light 33-50° API	Light-Sweet	Light-Inter. Sweet	Light-Inter. Sour	Light-Sour

Table 3: Crude qualities

21. To cope with unknown crude quality the crude quality of countries in the vicinity or the weighted average of the regions crude quality is used (chapter 5.2).
22. The average crude quality in producing countries stays the same over the years.
23. Crude produced in the same region is of similar quality, therefore changes of quality due to changing production outputs from fields will be marginal.
24. Crude quality of a country stays the same over time.

25. All though refiners are able to import specific qualities of crude from countries (different from the average quality), the average quality crude of the country is used to assess the weighted average of the quality of crude imported. (chapter 5.3)
26. Crude price is not taken into account.

1.6 Chapter division

In chapter 2 the focus will be on the product market. The different products, regulation on product quality and use and the development of supply and demand in different regions will be assessed in this chapter. Trend analysis will be used to describe the product market in the past, present and the future. The product balance (refinery output – consumption) and international trade streams will be described.

In chapter 3 the refinery industry is analyzed. By describing the different refinery processes and their typical configuration within the refinery, more insight in the types of refineries and their yields is given. Based on literature, different ways of classifying the refineries will be given. These classification schemes will be used to investigate the refinery sector in different regions and countries. Last, conclusions are drawn on the developments in the refinery industry in the different regions (North America, Europe and the OECD Pacific).

Chapter 4 is describes the crude market. First, ways of classifying crude qualities will be given. The crude quality of world production will be assessed, followed by the streams of crude to the consuming regions. From this data the average quality of crude consumed in regions and countries is calculated. The result will be the average quality of crude produced over time and the average quality of crude consumed over time.
Chapter 5 will describe the model used to predict the quality of crude consumed by using two indicators: refinery complexity and the residual fuel production. The input variables are the conversion ratio (a classification scheme) given in chapter 3, the crude qualities calculated in chapter 4 and the residual fuel production share (RFPS) given in chapter 2. Using the information given in chapter 2, 3 and 4 an equation is constructed which can predict the quality of crude consumed in the countries/ regions which are not assessed and no information is available. Using this data a prediction can be made on the quality of crude consumed in 2010 in the world.

In chapter 6 an actual prediction is made on the quality of crude demanded now and the future. The model described in chapter 5 will be put into practice. In addition some insights will be given on the impact of sulphur regulation in transportation fuels.

Chapter 7 will answer the questions asked in this introduction. The different regions are described separately.

Chapter 8, the last chapter, the conclusions will be drawn. The impact of all these changes in petroleum industry is described and the interaction between these impacts.

Recommendations are given on how to cope with the changes and impacts. Last a short evaluation is given.

2 Product legislation, demand and the product streams

This chapter will describe the supply and demand of the product market and regulation on product specifications, focused on sulphur content. The goal is to give more insight in the market for petroleum products with emphasis on product regulation and volumes demanded, supplied and traded.
By analysis more insight on the drivers for change in the refinery industry and eventually the crude market will be attained. The product market is getting increasingly lighter and shifts in the type of products consumed are posing challenges to the refinery industry (from gasoline to diesel). This has an impact on refinery industry which provides the product supply. The following causal diagram is a part of the diagram described in the introduction; the red circles are assessed in this chapter. The refinery complexity is assessed in the next chapter.

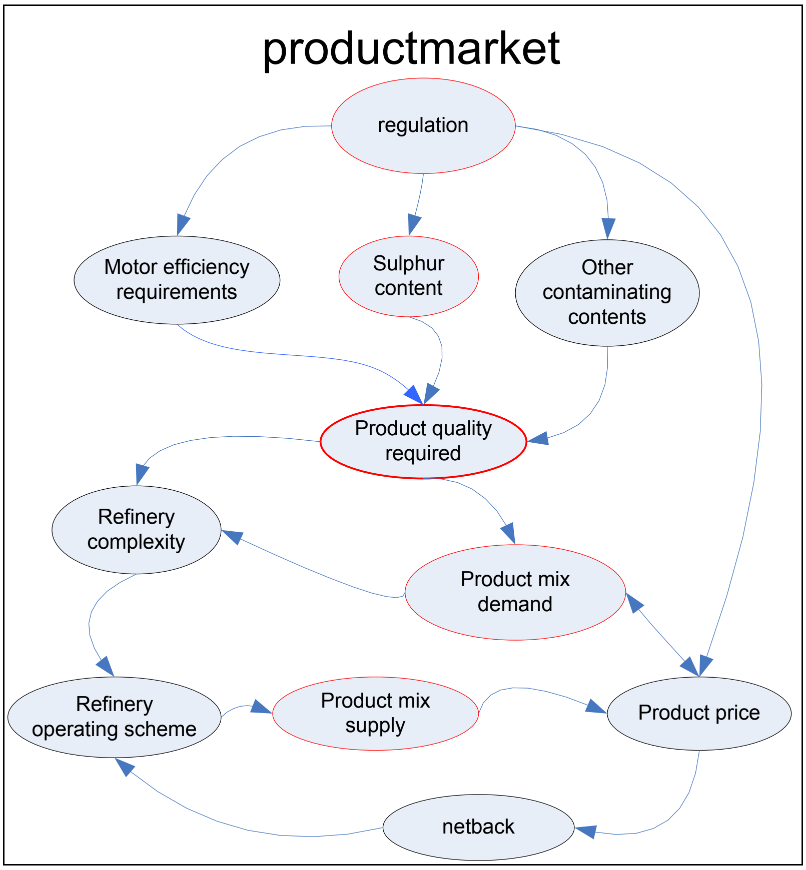


Figure 5: Causal diagram product market

The focus is on North America, Europe and OECD Pacific. The focus within these regions will be on the implications of changing specifications. The chapter will describe the different parameters in the causal diagram from up to down. This chapter will start with the explanation of the regulation on products specifications (product quality required); first by introducing the general product specifications at hand, than by describing these specifications in different regions (Europe, North America, OECD Pacific, Latin America, Asia and Africa). Sulphur content is the most important product specification here. In the following paragraphs the structure of the product market is described and a trend analysis is performed. Demand and supply of products in the different regions are compared. In addition the product streams between the regions will be mapped. At the end conclusions will be given.

2.1 Product specification in different world regions

This paragraph will describe product regulation in different regions. Focus is on sulphur content of transportation fuels. Sulphur affects the catalyst in the tail pipe of automobiles, which undesirable. First an introduction will be given on regulation of products, than the different regions will be described. After an introduction Europe will be assessed, followed by North America, OECD Pacific, Latin America, Asia and Africa.

2.1.1 Introduction on product specifications

Different world regions develop regulation in a different pace. A big portion of Asian countries are phasing out lead while other countries have already done this and start with regulation on sulpur content. It is beyond the scope of this report to focus on all the different compounds which are regulated. Appendix 1 Table 68 and Table 69 describes the minimum/ maximum specification of petrol and diesel in the European Union on different compounds and blend stocks (half products which are blended in the end product).
Regulation is mostly focused on environmental performance and in lesser extend motor performance, although they are intertwine. Now focus is on reducing CO_2 and NO_x compounds.

‘The adverse effect of sulfur content in petrol and diesel fuels on the effectiveness of catalytic exhaust gas after treatment technologies is well established for on-road vehicles and increasingly in the case of non-road mobile machinery.’ (Directive 2003/17/EC) Sulphur binds itself with catalysts used in tale pipes to reduce undesirable exhausts, making the catalyst ineffective (EPA 1999). In developed countries governments are now regulating sulphur content in fuels. The production of CO_2 with the production of lower sulfur containing fuels is surpassed by the gains possible with on-road emissions (Reinaud 2005 (checken)). According to EPA sulfur produces SO_2 acid, which causes acid rain.
There are no catalysts currently available on which the effect of sulphur is small enough to keep the sulphur levels as they are and reduce emissions (EPA 1999). The working of the catalyst depends on factors like positioning of the catalyst relative to the engine, speeds and loads of the car, fuel air mixture etc. (EPA 1999). Therefore reducing sulphur in fuel is the best way of making sure that the catalyst works sufficiently and long enough to be able to apply to emission regulation.

Next to sulphur reductions, rules on MTBE in reformulated gasoline are issued in the US. MTBE or oxygenate is used as blend stock for gasoline and enhances octane number and reduces exhaust. It is also a contaminant in the environment and especially in drinking water. Only small amounts (15-20 parts per billion) can make drinking water undrinkable (Bellamy e.a. march 2003).

2.1.2 European Union oil product regulation

The EU enacted new regulation in October 1998 on quality of gasoline and diesel fuel. The last revision was made in March 2003, this is as such the source used in this part. Regulation is issued to meet the requirements of the 'Community air quality' through regulating sulphur content in fuels, 'the reduction of the sulfur content in petrol and diesel fuels has been identified as a means of contributing to the achievement of those subjects [community air quality].' (EU 2003)
By the first of January 2005, the European Commission directs that 'unleaded petrol with a maximum sulphur content of 10 mg/kg is marketed within their territories.' By the first of January 2009, this should be the only petrol available in the EU. The same counts for diesel. For non-road vehicles a sulfur content of 2000 mg/kg in 2005 and in 2009 a 1000 mg/kg is compelled.

In the table below, the gasoline specifications of 2000, 2005 and 2009 are given. The 2009 specifications need to be available in 2005. Only the changed specifications are given here, the complete specifications for 2009 gasoline can be found in Appendix 1.

Parameter	Unit	2000	2005	2009
		max	max	max
Sulfur content	Mg/kg[2]	150	50	10
Aromatics	% v/v	42	35	35

Table 4: legislation changes on gasoline specifications.

The 2009 grade diesel specifications need to be available 'on an appropriately balanced geographically bases'. The only specification changing for diesel is sulphur content.

Parameter	Unit	2000	2005	2009
		max	max	Max
Sulfur content	Mg/kg	350	50	10

Table 5: Sulfur content for diesel

Also the bunker market is subject to regulation. There are rules for sulphur content of residual fuel for inland use for some time now. New rules are issued for inland as for maritime shipping. Rules on emissions on FO use in the European Union are three wise. There is a norms on quality of FO used in ports, in the territorial waters of the North-Sea, East-Sea, and the Canal, and for inland (industry, heating etc.).

Location of the use of fuel oil	Maximum sulphur content % by weight
Inland use (heating oil, industry)	<1.0%
North-, East Sea, Canal and ferries	<1.5%
Ports	<0.2%

Table 6: Sulphur content rules on fuel oil in the EU

[2] mg/kg relates to ppm one on one (EPA D-2; April 1999).

In 2010 0.1% for all inland waterway vessels and vessels in port is considered, considering a minimum of fuel change with arrival and departure (Official journal of the EU 22-7-2005).
To cope with legislation on emissions for fuel use in ports, it is best to use marine gas oil instead of residual fuel, for gas oil has lower degrees of PM (Particulate Matter) and sulphur[3]. The production of HFO with <0.2% is not per se needed to meet the EU-directives, gas oil can be used in this market (EU 2002). In ports energy (electricity) can be taken from land instead of ships producing energy from residual fuel.

2.1.3 North America oil product regulation

USA fuel specifications
In the US, just like in the EU, legislation on emissions has effect on the quality specifications of fuel. To meet Tier 2 legislation on emissions, reducing sulphur content is important. In California there are already restrictions on sulphur content in gasoline, which now yield a maximum of 30 ppm of sulphur. In the rest of the US the total sulphur content need to be reduced from 300 to 30 ppm in 2006. The next table summarizes the gasoline sulfur standards as announced by EPA (EPA, December 1999).

Ppm	Average	Corporate average	Cap
2004	-	120	300
2005	30	90	300
2006	30 (150*)	-	80 (300*)
2007 Western US	30*	-	80*

Table 7: Gasoline sulphur standards phase in. *Western US exceptions

In diesel the sulphur content needs to be reduced from 500 now to 15 ppm, this requirement needs to be reached in June 2006. Both changes (diesel and gasoline) are phased in, beginning in 2004.

Due to shortages in refinery capacity and the growing dependency on imports, applying these rules could mean fuel shortages. Due to legislation, capacity will be lowered with 1,5% for gasoline and 320.000 b/d diesel capacity will be shot down, resulting in even more shortages (Meloy e.a.;2003). Not all countries exporting fuel to the US can or want to effort the investments needed. In the case of diesel this may not be a problem because of a surplus production, for gasoline this can oppose a problem.

Canadian fuel specifications
In Canada the restrictions on sulphur is not as severe as in the US. The phase out of sulphur from gasoline begins in 2004 at 300ppm and 80ppm in April 2005 for retail. Regulation on the output of refiners begins in 2002 at 150ppm and on January 2005 30ppm. There is some differentiation on rules for the northern parts of Canada. Other specifications are region specific and beyond the scope of this report.

[3] For further reading on this subject, look at the EU website
http://europa.eu.int/comm/environment/air/transport.htm#3

<table>
<tr><td colspan="2">Sulphur limit (mg/kg)</td><td>On-Road Diesel Fuel</td><td>Off-road diesel fuel</td><td>Rail and Marine diesel fuel</td></tr>
<tr><td rowspan="2">500</td><td>Production or import</td><td>Since 1998</td><td>June 1, 2007</td><td>June 1, 2007</td></tr>
<tr><td>Sales</td><td>Since 1998</td><td>Oct 1, 2007</td><td>Oct 1, 2007</td></tr>
<tr><td rowspan="2">15</td><td>Production or import</td><td>June 1, 2006</td><td>June 1 2010</td><td>June 1, 2012</td></tr>
<tr><td>Sales</td><td>Sept 1, 2006</td><td>Oct 1, 2010</td><td>N/A</td></tr>
</table>

Table 8: Sulphur limits on diesel fuel in Canada

(http://www.ec.gc.ca/cleanairairpur/Pollution_Sources/Fossil_Fuels/Diesel-WS94F5583C-1_En.htm)

For heavy and light fuel oil (HFO/ LFO) there is no national regulation, regional regulation for LFO is mostly 0.2%wt and for HFO a maximum of mostly 1.0%wt of sulphur. Canada is looking into European regulation as example for future national regulation (Fuels Division, Oil, Gas and Energy Branch, Environment Canada, April 2003).

2.1.4 Asia oil product regulation

In Asia every country has its own rules on fuels. To cope with the many countries in Asia, they are categorized according to the level of regulation. One category is still phasing out lead from gasoline, others advance in specifications for sulphur, benzene, aromatics and olefins content. In most Asian countries diesel is consumed more compared to gasoline, only Australia consumes more gasoline than diesel (in 2000) (Kiuru 2002).
Here the categorization of The International Fuel Quality Center (IFQC) (Kiuru 2002) is used. The first category of countries has no regulation on transportation fuels at all, the second category is phasing out lead, the third category has regulation on sulphur and benzene in gasoline, and sulphur in diesel. The fourth category has regulation on benzene, sulphur, aromatics and olefins content in gasoline and sulphur in diesel on a higher level. The countries in this last are most interesting, the other countries are left out of further analysis.
The following table denotes the different countries in the categories. For every category the share of the total gasoline and diesel consumed in Asia is given. With this information an assessment of the consuming potential of Asia of low sulphur gasoline or diesel can be made.

	Country	% diesel	% gasoline
Category 1	Brunei, Nepal, Papua New Guinea	6	4
Category 2	Bangladesh, Indonesia, Vietnam, Pakistan	10	8
Category 3	China, India, Malaysia, Singapore, Thailand, Philippines	47	40
EU specification near future	Australia, New Zealand	4	9
Category 4	South Korea, Japan, Hong Kong, Taiwan	33	39

Table 9: Asian countries categorized by level of regulation on fuel specification and part of fuel use in 2000 (Kiuru 2002)

According Kiuru (2002) Australia and New Zealand would like to follow the EU legislation on fuel specifications, therefore these two countries are taken into account as well. China is mentioned by the Ministry of Economic Development of New Zealand (may 2005) with regulation on fuels in cities, but is not taken into account as consumer of low sulphur fuels because of the lack of information on the subject. This means that about 37% of the diesel and 48% of the gasoline consumed in Asia and Australasia will have or has restriction on sulphur content, and may have influence on the availability of low sulphur products in the world. The countries with sulphur regulation are all OECD Pacific countries.

Information is taken from the ministry of economic development of New Zealand 2005.

	ppm sulphur Gasoline	Year	ppm sulphur Diesel	Year
Australia	150, 50 (10)	Now, 2008 (2010)	50, 10	2006, 2009
New Zealand	150	2006	50, 10	Now, 2006
South Korea	50	2006	30	2006
Japan	50, 10	Now, 2007	50 (10)	2005 (2007)
Hong Kong	50	2006	10	Now
Taiwan	50	2007	50	2007
China	50	2008	-	-

* Ministry of Economic Development New Zealand 2005
** Diesel fuel news 11-24-03

Table 10: Regulation on sulphur content in Asia and Australasia

2.1.5 Latin America oil product regulation

Latin America has little regulation on sulphur content of diesel and gasoline. Only Chile has more stringent regulation, Argentina tends to follow. Brazil has some extra regulation on sulphur content in the major cities, still this doesn't tip to the ultra low sulphur specifications found in OECD and several Asian countries.

	Gasoline ppm	Year	Diesel	Year
Argentina	100	2006	100	2006
Brazil	400	2006	500	
Chile	50	2004	100	
Mexico	100		500	
Uruguay	350	2005	1000	2005
Colombia	200	2005	500	2005
Venezuela	600		5000	

Table 11: Sulphur content in gasoline and diesel in Latin America

Low sulphur products are demanded, this could lead to problems in there own fuel supply. This could impose problems in exporting fuels to the US. Still the regulation is not stringent; therefore Latin America is neglected in this report. Only Chile, Argentina and Mexico have stricter regulation. But this region has exporting potential to the US, therefore abilities to produce low sulphur gasoline or diesel may be important.

2.1.6 Africa oil product regulation

'Other than South Africa, which is mandating 500-ppm sulfur diesel by Jan. 1, 2006, no countries in Africa are regulating fuel-sulfur levels.' (Nakamura 2004) Therefore Africa will not be analysed in the context of products.

2.1.7 Conclusion

OECD countries are most advanced in regulation of fuel products. Therefore the focus will be on these countries. The following regions will be assessed further:

- North America, United States and Canada
- EU-15 plus Norway, Switzerland and Turkey (these countries are added because later on the conversion ratio is used for the refinery industry and this region is used in data available)
- OECD Pacific.

Latin America is starting up regulation on sulphur, but is not yet advanced as in most of the OECD countries. Latin America is therefore beyond the scope of this report.

The products which are assessed are the following:

- Naphtha, because it can be used as blendstock for gasoline
- Motor gasoline, because it is regulated on sulphur
- Kerosene, it is an important transportation fuel and middle distillate like gas/ diesel oil
- Gas/ diesel oil, because it is regulated on sulphur content
- Residual fuel, because it is a good indicator of the quality of crude used in combination with the complexity of refineries (Chapter 6)
- Other products, including refinery gas, LPG, ethane, aviation gasoline, gasoline type jet fuel, white spirit & SBP, lubricants, bitumen, paraffin waxes, petroleum coke and other petroleum products.

2.2 Product demand and supply mix in the different regions

The consumption and production of petroleum products over time in the different regions differ. Every region has an own development of the product market. This will be described in this paragraph.

Per region the consumption, the production and last the balance between consumption and production of petroleum products will be described. The consumption is extrapolated to 2010 by using the trend since 1990 and additional information on consumption provided by different sources. The paragraph will end with concluding remarks. Data used is from the IEA oil information cd-rom 2005 for OECD and non-OECD countries.

The main products assessed here are residual fuel oil, gas/ diesel oil, kerosene (kerosene type jet fuel and other kerosene), motor gasoline and naphtha. These products are chosen because of their relative importance compared to other products based on amounts consumed and produced. The products not mentioned here are grouped into the other products: other petroleum products, petroleum coke, paraffin waxes, bitumen, lubricants, white spirit & SBP, gasoline type jet fuel, aviation gasoline, liquefied petroleum gas

(LPG), ethane and refinery gas. When necessary, products will be lifted out of this category to give more insight.

2.2.1 OECD Europe product demand and production

OECD Europe demand

In the '60s and '70s residual fuel oil was the dominating product in Europe. During the '80s the demand shifted to middle distillates (gas/ diesel oil and kerosene), which are now dominating the market. The demand for Naphtha and other products is steadily growing. The use of motor gasoline grew until 1988, stabilized and started declining in 1992. Kerosene demand is dominated by the jet fuel type, in the '60 it took 60% of the total kerosene consumption, it gradually changed to about 90% now. The share of kerosene is steadily growing.

Gas/diesel oil dominates the market in Europe, followed by gasoline and other products. Residual fuel oil only takes a modest share (16% in 2004) compared to share it used to have (43% in 1960). 'Among other reasons, diesel consumption increased as tax policies encouraged the switch from gasoline to diesel-powered vehicles.' (Reinaud 2005) The product demand mix is shifting towards more gas/ diesel oil and kerosene and less gasoline and residual fuel consumption. According to Reinaud (2005) the growing squeeze on middle distillates will lead to growing margins in middle distillates and as result increasing complexity of refineries. In 2003 58% (46% in 1993) of gas/ diesel oil was consumed for road transport.

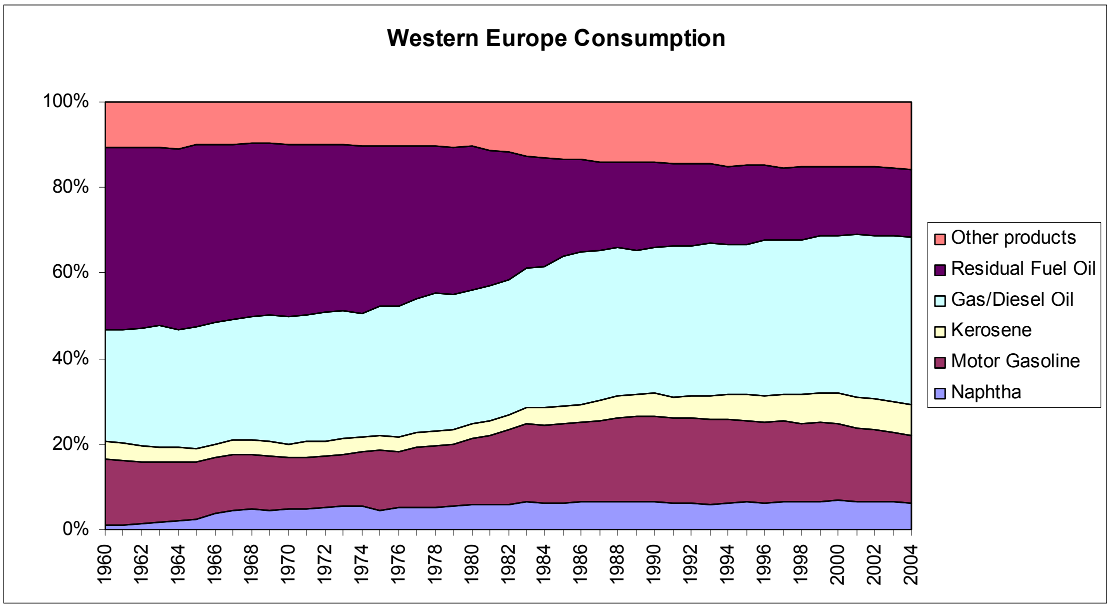


Figure 6: Product demand mix in OECD Europe until 2004 (IEA 2005).

To be able to extrapolate consumption of production until 2010, the average annual change in consumption of petroleum products is calculated. The result is given in table … The demand of residual fuel as well as the demand for gasoline is declining. Gasoline consumption slowly changed from growing to significantly decreasing in the 2000-2004 period. Since the European policy to promote diesel instead of gasoline fired engines is not expected to change in the near future, the shift from gasoline to diesel consumption will continue. The demand for kerosene declined in 2001 and 2002, but recovered in 2003 and in 2004 a growth of nearly 5%. Air transport industry seemed to be healthy and the use of air transport is expected to grow in the future, leading to more kerosene use.

	1990-1995	1995-2000	2000-2004	1990-2004
Naphtha	1,52%	2,34%	-2,47%	0,46%
Motor Gasoline	0,30%	-0,91%	-2,45%	-1,02%
Kerosene	3,94%	5,42%	0,78%	3,38%
Gas/Diesel Oil	2,02%	1,60%	1,96%	1,86%
Residual Fuel Oil	-0,08%	-2,01%	-0,20%	-0,76%
Other products	2,19%	1,26%	1,83%	1,76%
Total products	1,35%	0,73%	0,45%	0,85%

Table 12: Average annual growth of product consumption in Europe

The figure below shows the result of the extrapolation to 2010 based on the average annual growth since 1990.

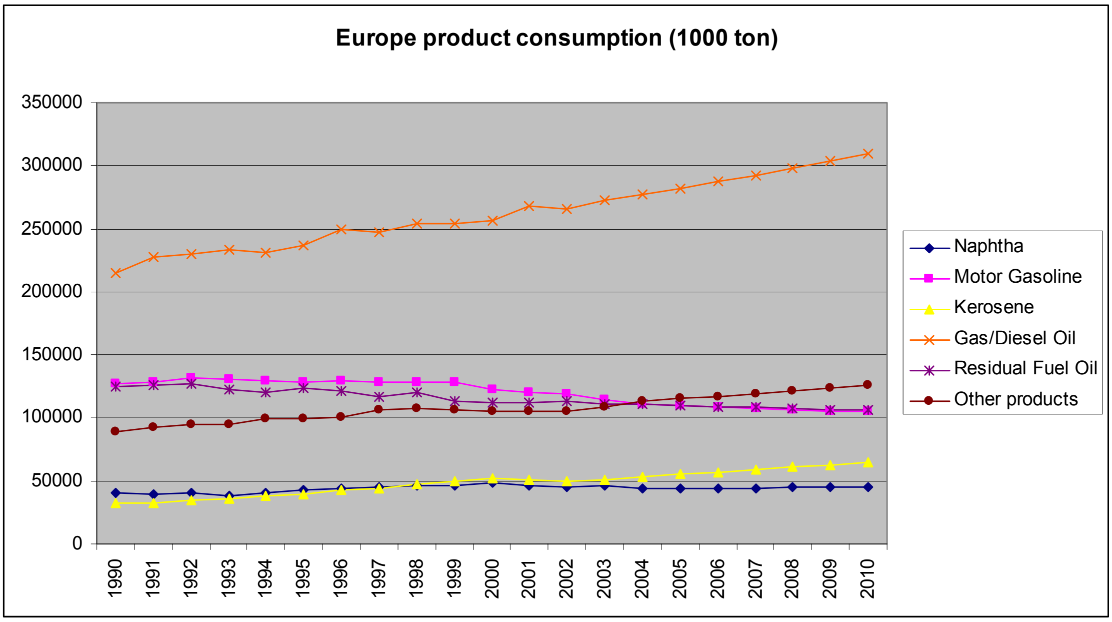


Figure 7: Product demand in Western Europe until 2010 (1000 ton per year) (IEA 2005)

As a result the following consumption shares are expected in 2010.

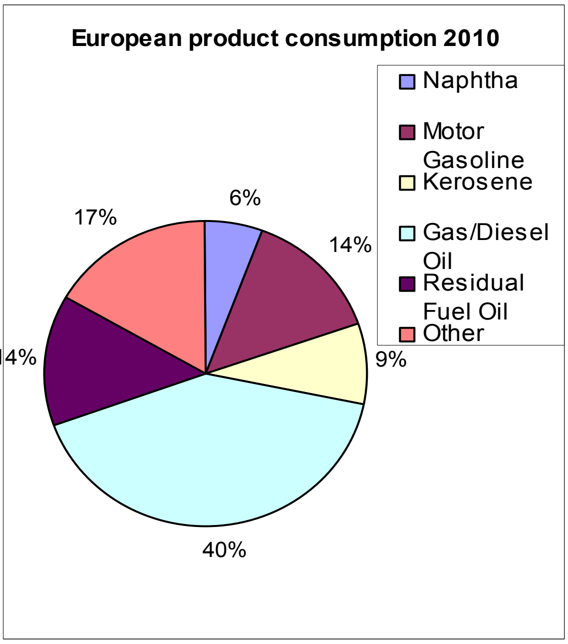


Figure 8: European product consumption shares in 2010.

Western Europe oil product production

As can be expected from the product consumption, gas/diesel oil has the largest share of production followed by motor gasoline and residual fuel oil. The share of naphtha, gasoline and the kerosene stay relatively constant. The share of residual fuel oil is steadily decreasing, but increased in 2004. The share of gas/diesel oil is increasing slightly. Within the other products, the share of LPG, bitumen and coke are the biggest.

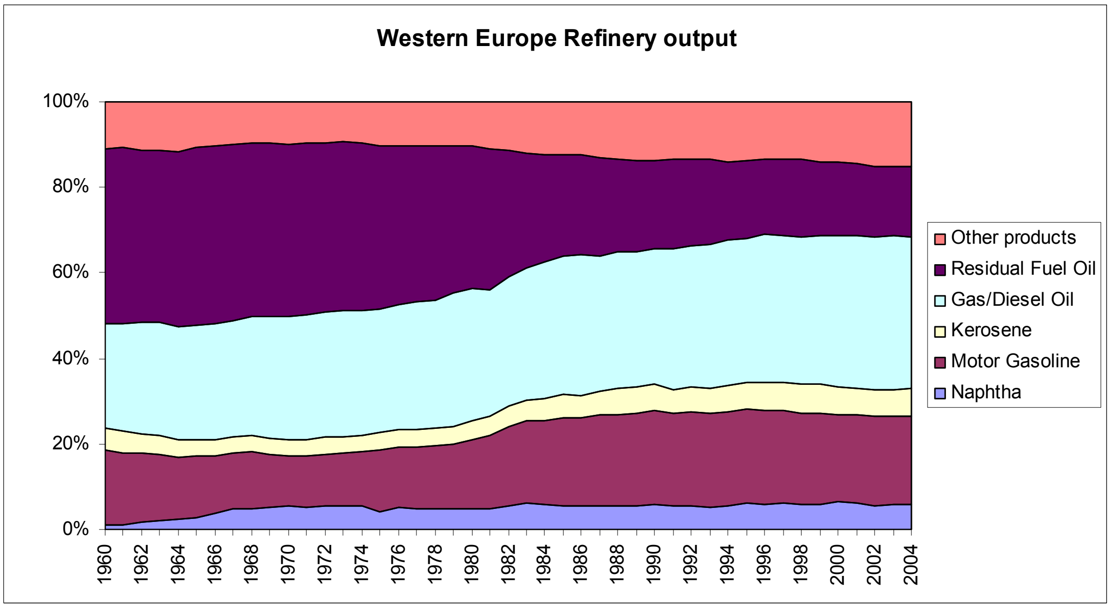


Figure 9: Relative production of products to total production from 1960-2004 (IEA 2005)

Actual residual fuel oil production has been steadily decreasing until 2000, since 2001 production is increasing again. Production of all products is increasing since 2001, all as it seems with the same pace. The growth of production of residual fuel oil, while demand is declining, indicates that conversion possibilities are running out and that extra production of diesel and gasoline will lead to extra production of residual fuel. This can be avoided by producing lighter crude which is obviously less beneficial.

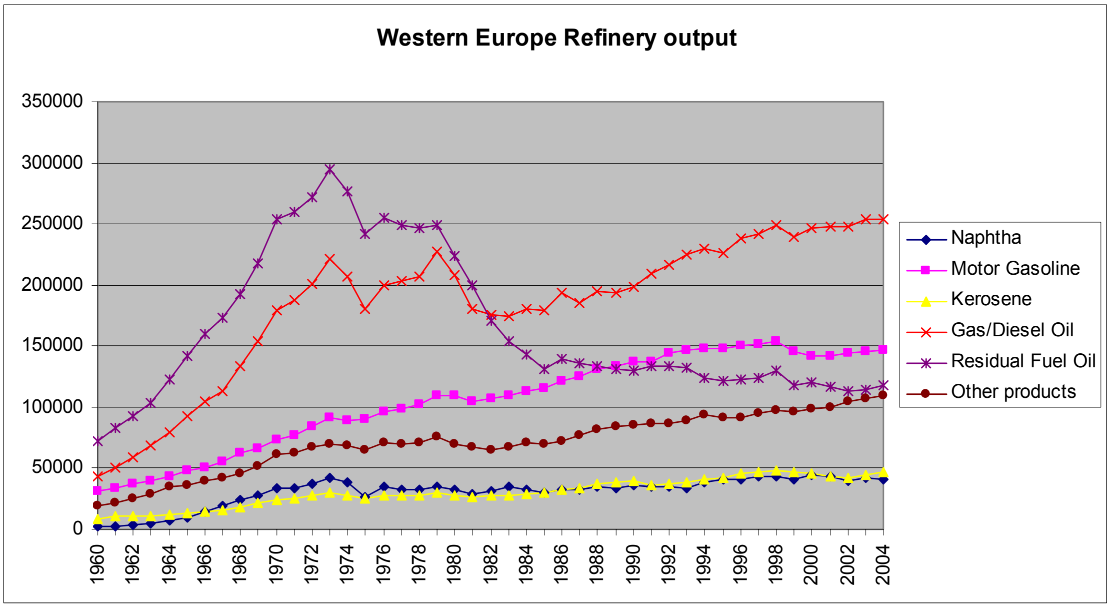


Figure 10: Actual production of products in tons per year OECD Europe (IEA 2005)

Concluding remarks

The figure below shows a volatile shortage of gas/diesel oil, with the shortage growing the last few years. A continuous surplus of motor gasoline since 1981 is noticeable, which explodes since 1998/1999. This is due to the combination of growing production and declining demand. It seems that the refinery sector is not able to reduce gasoline production in a profitable way. There is a constant shortage, although small, of naphtha and other products. New shortages are found with kerosene, which had a surplus until 1998. Residual fuel has a surplus, in 1994 and 2002 the refiners were able to balance demand and supply.

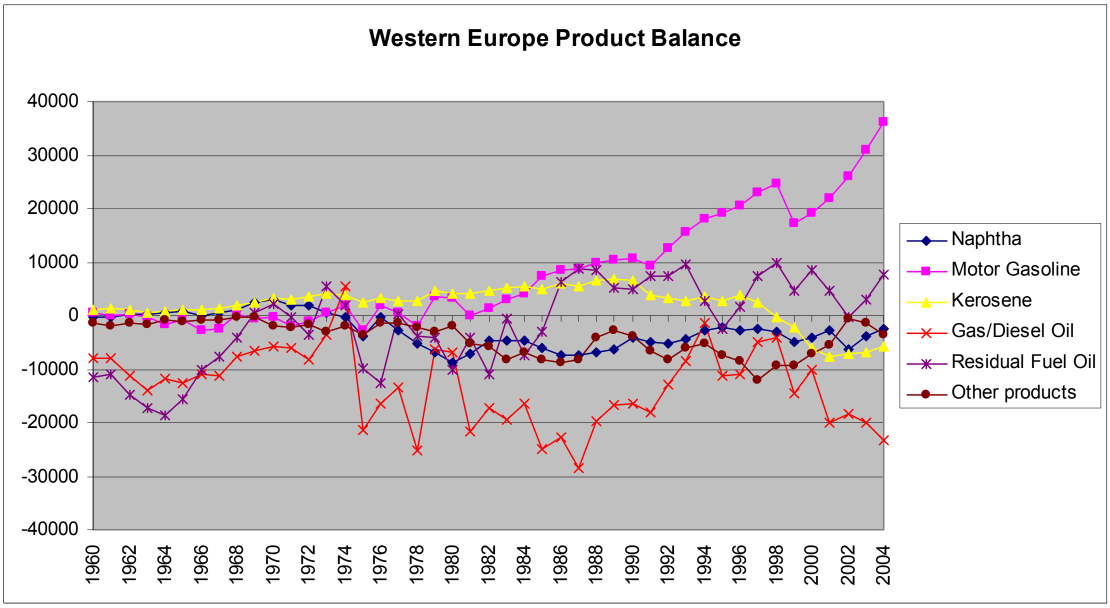


Figure 11: Shortage and surplus of petroleum products with own production (IEA 2005)

It is striking that the gas/ diesel oil and the residual fuel oil lines follow each other from the beginning of the nineties until 2002, from where the shortage of diesel and the surplus of residual fuel oil grows. Before the nineties both products show volatile lines. When the diesel production declines the residual fuel oil production declines as well.

Taking these figures, it can be concluded that refiners aren't able to or decide not to adapt to the decrease in demand of gasoline and an increase in demand of gas/ diesel fuel. If refiners are not able to adapt, this imbalance will not change in the short run. The configuration of refineries is gasoline rather than middle distillate (gas/diesel oil and kerosene) oriented (chapter 4).

There is a surplus of other petroleum products. The shortage of LPG, petroleum coke and ethane is growing. The other other products are mostly in balance.

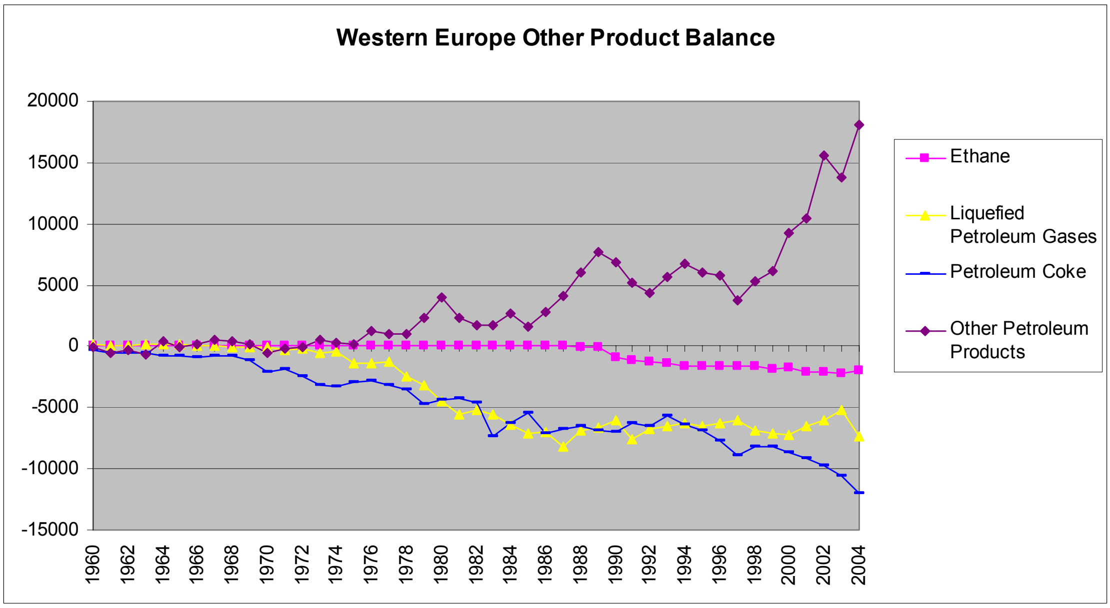


Figure 12: OECD Europe other product balance

The following points are of importance:

- producing a surplus of residual fuel seems a better option than processing lighter crudes
- Product market is shifting from gasoline to diesel, which is not resolved by disinvestment and investment
- Product market is getting lighter
- Overall the product market seems balanced

2.2.2 North America product demand and production

North America product demand

In North America the consumption share of residual fuel oil is declining. The use of middle distillates, gasoline and other products gain in share over the years. Gasoline is the most consumed product in this region, followed by gas/ diesel oil and other products. Kerosene is dominated by the jet fuel type, in 2004 it share was 96% compared to 75% in 1970. The last ten years not much has changed, only a small shift from residual fuel oil consumption to lighter products as gasoline and especially gas/ diesel oil can be noticed. With about 40% of total consumption gasoline is the most important product in North America. The product mix is rather stable.

In 2004 other products take a big proportion of consumption (22%), of which 23% LPG, 19% coke and 18% refinery gas.

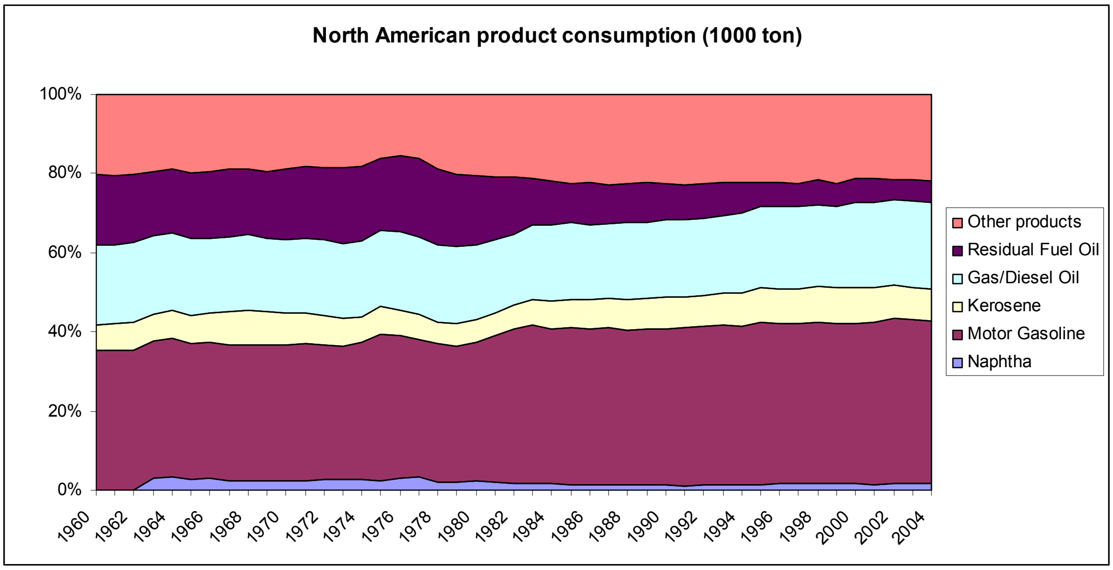


Figure 13: Product demand mix North America (IEA 2005)

The trend from 1990 till 2004 is taken to predict consumption in 2010. Gasoline will stay the most important product in North America, taking 40% of total consumption.

The average growth of consumption of all products is 1,54%, in the beginning of the 90's the growth was rather low, mostly due to residual fuel decline. This could be a result of substitution of residual fuel consumption by, for example, natural gas. The annual growth of gasoline is very stable, and therefore it is presumed that the growth will be the same the coming years. Diesel consumption has stable growth of about 2-3%. Kerosene consumption recovered in 2004, and probably keeps growing. Overall, consumption is shifting to lighter products.

	1990-1995	1995-2000	2000-2004	1990-2004
Naphtha	0,88%	8,63%	3,30%	4,27%
Motor Gasoline	1,56%	1,75%	1,67%	1,66%
Kerosene	2,18%	3,16%	-1,50%	1,28%
Gas/Diesel Oil	1,56%	2,95%	2,12%	2,21%
Residual Fuel Oil	-6,12%	2,20%	-1,54%	-1,82%
Other products	0,39%	1,24%	2,31%	1,32%
Total products	**0,70%**	**2,09%**	**1,42%**	**1,41%**

Table 13: Average annual growth 1990-2004 (IEA 2005)

It is taken that these trends will continue, at least until 2010.

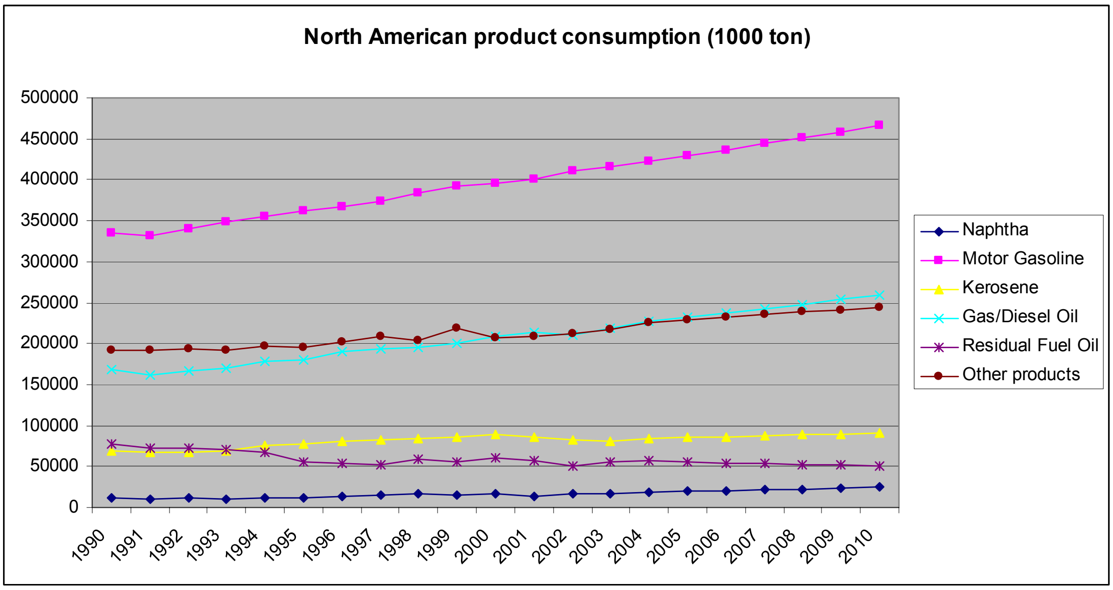


Figure 14: Product demand North America in thousand tons (IEA 2005)

North America product production

Motor gasoline is the most important product output, followed gas/diesel oil and kerosene (kerosene type jet fuel). About 80% of total output is transportation fuel. Residual fuel output is decreasing slowly.

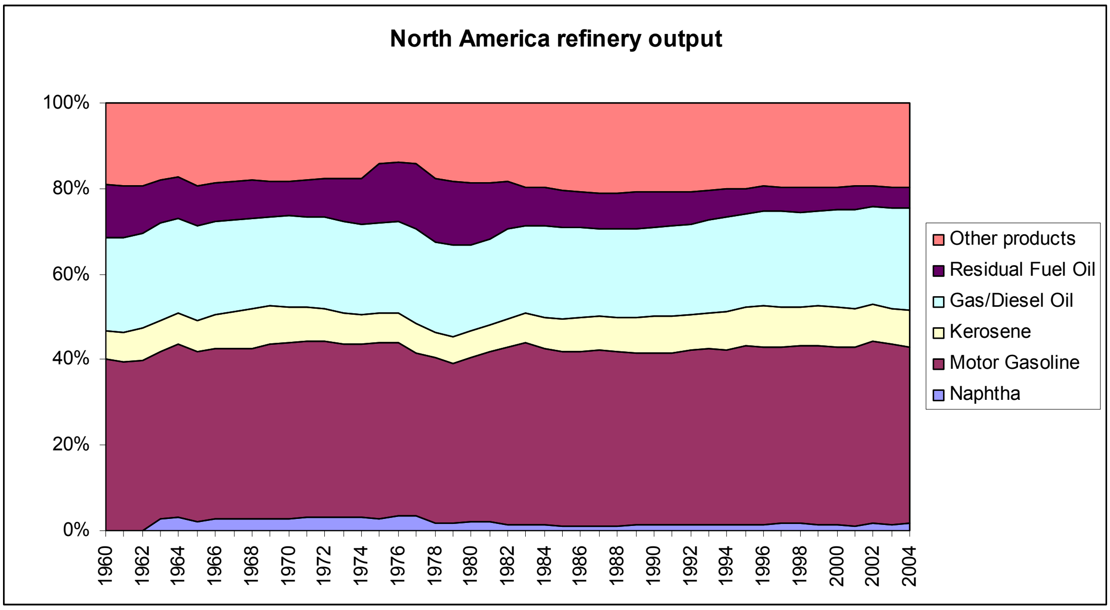


Figure 15: Relative production of products to total production (IEA 2005).

The absolute production of gasoline, diesel and other products is steadily increasing (Figure 16). Kerosene production steadily increases until the end of nineties, than production decreases. Only the production of residual fuel oil is decreasing since the end of the '70s.

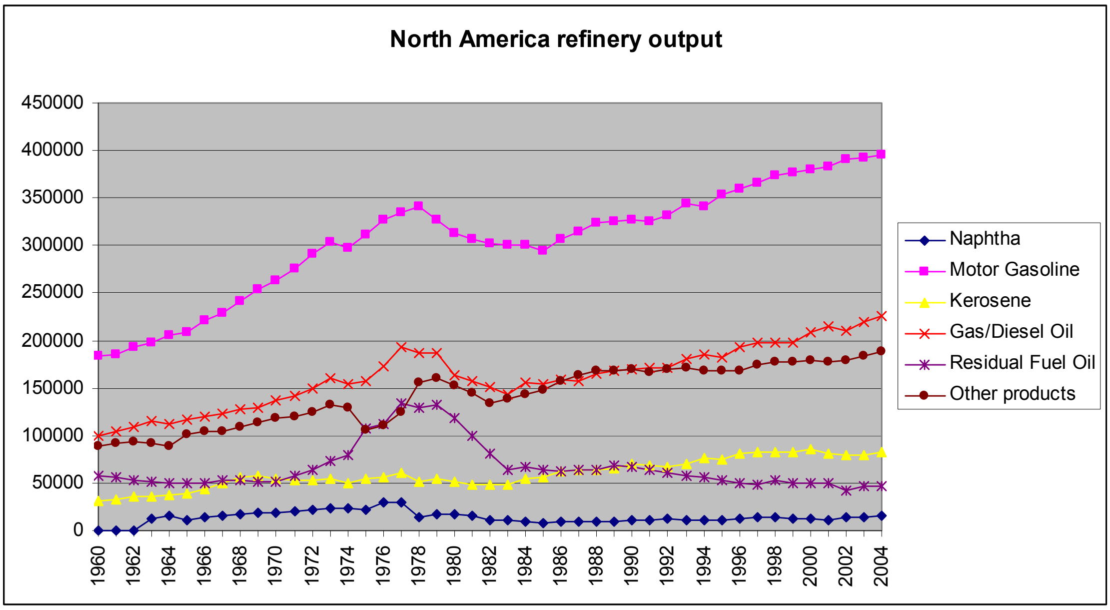


Figure 16: Refinery output in 1000 ton per product (IEA 2005)

Concluding remarks

Domestic production of products is insufficient. Gas/ diesel oil, kerosene, naphtha and residual fuel have relative small shortages, gasoline and other products have big shortages. The shortage of other products is mostly because of ethane and LPG. Motor gasoline shortage is growing steadily, which may bare some concern.

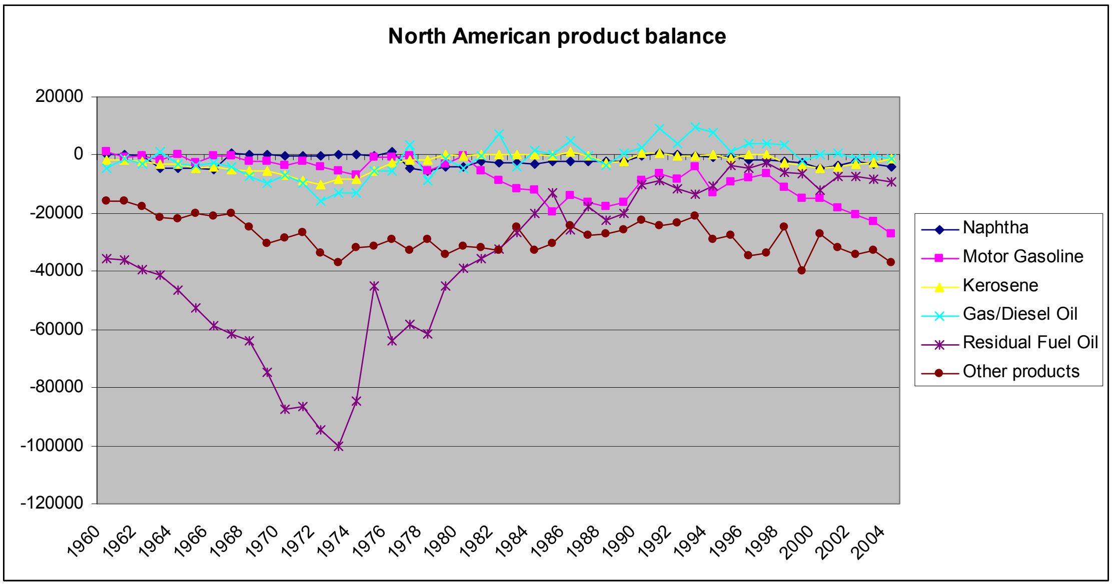


Figure 17: Production surplus and shortage in 1000 tons (IEA 2003)

The product market shifts to lighter products and more gasoline deficit.

2.2.3 OECD Pacific product demand and production

OECD Pacific product demand

OECD Pacific has a relative big share of naphtha consumption, and its share is growing. Gas/ diesel oil demand is highest followed by gasoline and naphtha, which have about the same demand. Most of the naphtha is used in the petrochemical industry (IEA 2005). Kerosene takes a relative big proportion of the products consumed. Residual fuel oil still has a great proportion in the total product consumption, but it is declining. With 50% share, LPG is the most important product in the other products group. Jet Kerosene (used in aviation) has the smallest proportion of total kerosene consumption, about 41% in 2004 (36% in 2002), while in 1970 this was only 18%. Other appliances of kerosene, next to fuel for jet engines, is heating (in Japan mostly) and cooking.

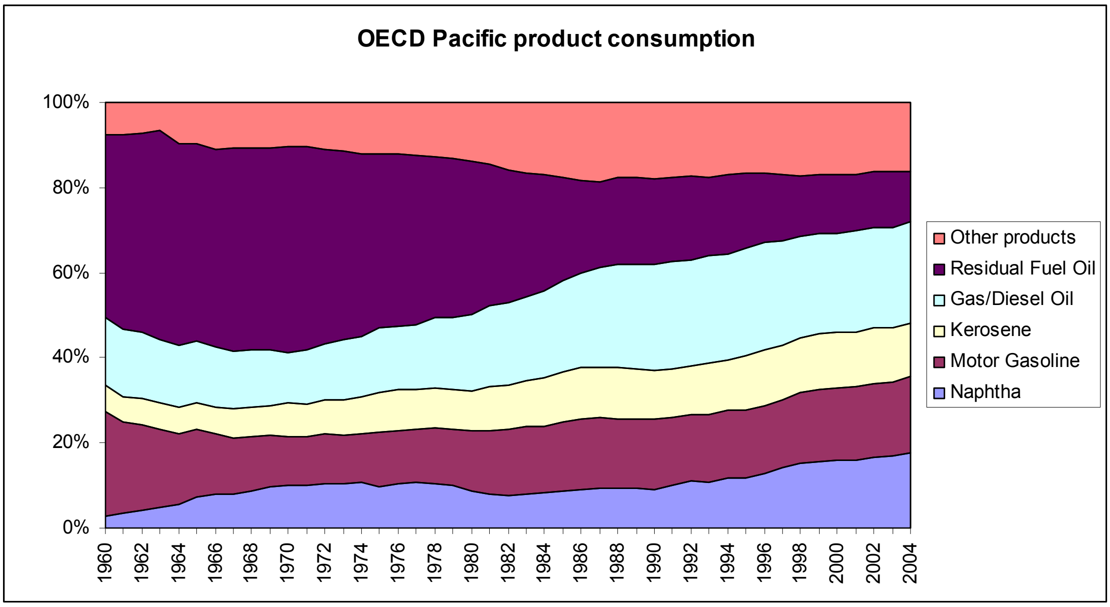


Figure 18: OECD pacific relative product consumption to total (IEA 2005)

The table below illustrates the overall reduction of product consumption growth since 1990. Overall, naphtha has the biggest growth, though it is presumed that the growth till 2010 will follow the trend 2000-2004, which seems more reasonable. The other products will follow the trend since 1990.

	1990-1995	1995-2000	2000-2004	1990-2004
Naphtha	9,84%	6,86%	2,33%	6,35%
Motor Gasoline	3,57%	1,92%	1,15%	2,21%
Kerosene	6,25%	1,33%	-1,23%	2,11%
Gas/Diesel Oil	4,43%	-0,86%	0,20%	1,26%
Residual Fuel Oil	2,21%	-3,01%	-2,77%	-1,19%
Other products	2,68%	1,05%	-1,43%	0,77%
Total products	**4,24%**	**0,74%**	**-0,22%**	**1,59%**

Table 14: Average annual growth 1991-2004 (IEA 2005)

In the beginning of the nineties the demand of diesel, kerosene, naphtha and some what lesser extend motor gasoline start to grew more rapidly. At about the same period the residual fuel oil demand declines less fast than before 1990 (it even expands in the beginning of the '90). The other products have an almost constant growth in demand. Since 1997/1998 consumption flattened or declined.

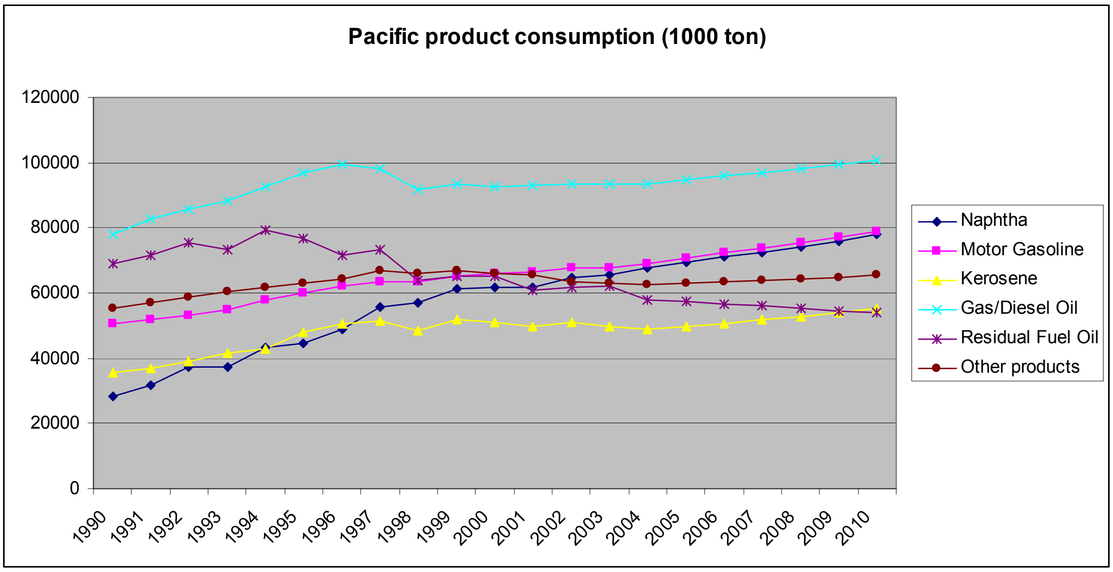


Figure 19: Product consumption OECD Pacific (IEA 2005).

OECD pacific product production

The same trends can be noticed in the refinery output as in the consumption. Residual fuel production is declining but still holds a great proportion of total products. The share of light products is increasing. Gas/diesel has the highest production share, followed by motor gasoline, residual fuel oil and kerosene. Naphtha and other products have about the same production level, with naphtha gaining terrain.

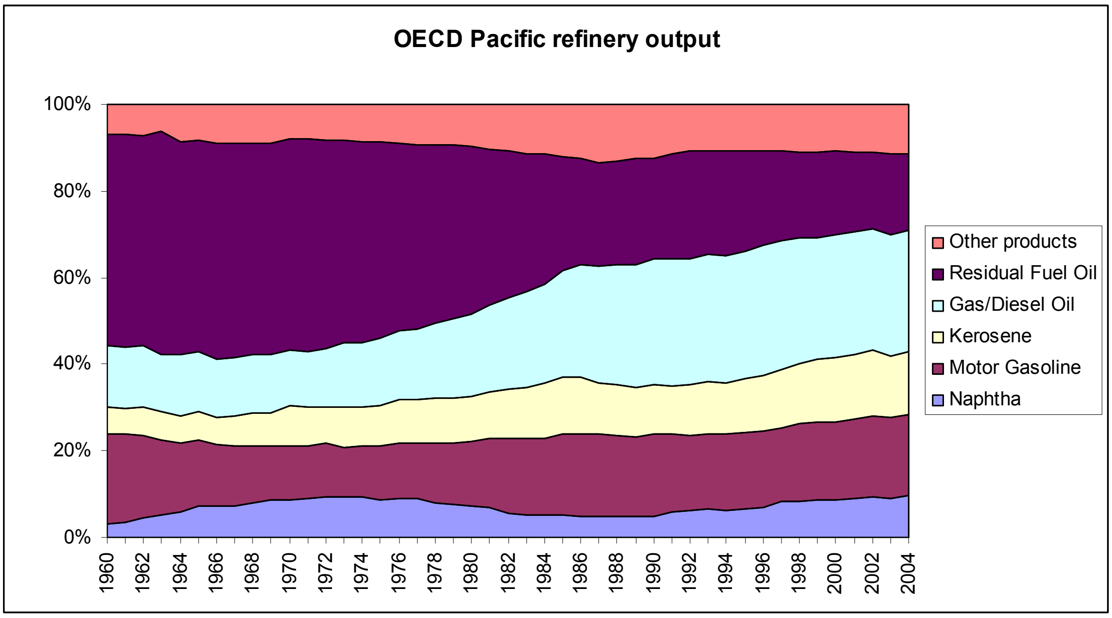


Figure 20: OECD Pacific refinery output (IEA 2005)

Gas/diesel absolute production grew until 1997 and declined afterwards. Residual fuel oil production declined until 1987, recovered a bit and is since the mid nineties declining again. Overall, the refinery output growth stagnated after 1997, according to the trend of consumption.

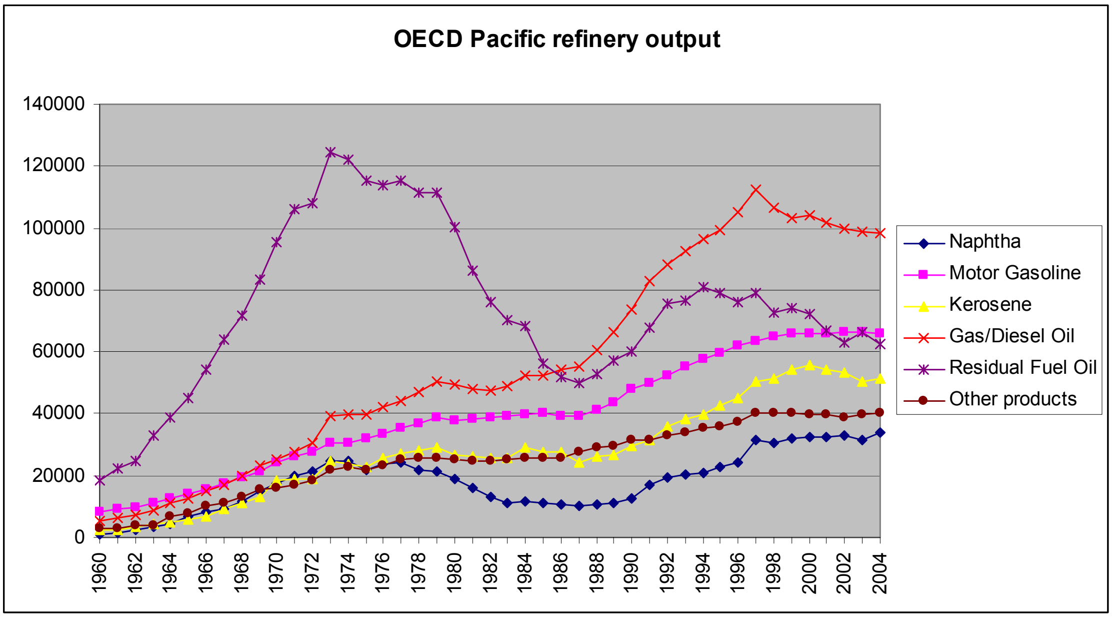


Figure 21: OECD Pacific refinery output (IEA 2005)

Concluding remarks on OECD pacific

There is a shortage of naphtha and other products. Kerosene and motor gasoline are about balanced. A surplus of residual fuel oil and gas/ diesel oil seem to correlate with some delay, both products have surplus production. Both surpluses are declining. The shortages grow or stay the same, except for other products. The declining surplus of diesel is due to reduction of production rather than a growth of consumption.

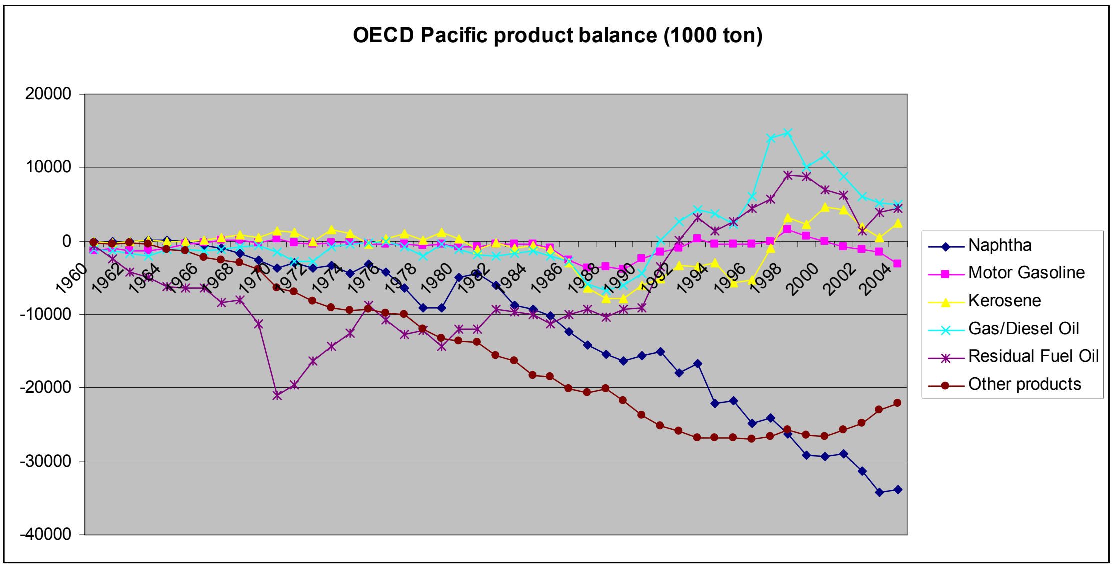


Figure 22: OECD pacific product balances (IEA 2005)

The shortage of other products is due to LPG and petroleum coke, the other other product are balanced. LPG dominates.

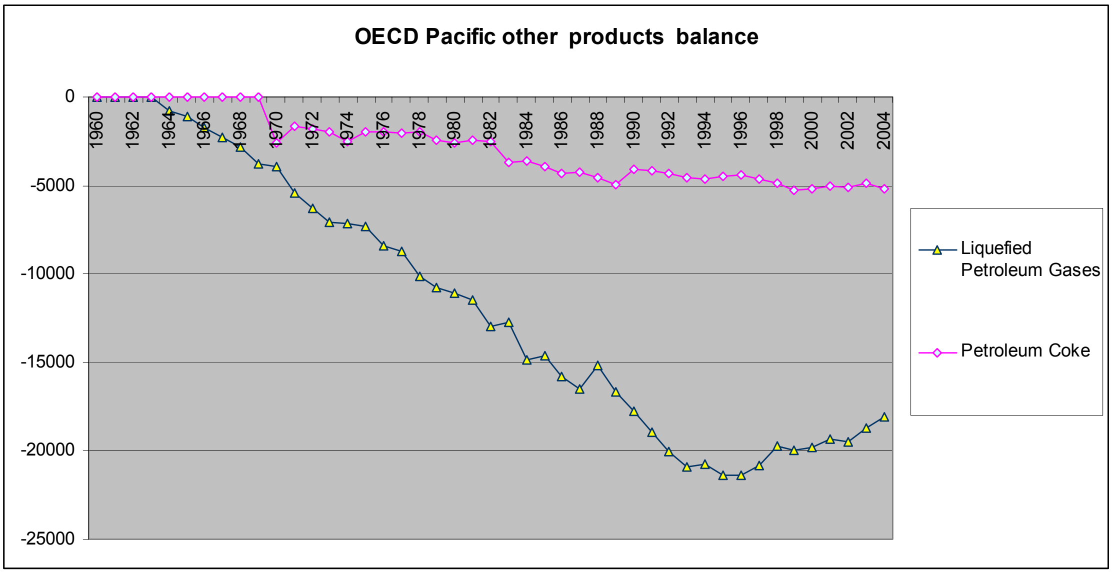


Figure 23: OECD Pacific other products balance, LPG and Petroleum coke (1000 ton) (IEA 2005).

Diesel is by far the most important petroleum product. Naphtha has production shortages, the same counts for LPG. The growth of residual fuel oil surplus could mean there is conversion capacity shortage.

2.2.4 Concluding remarks on the quality regulated product markets

- Motor gasoline and diesel almost always have a shortage, until the 90's, gasoline still has surplus and diesel production falls short.
- Since the beginning of the nineties, residual production is about the same as consumption. With a declining demand, a production which is growing in Europe, the surplus will be growing for the coming years.
- Production utilities are high, and the figure below shows some correlation between residual fuel production and gas/ diesel oil production. With growth of production of gas/ diesel oil, the production of residual fuel is expected to grow.
- Additional gas/ diesel oil production is straight run from the distillate unit instead of production from conversion processes (follows out former remark).
- The combination of demanding the same quality crude, conversion capacity running on maximum capacity and increasing the crude runs leads to a growth of residual fuel production. The amount of residual fuel produced can be reduced by adding conversion capacity or process lighter crudes.
- Refinery swing capacity is only in distilling capacity, which is limited due to high utilization rates.

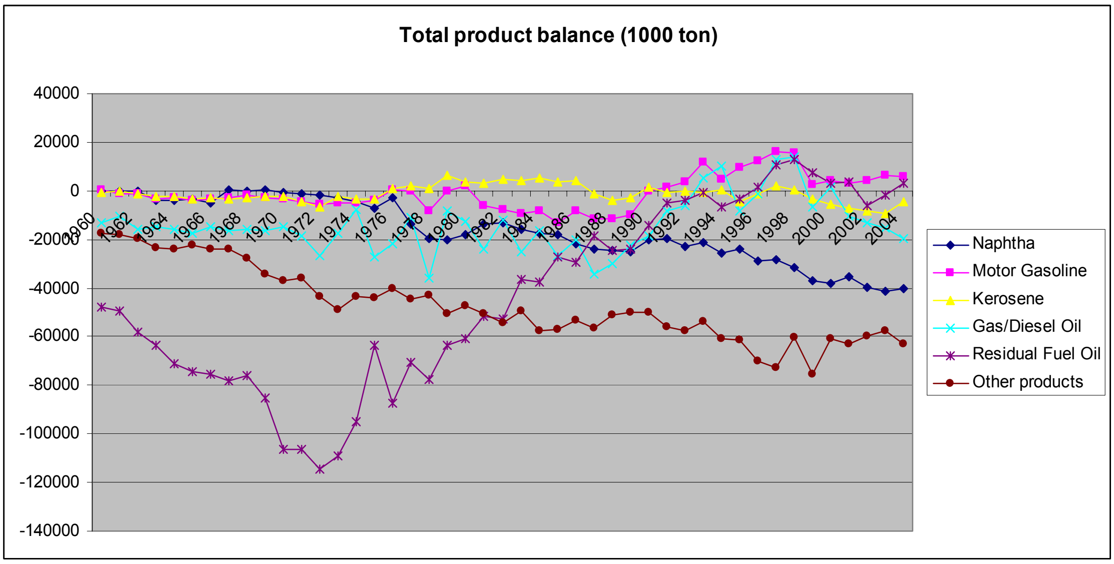


Figure 24: Total balance in OECD regions (IEA 2005)

2004	Europe	NAM	Pacific
Naphtha	-2475	-3866	-33893
Motor Gasoline	36149	-26944	-3132
Kerosene	-5845	-1384	2519
Gas/Diesel Oil	-23353	-1162	5066
Residual Fuel Oil	7722	-9299	4458
Other products	-3604	-37094	-22080
Total products	**8594**	**-79749**	**-47062**

Table 15: Product balances in OECD regions (1000 ton) (IEA 2005)

There is need for more conversion capacity in the refinery industry:

- to reduce the production of residual fuel (Europe)
- to increase production of diesel (Europe), naphtha (Pacific) and gasoline (North America).
- To increase flexibility on crude choice when extra production is needed

North America may be able to compensate shortages of gasoline by imports from Europe. Naphtha specifications are not regulated, but need to fulfill specifications made by the petrochemical industry, which is beyond the scope of this report.

The regulation of diesel and motor gasoline in these regions may have impact on supply. Knowing that almost all OECD countries have regulation, and taking that these countries produce the right quality, the following can be concluded:

- not enough gas/ diesel oil is produced in the OECD, meaning reliability on imports of countries without stringent sulphur content regulation and the willingness to invest in desulphurization of gas/ diesel oil in these countries
- there is enough gasoline production to compensate North American production shortage, though Asia need to find other sources to compensate their gasoline shortage because of the big distance to Europe.

2.3 Product streams between regions

In the former paragraph some surpluses and shortages of products are noticed. This paragraph will describe the ways these regions compensate for there product surplus and shortfall production. This paragraph will start with a description of product streams from and to OECD Europe, than OECD North America and last OECD Pacific.

2.3.1 Europe product streams

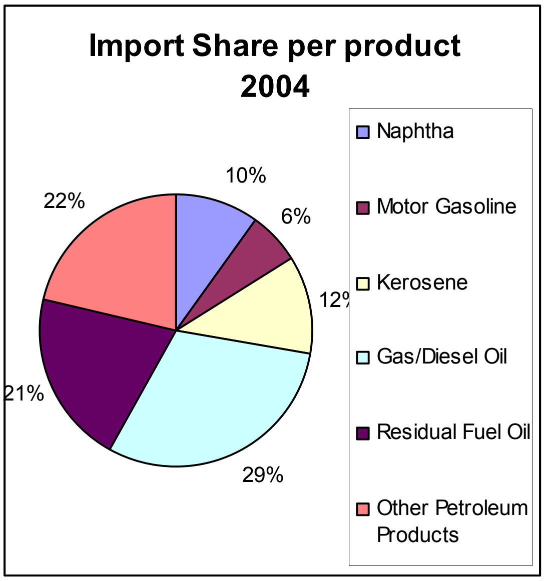
Europe products imports

In total, Europe imports 119 million ton of products in 2004 (93 million ton in 2000). Europe has relatively small shortages, but a big shortage of middle distillates: gas/ diesel oil and kerosene.

With utilization of refineries close to 95%, growth gas/ diesel oil consumption, and a recent increase of shortage of diesel production there will be a growing dependence on imports. Middle Distillate is the most imported product group (kerosene and gas/ diesel fuel take 41%).

Surprising is the amount of residual fuel imported, while Europe has a surplus.

Other product imports are dominated by petroleum coke (84% from the North America) and LPG (75% from Africa).



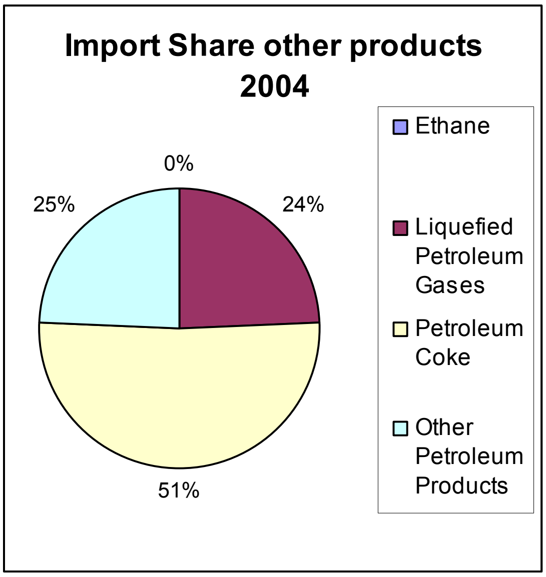


Figure 25: Product import shares for OECD Europe (IEA 2005)

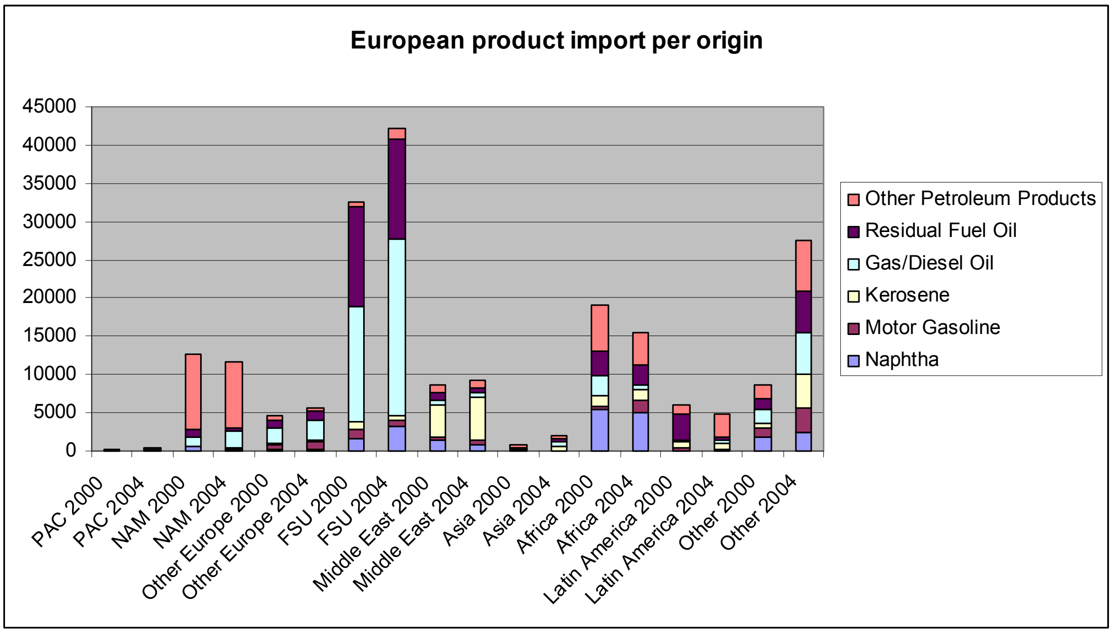


Figure 26: Import per product per origin region for OECD Europe in the year 2000. (IEA 2005)

Most imports are done within the EU-15 plus region, 61% of total imports. From outside this region, most of the imports are from the FSU, followed by Africa and North America and some from the Middle East. There are no imports from the Pacific.

Product streams from different regions provide different products. Residual fuel (54% of total) and gas/diesel oil (65% of total) are imported from the FSU, petroleum coke from North America, kerosene from the Middle East and naphtha and LPG from Africa. Asia and OECD Pacific take a very small share of total import; this is due to the large distance to this region.

The FSU is the most important import region, followed by Africa and North America. In 4 years time the gas/ diesel imports grew by 53%, this is mostly due to a rise of imports in 2001 (33%) and 2002 (10%). The growth of imports of diesel is related to the lack of capacity of the European refinery industry to produce diesel.

European product exports in 2004

Gasoline has the biggest share of exports. Most of the gasoline is exported to the US , 17 million ton. Residual fuel is exported to North America (9 million ton), Asia (3,5 million ton) and Africa (1,5 million ton). Some gas/ diesel oil to Africa and non specified other and other products are exported.

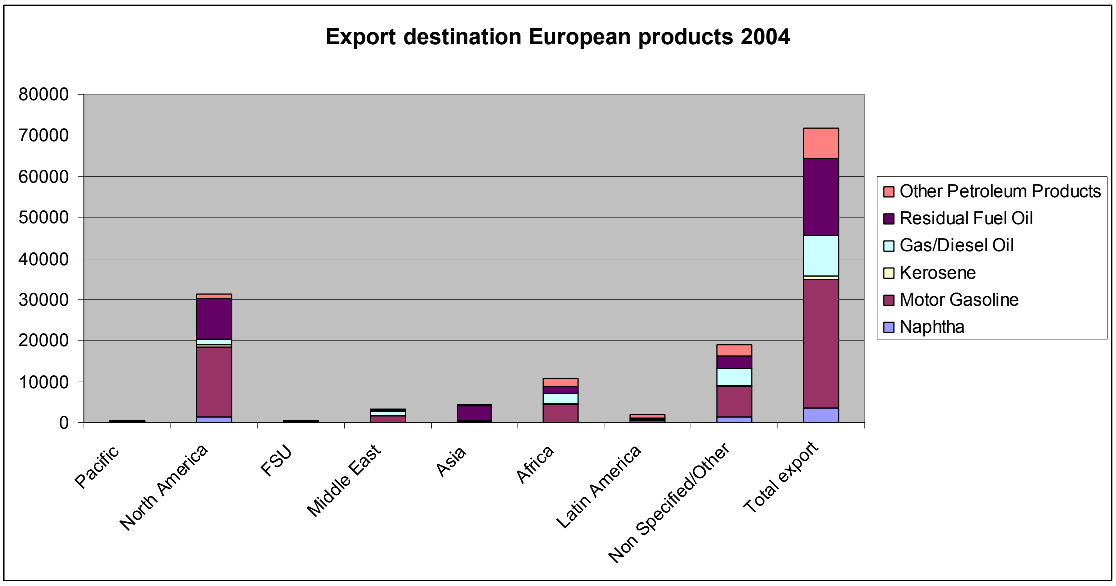


Figure 27: Export destinations of product produced in Europe. (IEA 2005)

Net import

Large amounts of gasoline are net-exported (export minus import). Residual fuel has a negative net import as well. All the other products have net imports. Overall net-import declined since 2000. Gas/ diesel oil and kerosene import almost doubled while gasoline export more than doubled. The negative net import is to the large increase of gasoline export rather than a declining export. This underlines the unbalance of the refinery production capabilities and product market. The refinery industry is focused on gasoline production while the shortage of middle distillates if growing. Europe imports vast amounts of residual fuel but exports more.

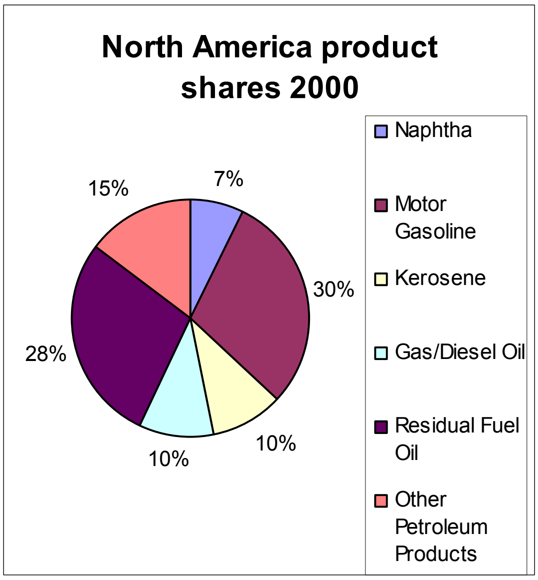
Net imports	2000	2004
Naphtha	6784	8126
Motor Gasoline	-13441	-32713
Kerosene	6986	12076
Gas/Diesel Oil	11526	23917
Residual Fuel Oil	-370	-8433
Other products	15145	12539
Total	**26630**	**15512**

Table 16: Net-imports of EU-15 plus (IEA 2005).

2.3.2 North American product streams

North American product imports

The share of gasoline imports into North America increased significantly in 4 years. The production in gasoline in the US falls short with demand and therefore imports are needed. The extra amount imported is about one third of demand growth from 2000-2004. The share of residual fuel import stays the same.



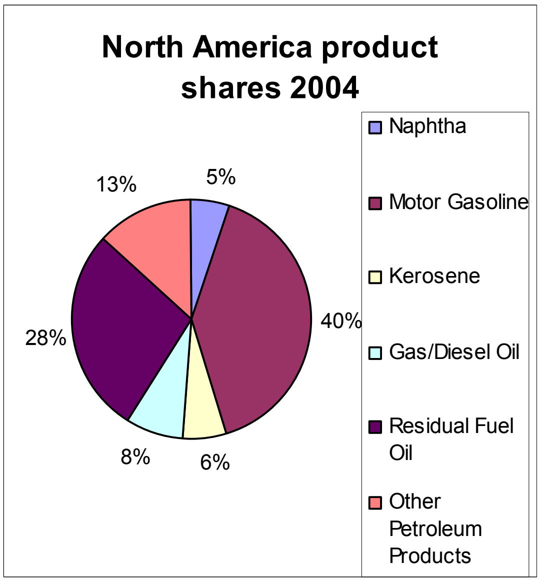


Figure 28: American imports share per product in 2000 and 2004. (IEA 2005)

In 2000 most of the North American imports are from Latin America (including Mexico) (42%), followed by Europe (22%). In 2004 Latin America and Europe have about the same share in exports to North America, respectively 35% and 33%. Imports increased from Europe and the FSU, imports from other regions declined.

A shift of gasoline imports from Latin America to Europe and the FSU can be noticed, with additional imports from Europe to compensate the gasoline shortages. This could mean that the gasoline quality in Europe is better than in Latin America sulphur content wise. With new regulation coming up, this trend might continue in 2005 and beyond.

Vast amounts residual fuel oil is imported from Latin America, some from Europe, FSU and Africa. Residual fuel oil import has a share of almost 30% of total. Kerosene is mostly imported from the OECD Pacific and Latin America. The Middle East has a small contribution to the total product imports.

Imports in-between Canada and the US take a share of 25% in 2004 (20% in 2000) of total imports.

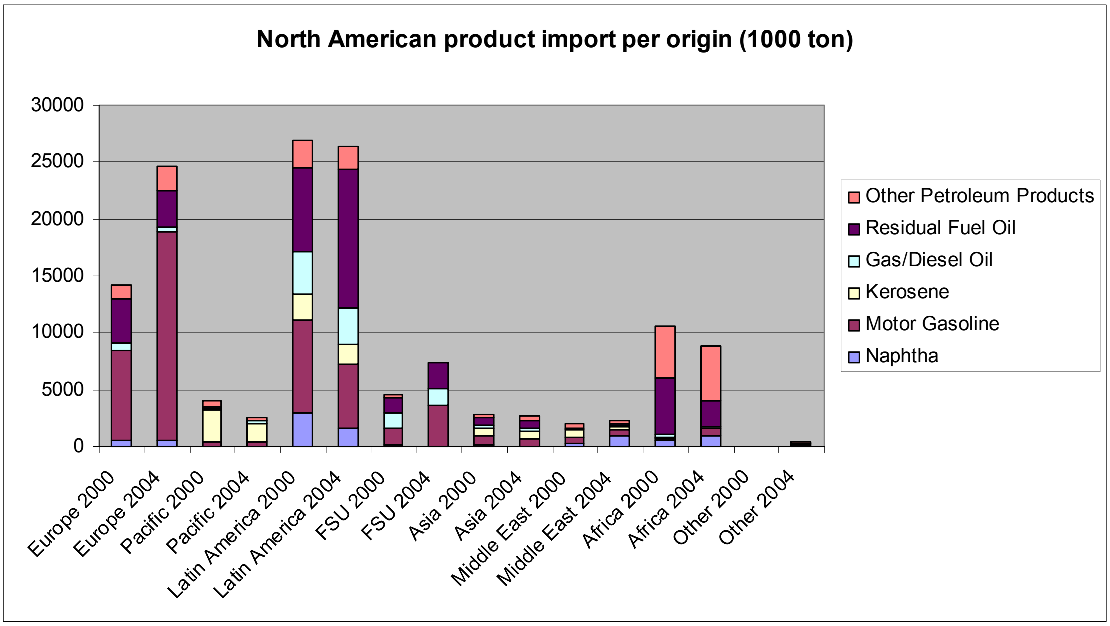


Figure 29: North American imports per origin and product (IEA 2005).

North American product exports

Most of the product export has destination Latin America. Motor gasoline, residual fuel and petroleum coke (other products), are the most important export products. Motor gasoline is exported to Latin America, this gasoline may be of inferior quality to the quality required in North America. Residual fuel has the same destination.

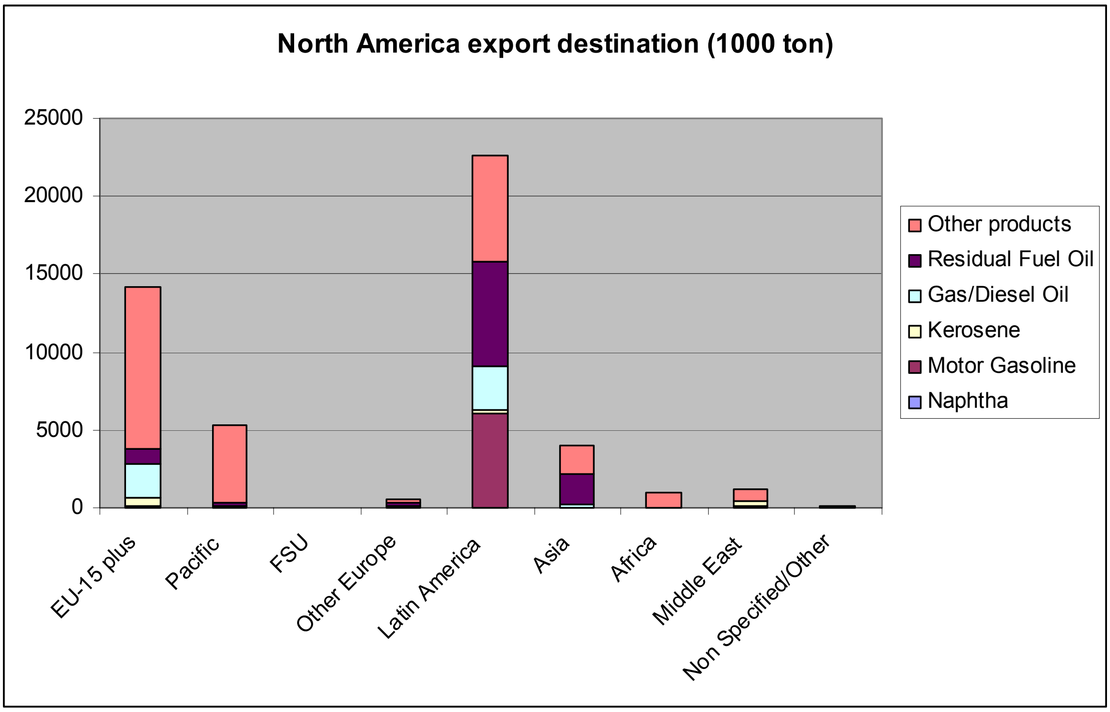


Figure 30: North America export destination in 2004 (IEA 2005).

Net import

Overall, North America imports more products than it exports. Only other products are exported significantly. This is mainly due to petroleum coke export to Europe and the Pacific. About the same amount of gasoline exported to Latin America is imported from Latin America.

Net-imports	2000	2004
Naphtha	4410	3808
Motor Gasoline	12421	24337
Kerosene	5526	3003
Gas/Diesel Oil	-1956	-490
Residual Fuel Oil	11772	10150
Other products	-13736	-15409
Total	**18437**	**25399**

Table 17: Net-import of North America (IEA 2005).

North America has an east and a west coast. The west coast will be able to trade with the Pacific, Asia and Latin America. The East coast probably trades more with Europe, Africa and Latin America. Therefore getting more insight in production and consumption of these two coasts may be of importance and explains the product streams better. According to IEA PADD 1 district imports most of the gasoline in 2003 (almost 90%) (Drevna 2005), PADD 1 is the East Coast. According to the NPRA, a shift of sources of gasoline may occur for the United States. 'Fuel spec changes may be reducing the number of import sources. Reduction in import sources may increase margins.' (Drevna 2005) Increased margins could lead to more investment. For example the product gas/ diesel oil: may be it is produced with surplus at the east coast, giving export possibilities to Europe, but at the same time shortages are filled with imports from the Pacific at the west coast.This is analysis will not be performed in this report.

2.3.3 OECD Pacific product streams

OECD Pacific product imports

The main supplier of products to OECD Pacific countries is the Middle East (56% in 2000, 53% in 2004), followed by Asia (27% in 2000, 30% in 2004). Little is imported from Europe, Latin America, the FSU and Africa. Some imports are from North America.The Middle East is the main supplier of Naphtha and LPG. Imports from Asia are more diverse. Imports of gasoline and gas/diesel oil are the most important in this respect. Petroleum coke is imported from North America.

Naphtha is the most important import product for the Pacific (46% in 2004), followed by other products (32% in 2004). Gas/ diesel oil, residual oil, kerosene and motor all take 5-6% individually.

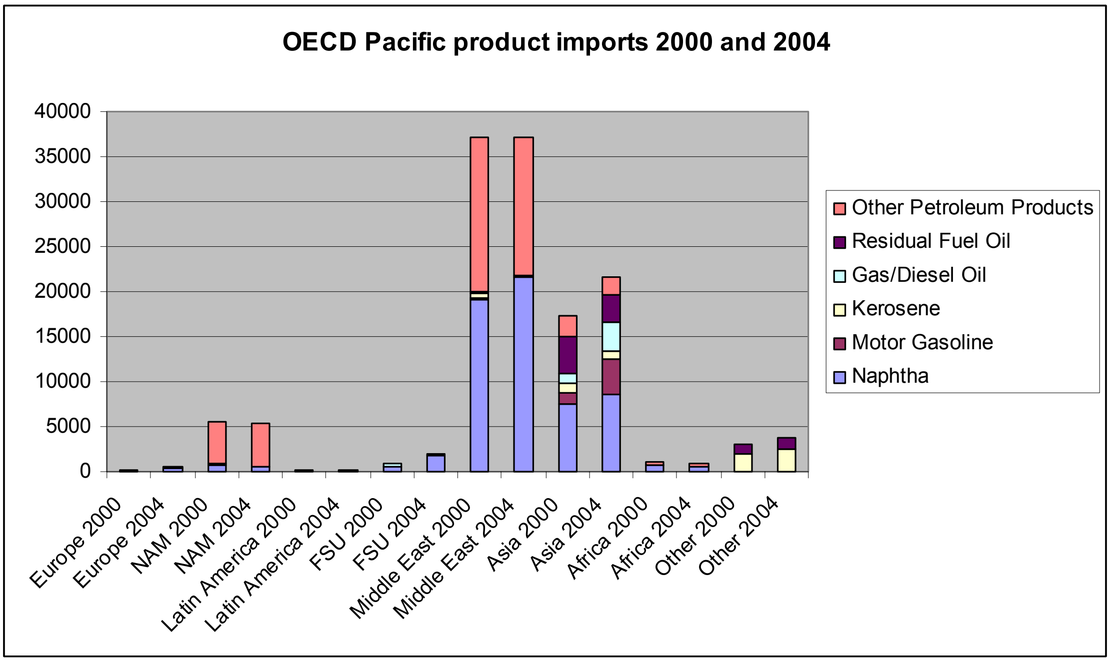


Figure 31: OECD Pacific product import per origin (IEA 2005).

OECD Pacific product exports

A large portion of the export is to the other Asian countries, with gas/ diesel oil and residual oil the most important export products. Kerosene is exported to North America and Asia.

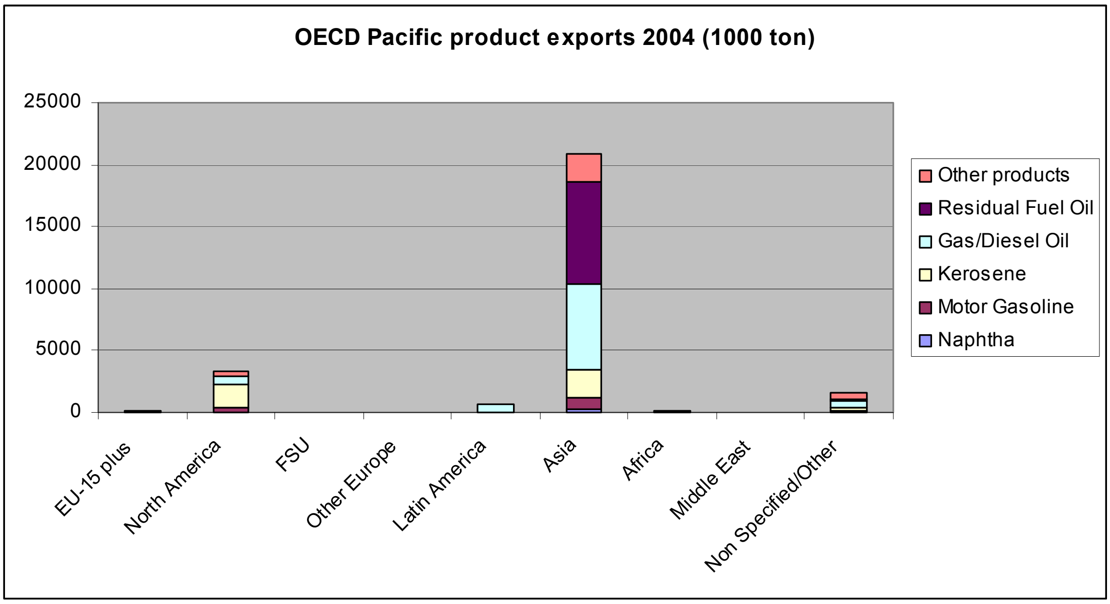


Figure 32: OECD Pacific product export in 2004 (IEA 2005).

Net import
OECD Pacific is a net-importer of Naphtha, gasoline and other products (petroleum coke and LPG). Naphtha is the most important product in this respect. This region became net importer of gasoline since 2000.

Net-imports	2000	2004
Naphtha	29442	33561
Motor Gasoline	-156	2758
Kerosene	-1997	-2728
Gas/Diesel Oil	-11450	-6137
Residual Fuel Oil	-6735	-4025
Other products	22985	20227
Total	**32089**	**43656**

Table 18: Net imports OECD-Pacific (1000 ton) (IEA 2005).

2.3.4 Conclusion

- Compared to Europe and North America, the product streams from and to the Pacific is most homogenous: great amounts of imports of naphtha and other petroleum products from the Middle East and Asia, small exports of kerosene, gas/ diesel oil and residual fuel to Asia and North America. North American and European streams are more complex.
- Since the year 2000 the gasoline import of North America changed from Latin America to Europe, may be due to regulation, higher price in Latin America than in Europe or geopolitics.

2.4 Conclusion on the product market

Regulation on products in the OECD is focused on sulphur content in transportation fuels. The ability to remove sulphur from products or feedstock is of growing importance. It influences the ability to export to developed countries with high consumption. Importers could choose to treat the imported products themselves.

Overall the refineries within regions are not able to match local product demand. Europe has great shortages of gas/ diesel oil, North America of gasoline and OECD Pacific of naphtha.

The European refinery industry has no capacity shortage, but the capacity it possesses is not able to produce the right amounts of specific products. The demand of diesel is too high and the demand of gasoline is too low for the capacity the refinery industry. If the gasoline produced was gas/ diesel oil there wouldn't be a problem. The shift from gasoline to diesel in the demand is due to policy. This policy creates problems in the refinery industry. Investments as well as disinvestment are very expensive in this sector, therefore it is a slow changing industry and unable to adapt their product output fast enough to changes in demand.

The growing imbalance of production and demand in the OECD Pacific and Europe and lack of refinery capacity in North America stimulates the international market for products. New refinery centers as in the Middle East, Africa and Latin America may have opportunities to export large amounts of products to the developed countries.

Investment to produce low sulphur diesel is partly in the hands of countries from outside the OECD. For Europe this may impose problems, the shortages of diesel is filled with imports from the FSU. The ability to do so depends on the desulphurization possibilities the FSU has (FSU is the major source for diesel in Europe). 'The deficit in diesel supply in Europe is currently resolved through significant imports of both finished products and high sulfur gas oil (which requires further processing) from the Former Soviet Union.' (McAlpine 2006)

The product demand is increasingly lighter. In the introduction several strategies were given to cope with this problem.

- Europe seems to take a strategy of higher production of residual fuel more beneficial than processing lighter crudes. It could be that the crude processed the last couple of years were heavier than previous years, this is assessed in chapter 4 on the crude market.
- European and North American product market are developing in opposite direction from a product mix perspective. The European gasoline surplus is largely exported to North America. North America seems to rely on imports on this matter.
- It can be expected that the gasoline surplus in Europe will increase, since disinvestments will not be done and the North American gasoline market can take the surplus.
- Product regulation pressures the refinery industry to invest in treatment or process lower sulphur crude.

3 Description of refinery industry

The configurations of refineries vary widely. The types and size of equipment, the way this equipment is tuned (operating/ processing scheme) together with crude quality used influences 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.' (Correlje, 1994: 181) Therefore analyzing the refinery capacity worldwide is a complex business when all parameters are taken into account. The second problem is the amount of information to predict the possible product yield is not available. That is why a simplification of configurations, capacities and yields are needed. This chapter will address this problem.
The causal diagram below, taken from the causal diagram in the introduction show the parameters involved:

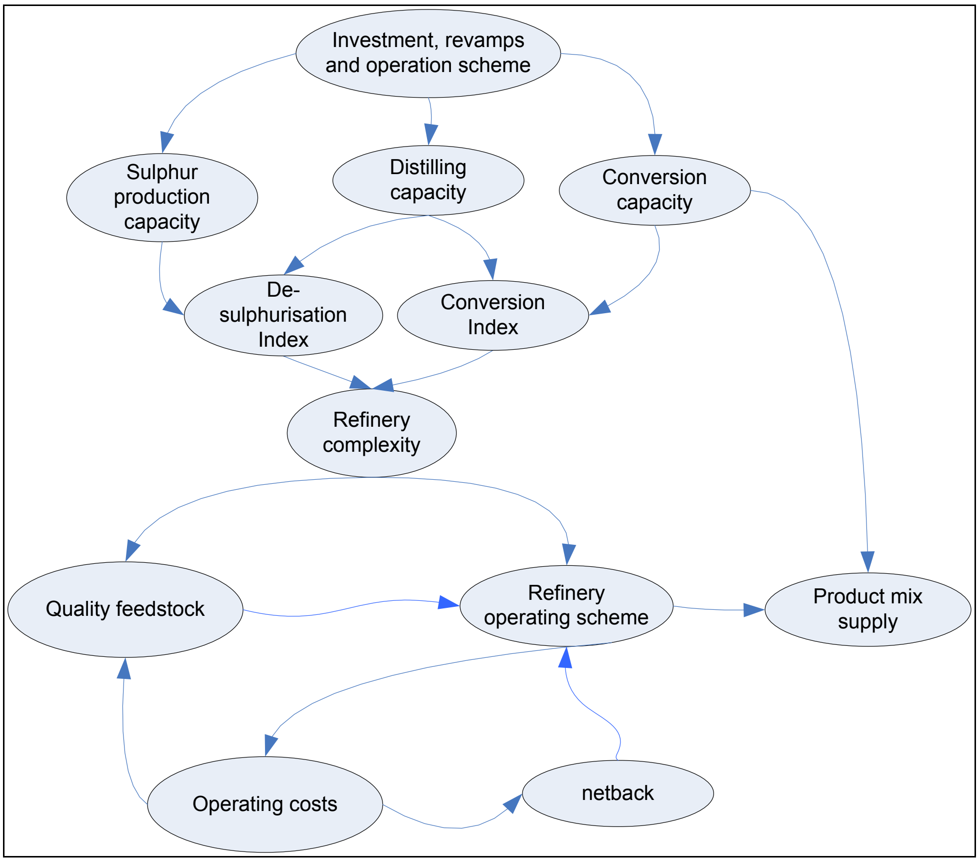


Figure 33: Causal diagram of the refinery industry

Focus in this chapter is on the conversion capacity, with emphasis on the different kinds of processes possible and their possible yields, therefore an extra link (from conversion capacity to product mix supply) is presented which is not denoted in the overall diagram for readability reasons. To cope with the product demand attention will given to the possible investments involved. The refiner scheme, netback and operating costs are out of the scope of this report.

First the different processes of refineries are described. Emphasis will be on conversion processes and their typical yields. On the basis of this information assumptions will be made on the yields of different kind of refineries described in the next paragraph.
In paragraph 4.2, some schemes on classifying refineries are highlighted, not very extensively, but the basics will be described. The classification used in this report will be given.
In paragraph 4.3 the required investments of refineries for coping with new regulations are described. Focus will be on regulations from OECD countries described in chapter 3.
Some attention will be on non-OECD countries, which have a tradition of exporting to OECD countries (the OECD countries mostly have complex regulation). These countries fill up deficits in the OECD countries, and when they do not apply to the new regulation, they won't be able to export their products and shortages may occur in OECD countries. This assessment will be on a qualitative basis, quantitative methods are difficult to use because of the amount information needed which is not always available and therefore such analysis would be incomplete and therefore useless.

The second part of this chapter will describe the actual refinery industry in the different regions. In paragraph 4.4 a tally of the typical refinery configurations per region, using the classification scheme described in paragraph 4.2, will be given, followed by the investments made in new capacity and a trend analysis on the growth of capacity of the main conversion processes per region. The refinery configurations will be coupled to the typical yields of those configurations.
In paragraph 4.5 a specification of the complexity and the sulphur ratio will be given.

3.1 Refinery processes and their typical yields

The most basic refineries are of the hydroskimming kind. 'Refineries that have only crude distillation (DU), catalytic reforming (RFU) and product treating facilities are referred to as hydroskimmming refineries.' (Wijetilleke e.a.1984, also Bacon e.a. 1990) This kind of refinery can only change their yields by taking different crude's as feedstock.
The typical yields of different crudes are given below, when processed by a hydroskimming refinery.

	Nigerian Bonny light	Arabian light	Iranian light	Arabian heavy
°API gravity	38.2	34.2	34.1	31
Hydro carbon Gas/ H_2S	1.0	0.6	0.6	0.8
LPG	2.0	1.5	0.6	0.6
Naphtha/ gasoline	23.4	20	20	18
Kerosene	15.2	14	13.7	12.5
Gas/ diesel oil	28	18.9	17.1	13.1
Residual Fuel oil	30.4	45	48	55

Table 19: Comparative yields by primary distillation from different crude oils (% weight) (Wijetilleke e.a.1984)

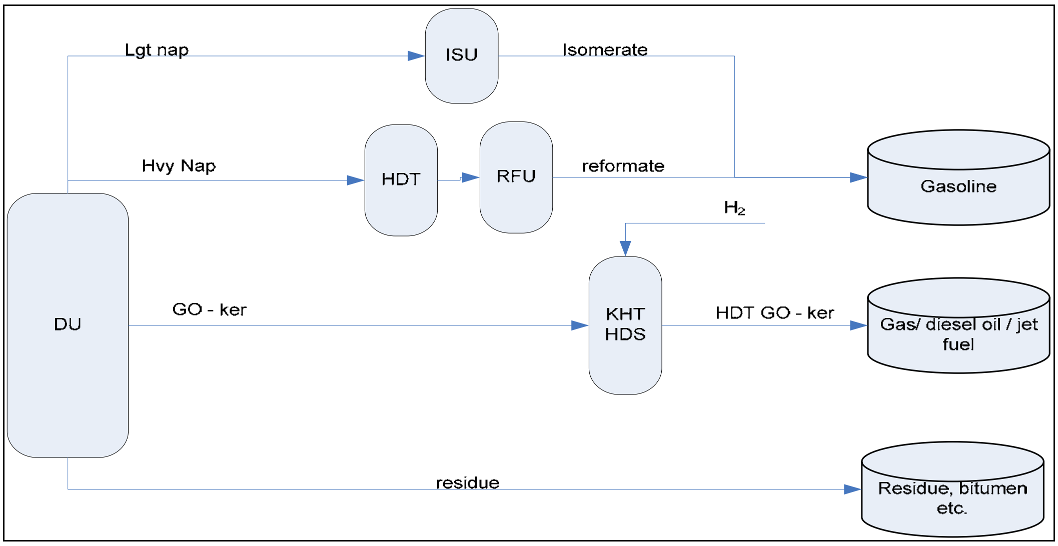


Figure 34: Simple refinery

ISU, HDT, RFU and KHT are treating processes to enhance octane or cetane number or remove sulphur and other contaminants.

To have more flexibility of product yield from particular crude, three sorts of processes can be added to the hydroskimming refinery. The first one has some extra 'thermal processing facilities', the second has 'secondary conversion processes which yield large quantities of high quality distillate fuels' (Wijetilleke e.a. 1984) and the third extra process equipment is deep conversion capacity (Favennec 2001), mostly used to reduce vacuum bottoms or residual fuel oil. This group contains coker, residual fluid catalytic crackers (RFCC) and residual hydrocrackers (RHCC).

3.1.1 Thermal processes

Thermal process facilities start by vacuum distillation/ flashing. Vacuum flashing (VDU) separates lighter products from heavier parts by vaporizing them with lowering the pressure below atmospheric pressures (Leffler 2000; 44). The yields have very low quality and contain the most contaminants which are bad for catalysts. Vacuum gas-oil contains much sulphur. It can be blended in small amounts with good quality gas-oil and it is used for further processing (Leffler 2000). Vacuum residue is used for asphalt and for thermal cracking or deep conversion feed.

	Vacuum gas oil (VGO)	Vacuum bottoms
Yield, weight % of feed	65.5	34.5
API gravity	22.2	6.9
Specific gravity @ 60ºF	0.9206	1.0334
Sulphur, weight %	2.48	4.00
Viscosity Cst @ 122ºF	75	225,000
Cetane No.	<20	-

Table 20: Vacuum Unit Yields, Feed: residual Fuel Oil (from Arabian light crude oil) (Wijetilleke e.a.1984)

The figure below is a configuration which may occur. The VDU can be replaced with thermal cracker or coker with out large alterations.

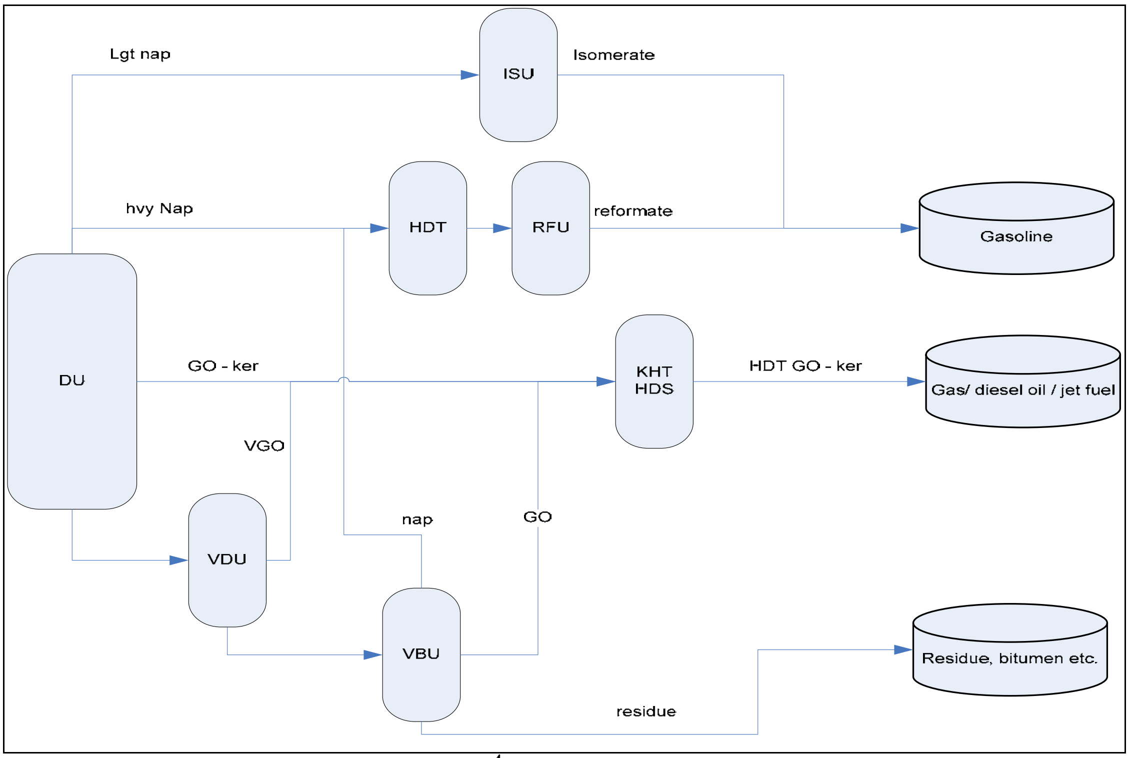


Figure 35: Refinery with thermal operations[4]

Four processes to reduce residual fuel by thermal processes are: Thermal cracking, De-asphalting, Visbreaking and Coking (Wijetilleke e.a. 1984). Coking is seen as deep conversion process. The yields of these processes are all of bad quality and need to be blended in small amounts with good quality yields or they need further processing (Favennec 2001, Wijetilleke e.a. 1984). Sulphur content may be a problem; it makes the cat-

[4] Lgt = light, hvy = heavy, nap = naphtha, GO = gasoil, ker = kerosene, HDT = hydrotreating, ISU = isomerisation unit, RFU = Reformate unit, HDS = hydrodesulphurization, VBU = Visbreaker

alyst used for cracking useless. Sulphur is mostly removed by hydro-treating. Although these processes reduce residual oil, these processes are not regarded to promote the refineries to a much higher class than the hydroskimming refinery (except for coker capacity). The quality of products is very low, the processes are cheap and difficult to control (except for cokers).

The thermal cracker produces gasoline, mid-distillates, fuel oil and gas. For Arabian light, the residue is converted to 55% distillates and the rest fuel oil. ‘Visbreaking of fuel oil is essentially a mild thermal cracking operation, the primary objective of which is to reduce the viscosity of fuel oil and improve its pore point characteristics.’ (Wijetilleke e.a.1984) This is done ‘so that less middle distillate is required as a cutter stock to blend them to fuel oil viscosity specifications.’ (Ellis Jones 1988; 140) Middle distillate has more worth than fuel oil. Some middle distillates are produced, but of poor quality.

	Gasoline		Mid-distillate		Fuel Oil		Other (gas)	
Yield, weight % of feed	18.0	30*	28.0	25*	45.0	20*	9.0	25*
Sulphur, weight %	0.5		2.0		4.6		-	
Viscosity. Cst @ 122ºF	-		2.5		400,000		-	
Octane No.	40-45		-		-		-	
Cetane No.	-		40		-		-	

Table 21: Thermal cracker yields, feed: residual fuel oil, (Arabian Light) (Wijetilleke e.a.1984)

*Taken from Leffler 2001; 112, yields from West Texas crude, the difference can be explained by the difference in properties of the feed and the processing schemes.

	Lt. Ends	Gasoline	356-650ºF	650-1050ºF	1050ºF+
Yield, weight % of feed	2.5	5.9	8.8	19.4	63.4
Sulphur, weight %	-	1.0	1.6	3.1	4.6
Viscosity. Cst @ 50ºF	-	-	1.9	150	$2.5*10^6$
Octane No.	-	40-45	-	-	-
Cetane No.	-	-	43.0	-	-

Table 22: Visbreaker (VBU) Yields, Feed: Vacuum Bottoms (Wijetilleke e.a.1984)

De-asphalting separates out asphalt and metal free oil. The leftover is called pitch, contains asphalt and metals. The oil produced is of bad quality and needs further processing or blending in small amounts in good quality oil.

Yield, weight % of feed	
Deasphaltated and dematellized oil	55
Pitch	45

Table 23: Solvent Deasphalter Yields, Feed: Vacuum Bottoms (Wijetilleke e.a.1984)

The coking process reduces coke in fuel oil, improving the proportion of hydrogen relative to coke. The higher the hydrogen proportion, the lighter product usually is. The coke is useless for metallurgy industry because of contaminations by sulphur and metals, unless low sulphur feedstock is used (Leffler 2000, Ellis Jones 1988). It produces a relative large amount of distillate fuel compared to the other thermal processes, the quality is low, and the capital and operation costs are very high. 'Where there is both the capability to produce these premium grades of coke rather than fuel grade coke and a market demand for them the economics of building a coking unit may be considered.' (Ellis Jones 1988; 141) Because of the large investments needed for this process, and the great ability reduce residue, it is mostly regarded as a process belonging to a very complex refinery.

	C_5-356ºF Gasoline	Mid-distillates	Fuel oil	Coke	Other (gas)
Yield, weight %of feed	13.9	26	16.6	32.8	10.7
Sulphur, weight %	0.9	2.4	3.8	5.6	-
Viscosity. Cst @ 50ºF	-	2.6	7.5	-	-
Octane No.	40-45	-	-	-	-
Cetane No.	-	37	-	-	-

Table 24: Coker yields, Feed: Vacuum Bottoms (Wijetilleke e.a.1984)

Conclusion

When these processes are used, additional processes are needed to produce high quality products. All processes described above deliver bad quality and instable yields, not suitable for products (except blending small amounts) but very suitable yields for further processing. The sulphur content is mostly high, especially in the heavier parts and the octane and cetane numbers are rather low.

3.1.2 Secondary refinery processes: conversion

Secondary processes are more advanced than the ones described before (except for coking). Fluid catalytic cracking (FCC) and hydrocracking (HCC) convert vacuum gas-oil into distillates. Both processes will be described in this paragraph.

Fluid Catalytic Cracker (FCC)

FCC is a process to convert heavy yield into lighter products. Typical cracker feeds are on the heavier ends of the distilling process and vacuum gas oil (VGO). FCC has three output products: cat cracked naphtha (gasoline group), cat cracked distillate (distillate group) and heavy cracked distillate (residue group). The naphtha produced is of high quality, 'it has a high octane number and can be blended in without further processing.'

(Horsnell 1997; 405) With new regulation the naphtha needs treating, this will be described in the next paragraph. FCC is commonly used to produce gasoline, but can be used for producing middle distillates, although quality of diesel will be low.
Refiners mostly use catcrackers on their maximum capacity, because ‘Cat crackers usually make so much money by converting heavy feed to light’ (Leffler, 2000; 68). ‘The key feature in the FCC process is its ability to remove hydrogen from hydrocarbons of high molecular weight while creating more, lower molecular weight hydrocarbons. The result is a very significant volume gain in liquid products. It is this volume gain which makes the FCC process a attractive refinery conversion process.’(Wijetilleke e.a. 1984)

The cat-crackers capacity is partly influenced by the weather. If the weather is colder the cat-cracker is able to produce more gasoline than when it’s warm. So in summer more heavy fuel is produced and in winter more gasoline. This is contra the demand, because in summer more gasoline is needed (driving season in the US) and in winter more heavy fuel for heating. Also day and night has its influence. (Leffler, 2000; 68-69)

The following two tables include FCC yields with feedstock: vacuum gas oil, desulphurized residue, or deasphalted oil. The first table contains values for FCC in the maximum gasoline mode and the second table for yields in the maximum middle distillate production mode.

	HCC Gas + LPG		Gasoline		Light Cycle oil		Clarified oil		Coke	
yields FCC in the maximum gasoline mode										
Yield, weight % of feed	17.2	27*	48.9	43*	15.7	17*	8	6*	5.5	6*
Sulphur, weight %	-		-		2.8		5.2		-	
Viscosity. Cst @ 122ºF	-		-		1.5		2.5		-	
Octane No.	-		91.5		-		-		-	
Cetane No.	-		-		20-34		-		-	
yields FCC in the maximum middle distillate mode										
Yield, weight % of feed	12.0		29.6		44.3		9.1		5.0	
Sulphur, weight %	-		-		2.9		5.2		-	
Viscosity. Cst @ 122ºF	-		-		1.5		2.8		-	
Octane No.	-		89		-		-		-	
Cetane No.	-		-		20-34		-		-	

Table 25: Yields of FCC in gasoline and mid-distillate production mode (Wijetilleke e.a.1984)

Yields are taken from Leffler 2000, in this table for light cycle oil, light gas oil plus cycle oil are meant and for clarified oil, heavy gas oil is meant. The feed was 40% heavy gas oil and 60% flashertops.

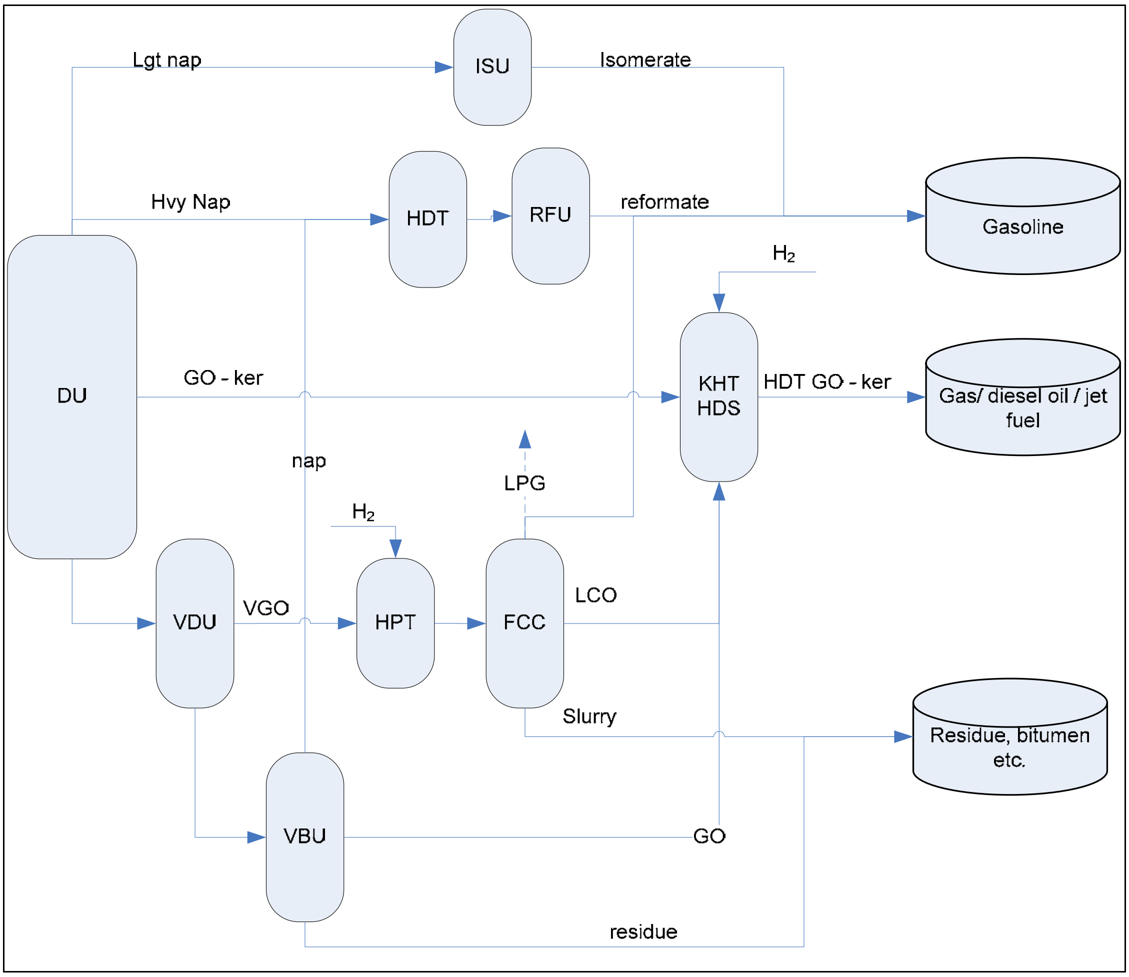


Figure 36: Refinery configuration with FCC unit, with hydropretreatment (HPT)

Hydrocracker (HCC)

The hydrocracker (HCC) is some more advanced than the FCC. The heavy molecular weight of the hydrocarbons used as feed, have relatively a greater amount of carbon and less hydrogen molecules than lighter hydrocarbon molecules. 'To make significant quantities of low boiling point distillate fuels from high molecular weight stock, either carbon must be removed or the hydrogen deficiency be corrected.' (Wijetilleke e.a 1984) The feed is processed at high temperatures and pressure for the hydrogen to react with the hydrocarbons. 'The capital cost of this process is substantially higher than for an FCC unit processing the same quantities of feed. However, a hydrocracker gives greater product flexibility, higher yields and better quality middle distillate products than a FCC. Its process is highly flexible and can produce wide range of high quality products, in different quantities.' (Wijetilleke e.a.1984) A hydrogen plant is needed to provide hydrogen.
The yields of this process is given in three ways: two stage maximum gasoline production, two stage maximum mid-distillate production and single stage maximum mid-distillate production.

	LPG	Gasoline	Middle distillate	Fuel oil	Sulphur + HCC gas other
(i) Two stage – maximum gasoline production					
Yield, weight % of feed	15.2	85.8	-	-	2.8
Sulphur, weight ppm	-	5	-	-	-
Octane No.	-	65	-	-	-
Cetane No.	-	-	55	-	-
(ii) Two stage – maximum mid-distillate production					
Yield, weight % of feed	5.3	20.2	74.2	-	2.6
Sulphur, weight ppm	-	7	7	-	-
Octane No.	-	65	-	-	-
Cetane No.	-	-	55	-	-
(iii) Single stage – maximum mid-distillate production					
Yield, weight % of feed	3.6	11.5	84.6	-	2.7
Sulphur, weight ppm	-	5	5	-	-
Octane No.	-	65	-	-	-
Cetane No.	-	-	59	-	-

Table 26: yields hydrocracker (Wijetilleke e.a.1984)

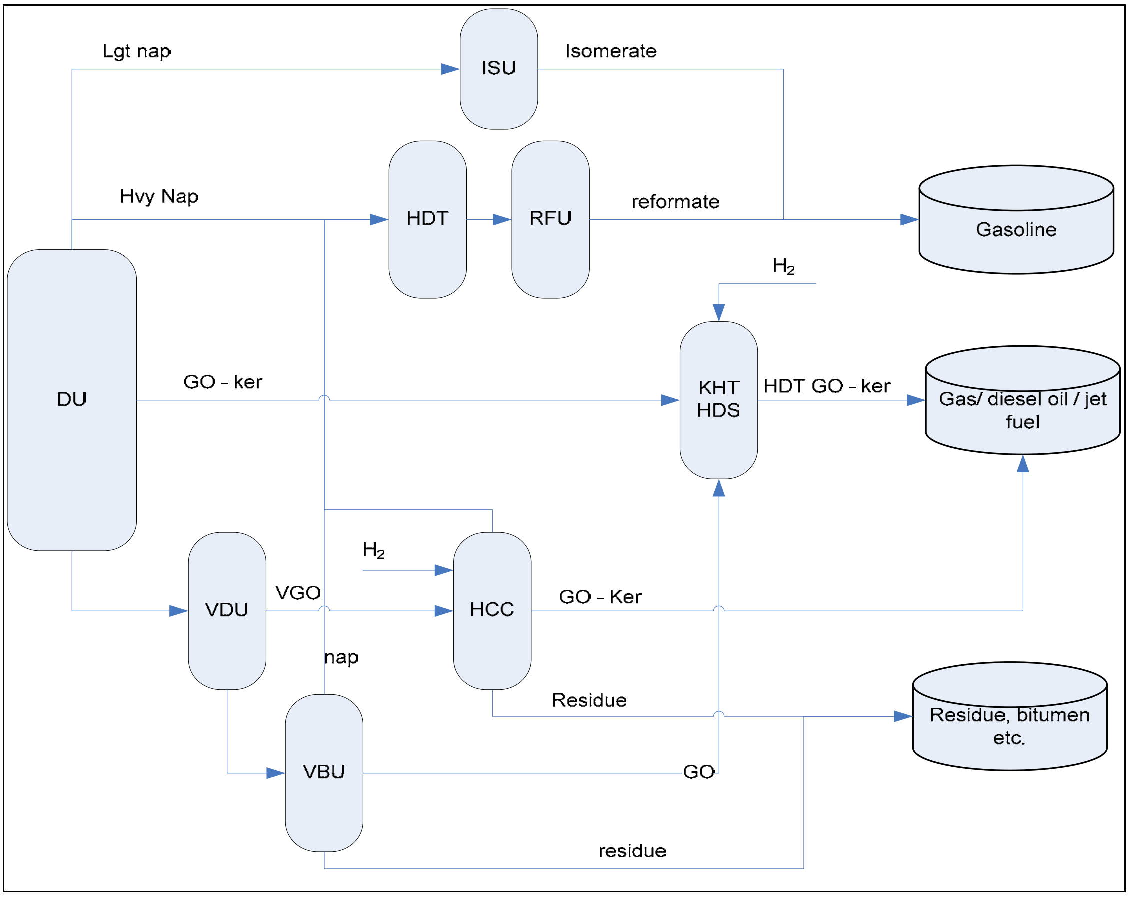


Figure 37: Refinery configuration with HCC unit

Conclusion
The major difference in yields of a FCC and a HCC is the difference in quality of diesel and gasoline. The octane[5] number of FCC gasoline is high compared to the cetane[6] for diesel, and vica versa for the HCC. The HCC can produce large amounts of gasoline with low sulphur content but with a low octane number, the diesel produced has low sulphur content and high cetane number.

3.1.3 Deep conversion

'As demand for heavy fuel declined, deep conversion units were developed to process atmospheric or even vacuum residue and operate effectively as residue destruction units.' (Favennec 2001; 129) Cokers are a good example, widely used in the US to remove residue. Residual fluid cat crackers (RFCC) were developed, 'using catalysts with improved resistance to poisoning and upgraded recovery systems.' (Favennec 2001; 129) This cracker is fed by the residuum of the primary distilling column. It is able to process residue of lighter crude's with low contamination levels.
Also hydrocracking plants for heavy feedstocks are developed, 'these are often a combination of hydrocracking and catalytic cracking technologies in what are called "ebullating bed crackers".' (Favennec 2001; 129) These processes are even more expensive than hydrocrackers, put can process more heavy and sour crude feedstocks found in Venezuela, Mexico and Canada.

3.1.4 Conclusion

The following points from the description above are of importance:

- Hydroskimming refineries are only able to diversify their yields by changing (crude) feedstock.
- Thermal processes mainly produce low quality products (high sulphur content and low cetane or octane numbers) and therefore need to be blended in or further processed.
- Visbreaking is used to reduce viscosity of fuel oil to comply with fuel oil viscosity specification without blending in more valuable middle-distillates (Wijetilleke e.a. 1984, Ellis Jones 1988)
- FCC produces high quality gasoline and low quality diesel, therefore it is taken that this process is mainly used to produce gasoline.
- HCC produces high quality middle distillates and low quality gasoline, therefore it is taken that this process is mainly used to produce middle distillates.
- HCC has higher operation costs than FCC units, but it has a higher flexibility in yields and reduces sulphur from products.
- HCC and FCC units are mostly run on their maximum capacity because of their large yields of light valuable products.

An overview of the refinery processes and the products which can be produced are presented in the table below.

[5] Octane, anti-knock, number denotes the ability of the gasoline to auto-ignite, or better, not to auto-ignite.
[6] Diesel engines are based on auto-ignition, cetane number is an indicator on the ability of fuel (diesel) to auto-ignite.

PRODUCTS → REFINERY UNITS ↓	Section	LPG	Gasoline	Kero/ naphtha	Heating oil/diesel	HFO	Base Oil	Coke/ bitumen	Special
Carbon n° range		C_3-C_4	C_4-C_{12}	C_8-C_{17}	C_8-C_{25}	>C_8	>C_{15}	>C_{30}	
Alkylation	2								
Base Oil production	3								wax
Bitumen production	4								
Catalytic cracker	5								
Residue cracking	5								
Catalytic reforming	6								H_2
Delayed coking	7								
Flexicoker	7								low joule gas
Gasification	10								syngas
Etherification	11								MTBE
Gas separation processes	12								Refinery fuel gas
Hydrogen plant	14								H_2
Residue Hydroconversion	14								H_2
Hydrocracker	15								
Hydrodesulphurisation	15								
Isomerisation	17								
Crude atmospheric distillation	19								
Vacuum distillation	19								
Thermal cracking/Visbreaking	22								
Sulphur recovery unit	23								S

Table 27: Refinery processes and their typical yield

3.2 Indicators for classifying refineries

This paragraph describes classification schemes used for the refinery industry. First a description of single complexity indicators, than a description will be given on classification schemes of refinery configurations.

3.2.1 Single complexity indicators

'In the 1960's, when building refineries as fast as they could, Wilbur Nelson devised a shorthand for characterizing how much plant and equipment a refinery had.' (Leffler, 2000: 216). He introduced a measure called the Nelson index, based on the construction costs of an average size unit of equipment (conversion, treatment or other units) and the capacity in volume of conversion in reference with an average size simple distillation unit. The simple average distillation unit gets a unit factor of 1, and for example, 3 for thermal cracking, 5.5 for catalytic cracking etc. (Chen 2005). Refineries are divided by their complexity, from simple to very complex on the basis of one indicator (the Nelson index) on a scale. The following equation is used to calculate the Nelson Index when all unit factors are known:

Nelson index = $\Sigma\{\text{unit factor} * ({}^{\text{Unit capacity}}/_{\text{Distillation capacity}})\}$

Margareth Chadwick (Bacon e.a., 1990: 163-164,) characterizes different types of refineries by the concept of 'capacity by type of yield' it is able to produce. These yields are divided in topping, simple (often taken together), semi-complex, complex and Ultra-complex. According to Chadwick Ultra-complex is not often used (in 1986), so three types are left: simple (hydroskimming), semi-complex and complex. To characterize refineries, it is not important what quality, but the amounts it produces.
Another way of looking at refineries is by calculating 'the conversion ratio'. 'The ratio is generally quoted in terms of FCC equivalent, as that is the most common conversion unit.' (Favennec 2001; 130) It is calculated by the equation:

Conversion ratio = $^{\Sigma(\text{FCC equivalent*conversion capacity})} / _{\text{Distillation capacity}}$.

Like with the Nelson index the reference unit factor is 1, this is assigned to the Fluid Catalytic Cracker (instead of the distillation unit). The other units get equivalent factors on the basis of their ability to convert petroleum cuts (see Table 28).
The conversion index provides us with insight in the ability of refineries to convert, instead of insight in investment needed to build a refinery (Nelson Index). It is uncertain that the cost of investment correlates with the ability to convert. The conversion index seems most suitable to find a relationship between the refinery complexity and the quality of crude processed.

The distilling capacity plays a central role in the calculation of the conversion index, but this capacity is not used in full. To assess the quality of crude used in certain refineries this needs to be taken into account. In chapter 5 a relation will be searched between the conversion ratio and the quality of crude. Refineries which do not use their full distilling capacity, produce less vacuum gasoil and therefore are able to convert a larger percentage of it into light products since the conversion capacity is used in full. To be able to compare refineries strategies on the crude quality consumed this needs to be normalized. To be able to do so, the conversion ratio will be calculated by the following equation:

Conversion ratio = $^{\Sigma(\text{FCC equivalent*conversion capacity})} / _{(\text{crude runs})}$

This equation is better than the latter because the conversion ratio is now normalized to the amount of crude run through the refinery and therefore the conversion ratio of the different regions and countries are comparable.

Conversion type	Configuration	Conversion factor to FCC eqv
Asphalt	Asphalt	0.25
Catcracking	DCC (Deep CC)	1.1
Catcracking	FCC	1
Catcracking	FCC-Resid	1.9
Catcracking	TCC (Thermal CC)	0.8
Coking	Coking-delayed	1.35
Coking	Coking-fluid (flexi)	1.35
Coking	Coking-F/D	1.35
Coking	Coking-FXC	1.35
Desulf-resid	HDS-resid	0.2
Desulf-VGO	HDS-VGO	0.05
Hydrocracking	Hydroc-Distillates	1.3
Hydrocracking	Hydroc-Mild	0.3
Hydrocracking	Hydroc-Resid	0.4
Lube	Lube	0.5
Other	DDW	0.1
Other	Other	0.1
Otherconv	Hyres-gas	1.3
Otherconv	Otherconv	0.1
Thermal cracking	Thermal cracking	0.65
Visbreaking	Visbreaking	0.25

Table 28: FCC equivalents for calculation of conversion index (ENI 2005)

3.2.2 Classification schemes

Margareth Chadwick (Bacon e.a., 1990: 163-164,) characterizes different types of refineries by the concept of 'capacity by type of yield' it is able to produce. These yields are divided in topping, simple (often taken together), semi-complex, complex and Ultra-complex. According to Chadwick Ultra-complex is not often used (in 1986), so three types are left:

- Simple refinery: Crude Distillation (CDU), catalytic reformer (CRF), Hydrotreating (HDS)
- Semi complex refinery: simple + thermal cracking (THCC)
- Complex refinery: semi complex refinery + catalytic cracking (FCC) or hydrocracking (HCC)

To characterize refineries, it is not important what quality, but the amounts of products it produces.

Favennec (2001) uses the following classifications for refineries:

- 'simple refineries have atmospheric distillation, normally a catalytic reformer for the manufacture of high octane motor gasoline components, and middle distillate hydrodesulphurization units
- complex refineries have, in addition, traditional types of conversion units such as fluid catalytic crackers, hydrocrackers or visbreakers

- ultra complex refineries have both the above conversion plant and deep conversion units that can operate directly on atmospheric or vacuum residues and convert them to light products'

Leffler (2000) uses the following classification:

- 'simple refinery- crude distillation, cat reforming, and distillate hydrotreating
- complex refinery-simple refinery plus cat cracker, alky plant, gas processing
- very complex refinery-complex refinery plus coker which eliminates residual fuel'

These classifications are often derived from the Nelson index, except the classification of Chadwick.

These three classifications do not fulfill the information needed for this thesis, since no division in the abilities of producing certain products are included. Therefore these classifications will be used as first basis, but replenished with extra sub-categories. Further classification is based on the ability of different sorts of refinery processes to produce a different product mix (of respectable quality).

Julia Reinaud (researcher for the IEA) (2005) gives us some extra insight. She incorporates the differences of refineries on the ability to produce certain products as well as the ability to reduce residue. The focus is mainly on production of gasoline or diesel or both. The following classification is used by Reinaud (Taken directly from her paper):

Refinery category	Refinery Type	Descryption
Simple	Topping refinery	This refinery consists only of an atmospheric distillation unit.
	Hydroskimming (HSK)	This type of refinery has a very rigid product distribution pattern – characterised by high Heavy Fuel Oil (HFO) production, due to the lack of conversion units. The produced fuels are almost entirely fixed by the type of crude being processed. Naphtha streams production is limited, with little ways of high octane material blending which forces a significant (about half) portion of naphtha material to be sold as is, at a lower price than gasoline. Most of the hydroskimming refineries include a visbreaker or thermal crackers in their plant layout. The production from a hydroskimmer is mainly destined for the local market where blending the output may be necessary for compliance with European diesel or gasoline specifications.
Semi-com,plex	HSK + fluid catalytic cracking (FCC) + delayed coking (DC) and or Visbreaking	The Fluid Catalytic Cracking, FCC, unit provides a mean of reducing the carbon-to-hydrogen ratio by depositing coke on the circulating catalyst. This coke is removed more or less completely in the regenerator (Maples, 1993). The FCC units are specifically designed to increase the duction of **gasoline** (55% of feed). Product yield is rised by very low HFO production as well as some coke. A major problem with cat gasoline is the high sulphur content –

		requiring significant and expensive hydrotreating of end products under several countries' regulation (e.g.,, US, rope, etc.). Likewise, the fuel & loss value is also increased compared to other configurations.
	HSK +Hydrocracking HCCU (+DC)	Hydrocracking units, HCCU, are specifically used to maximize the production of gasoline and middle distillates. This type of refinery has a higher degree of flexibility with respect to either maximum gasoline or maximum middle distillate production. This flexibility comes at a high price: the high expense of a stand-alone hydrocracker and its associated hydrogengenerating infrastructure. A hydrocracking unit is more expensive because it requires special metals to resist to higher pressures, temperatures, and quantities of hydrogen. HCCU is different from FCCU as products from the former are of better quality; it adds hydrogen, and prevents the formation of olefins. In contrast with the coking and deasphalting processes, hydrocracking decreases the carbon-to-hydrogen ratio by the addition of hydrogen rather than the removal of carbon. This type of refinery in Europe is mainly **diesel / gasoil** oriented as the hydrocracking units produce very good quality diesel material.
Complex	HSK + FCC + HCCU	This complex refinery produces a lower amount of gasoline than an FCC + DC, but higher than the HCCU +DC. Diesel production is higher than FCC + DC but lower than HCCU + DC. It could be viewed as representing an average between semi-complex and complex configurations. In the case where an IGCC is built in the refinery, the amount of residues is close to zero. There is no more HFO. The only heavy product available is bitumen.
Complete conversion	HSK + HCC / FCC + DC	Coking is used as a means of reducing the carbon/hydrogen ratio of residual oils. If a Delayed Coker is included, HFO production is greatly reduced, but on the other hand, a low value product is produced (coke). The purpose of a DC is also to increase cat cracker feedstock availability and of reducing the production of residual oil. Only 8 cokers exist in Europe. This unit is present in the United States since coker allows reducing the production of heavy fuel oil – a product still used in electricity generation (e.g.,, in Italy and Japan).

Table 29: Classification according Reinaud (Nov 2005) based on the European situation.

The more complex the refinery, the less residue and the more light products like gasoline are produced. The hydrocrack refinery is able to reduce sulphur levels and produce high quality diesel, the FCC refinery is able to produce high quality gasoline but the ability to reduce sulphur is limited, therefore these are different types of refineries. The hydrocrack refinery may need to do less investment to cope with sulphur regulation than an FCC refinery, because it has the characteristic to reduce sulphur significantly.

3.2.3 Conclusion

The conversion ratio is most suitable for analyzing the complexity of the refinery industry in different regions. The conversion ratio primarily looks into the ability of refiners to convert and treat crude to products, the more complex the heavier the feedstock and/ or the lighter and more valuable the possible yield. Therefore the conversion ratio is good indicator for the quality of crude used as feedstock.

To be able to compare different refinery strategies, the conversion ratio needs to be normalized to the amount of the capacity used. Therefore the distilling capacity in the equation is substitutes by the actual crude runs. The result will be a higher conversion ratio.

The conversion ratio indicates the ability to produce light products by converting residual fuel. Residue was not converted in to light products, and may be a good indicator for the production of light products, for the quality of crude and the refinery complexity.
Paragraph 4.2.2 assesses different classification schemes. As a result the classification from simple to very complex used in this report will be:

1. Simple refinery: crude distillation and treating facilities like cat reformer and hydrotreater, sometimes hydrodesulphurization
2. semi complex refinery: simple refinery + thermal processing (vacuum distillation, thermal cracker, visbreaker, deasphalter)
3. Complex refinery: semi complex refinery +
    a. FCC
    b. HCC
    c. FCC and HCC
4. Very complex refinery: deep conversion (residual FCC and Coker for minimizing residue)
    a. with FCC
    b. with HCC
    c. with FCC and HCC

3.3 Refinery investment possibilities to cope with new regulations

Looking at different studies, i.e. for the European Union and the US, hydrotreating is the most mentioned process to reduce sulphur, as well as for diesel as for gasoline. Hydrotreating is a process which uses high pressure, high temperature and a catalyst to stimulate a reaction of sulphur and other contaminants with hydrogen to remove these contaminants from the products being treated. The heavier fractions of the crude slate contain the most sulphur, have a more complex molecule structure. Therefore it is considered to be more difficult to reduce sulphur in diesel than in gasoline (diesel is heavier than gasoline) (Birch 2000; 12). This paragraph will first address options for gasoline, than for diesel and last fuel oil.

3.3.1 Refinery possibilities to reduce sulphur from Gasoline

The problem with hydrotreating is the reduction of octane number of naphtha. Naphtha is a blending component for gasoline and a high octane number increases the quality of gasoline. According to Birch (2000), straight run gasoline contains very little sulphur, but cat cracked naphtha, used as blendstock for gasoline, does.

The next figure, taken from Foster Wheeler's website (1999), illustrates that the sulphur content increases with boiling point, with a rapid rise in sulphur content after the 210ºC. 'About half of the total sulphur in the cut is found in the final 10% of the boiling range.' (Foster Wheeler 2001) Undercutting (lowering the boiling point of naphtha) FCC gasoline is a way of avoiding heavier naphtha, with higher sulphur content, is blended into gasoline and therefore sulphur levels can be controlled better (Birch 2000).
'Olefins provide much of the superior octane qualities of FCC naphtha.' (Foster & Wheeler 2001) Hydrotreating reduces the amounts of olefins, which is not a good thing for gasoline quality. Olefins can be used to produce alkylate, MTBE or TAME (Dastillung 2005) which all increases octane number. For desulphurising, the focus should be on the heavier part of naphtha, to prevent unnecessary octane loss (by olefin reduction) of already low sulphur light naphtha.
The figure clearly shows a decrease in olefins with increasing boiling point, a rapid increase of aromatics content in the medium heavy naphtha cut.

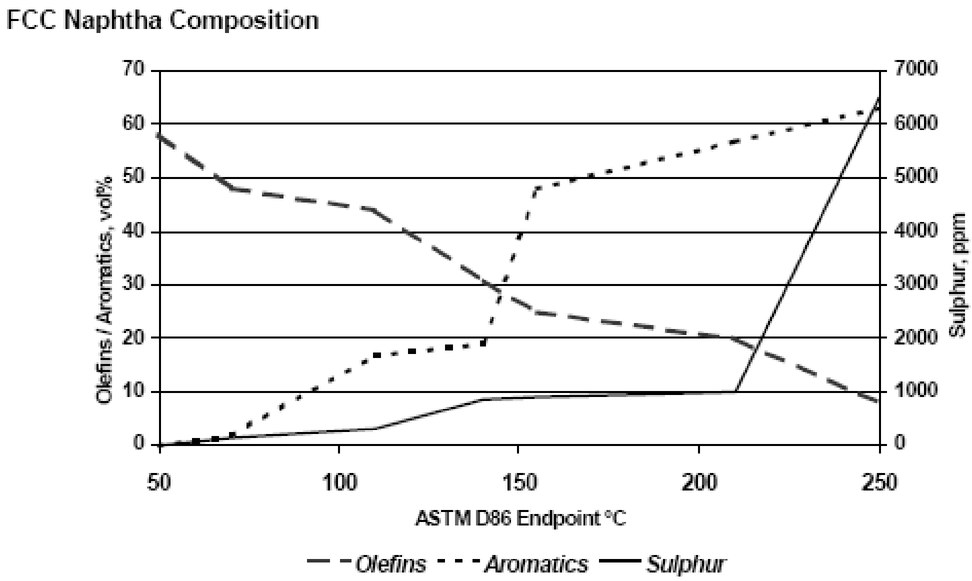


Figure 38: FCC naphtha composition (Foster Wheeler 2001)

The following figure shows the refinery scheme to desulphurize naphtha. By first splitting heavy from medium and light naphtha, separate treatment is possible. The light naphtha is run through a caustic treater, the medium naphtha is processed in a reformer and the heavy naphtha is hydrotreated.

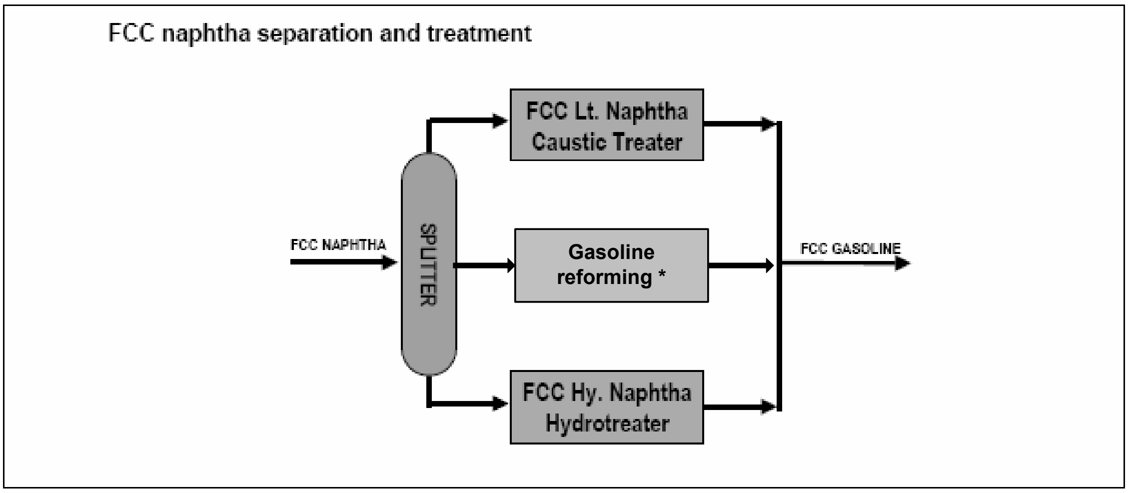


Figure 39: Naphtha processing scheme (Foster Wheeler 2001)

* edited according to information from Dastillung 2005

Light straight run streams from refineries, can be processed by mercaptan extraction units (like the caustic treater) (Foster Wheeler 2001, Sieli 2000) to remove sulphur. The same is done with the light end of the FCC naphtha yield (Dastillung 2005). Caustic (NaOH) used in a caustic treater, can easily extract H_2S (a sulphur compound), carbonyl sulfide and mercaptans (90% of total) from gases like LPG and light naphtha's. It removes about 40-46% of the total sulphur in the stream (Foster Wheeler 2001, Sieli 2000). This is only useful if sulphur content in these runs is significant. It is a cheap to use process for reducing sulphur in products and there is no loss of octane number.

Medium heavy FCC naphtha (140ºC cut) can be desulphurized by cat gasoline reforming. 'Investment is required to modify the existing cat gasoline splitting and naphtha reformer feed pretreatment facilities and make other reformer peripherals changes. This process removes essentially all sulphur, with an octane credit of 8 to 11 MON and aromatics increase by some 40% to 46% v/v.' (Dastillung 2005) Aromatics increase the octane number but also increase unwanted exhausts. Aromatics content is regulated, it maximum content in gasoline is 35% in the EU. The use of this process to reduce sulphur may increase problems on aromatics content, but the octane number will increase.

Desulphurisation by hydrotreating is applied on the cut of medium heavy and heavy naphtha/light gasoil between 180ºC and 221ºC. 'Some 96% of the sulphur is reduced with octane loss of 3 RON and 1 MON. Sulphur removal of 99.5% can be achieved, however at the expense of reduced selectivity and increased octane loss.' (Dastillung 2005). Hydrotreating reduces the olefin content and therefore the octane number. Because the heavier naphtha contain relatively less olefins and the most sulphur, quality is reduced less through octane loss (olefin reduction) and quality increases through sulphur removal.

To meet with sulphur specifications, a trade off can be reached by blending low sulphur components with high sulphur components to comply the rules (Foster Wheeler 2001, Seili 2000). The possibility to invest in desulphurization of one blendstock and neglect another and blend them together to meet sulphur regulation is plausible. Refiners can trade blendstock to meet sulphur specifications and avoid major investments. Corporations with multiple refineries (with different configurations) will take most advantage of trading blendstock.

Another possibility is to reduce sulphur in the cracker feed by hydrotreating (pretreating), ‘but intermediate and heavy cat gasolines may still need desulphurization to meet very low gasoline sulphur specifications.’ With the gofiner (hydrotreating) process ‘some 95-96% desulphurization of the cat feed and 17% to 30% conversion to products lighter than the feed is achieved.’ (Dastillung 2005) ‘However, FCC feed hydrotreaters incurs high capital costs which is a significant disincentive to their use.’ (EPA 1999)

3.3.2 Refiner possibilities to reduce sulphur in diesel

‘Diesel desulphurization is currently primarily carried out using hydrotreating processes.’ (Birch 2000) But to cope with regulation more expensive catalysts and higher pressure needs to be used. Straight run diesel is of good quality (high cetane and low polyaromatics content) but need hydrotreating to remove suplhur.

FCC diesel blendstock, light cycle oil, is of poor quality. ‘Light cycle oil (LCO) is low cetane, high density, high in aromatics and high in sulfur content unless the FCC feed has been pretreated.’ (Birch 2000) It is used for blending in the lower quality heating oil, but demand in Europe is slacking and demand for diesel oil is growing. Upgrading cycle oil is considered although expensive. Hydrotreated diesel is of high quality, good cetane, low polyaromatics content and low sulphur content. Yet, to produce ultra low sulphur diesel (ULSD), extra attention on desulphurization capabilities need to placed. In other words, desulphurization needs to be intensified to produce very low sulphur diesel.

Switching to other, mostly more expensive, catalysts or using more catalysts (depending on the crude being processed) in treating units is needed. Nickel Molybdenum (NiMo, catalyst) can be used to boost desulphurization. It uses somewhat more hydrogen because it saturates aromatics; raising cetane quality (Birch 2000) (hydrogen is absorbed by carbon).

In addition, to meet ULSD demand, higher pressure for treating is needed. Refiners with low pressure hydrotreating units may need to invest in higher pressure (50-60 bar to meet 50ppm diesel) and change catalyst. To reduce the amount of cycle oil, high pressure hydrotreating is very useful (90-100bar). Some refiners will revamp their hydrotreaters, others need to invest in new ones. Low pressure hydrotreaters can be revamped to meet the 50ppm sulphur regulation. Medium pressure hydrotreaters are able to produce the 10ppm sulphur diesel with intensification of the use of catalysts and other measures. High pressure hydrotreaters are able to meet the ulsd reguirements.

Diesel from HCC units are mostly low sulphur, some may need extra hydrotreating.

3.3.3 Refinery possibilities to Reduce sulphur in fuel oil

Reducing sulphur in fuel oil can be done by using sweeter crude’s. Also by blending in with low sulphur components is an option, but the most effective alternative is fuel oil treating by a hydrotreater. More often are these treaters used as pre-treaters for the FCC process. It is an expensive piece of equipment and operation costs are significant, therefore it is more attractive to use this operation for pre treating FCC feed to produce low sulphur light product than the relatively cheap bunker fuel of HFO. The use of the residue treater for both purposes makes this process, all though expensive, more attractive to invest in.

3.3.4 Conclusion

For gasoline, splitting naphtha to light, medium and heavy naphtha and treating the cuts separately is the main solution to prevent octane loss and reduce sulphur levels. Light naphtha can be treated by the caustic treater, the medium heavy naphtha by the gasoline reformer. The hydrotreater reduces the octane number and desulphurises thoroughly and is only used for the heavy naphtha which has a low octane number anyway and the most sulphur.

ULSD can be produced by hydrotreating the blendstock for diesel more extensively. This can be done by revamping hydrotreaters to higher pressures and by using more or different catalysts. FCC refiners need to treat their diesel yield more extensively than HCC refiners. Treating the feedstock before it enters the cracker as treating the yields after it left the cracker are both possibilities.

Hydrotreating residue is used to reduce sulphur in HFO. This is an expensive process, therefore it is often used to pre-treat FCC-feed. Since this process is useful for these two purposes it may be interesting to invest in pre-treaters.

These possibilities stand next to changing the feedstock to lower sulphur crude. To be able to suffice to the regulation described in the former chapter, one of these option needs to be introduced.

3.4 The refinery configurations per region and trend analysis

This paragraph will describe the refinery industry by doing a tally of refinery configurations according to the classification described in paragraph 4.2. Than an oversight of investments made to enhance distilling, conversion and sulphur treating capacity will be given. The regions Europe, North America, OECD-Pacific and the other regions (Africa, Latin America, other Asia, other Europe and FSU) will be assessed separately. The other regions are taken into account to research their export potential to the sulphur regulating regions.

3.4.1 The European refinery industry

The table below contains a tally of the equipment available at the European refineries. The table is constructed by categorization of the refineries and than count them.

EU-15 plus Country	refinery type								
	1	2	3a	3b	3c	4	4a	4b	4c
Austria			1						
Belgium	1	2	2						
Denmark		2							
Finland			1		1				
France			11		1				
Germany		1	4	3	1	1	1	1	1
Greece	1	1	1		1				
Ireland	1								
Italy	1	6	2	3	2		1		1
Netherlands		2	1	1				1	1
Norway		1	1						
Portugal		1			1				
Spain		2	2	1	2		1		1
Sweden	1	3			1				
Switzerland		1	1						
Turkey	1	2		1	2				
UK	1	2	6	1			1		
Totaal	7	26	33	10	12	1	4	2	4

Table 30: European Refinery sector configuration (OGJ Dec. 2005)

The following points stand out:

- The average size of the European refineries is about 151.265 b/cd (distilling unit).
- Most European refineries are of the FCC kind, referring to the classification given above, the 3a type. In total 53 refineries have a FCC unit. These refineries are well suited to produce gasoline of high quality.
- 28 refineries are equipped with a hydrocracker. Most of the refineries equipped with hydrocracker have additional conversion processes like FCC units (16) or deep conversion units (6 of which 4 also have FCC units).
- Almost all refineries with deep conversion possibilities are equipped FCC, only 2 of them have HCC capacity without FCC capacity.
- One refinery has a coking unit without other cracking capacity.
- The residual hydrocracker is used in Germany (combined with a coker), Italy and the Netherlands (both with FCC and HCC combined with residual HCC without coker).
- In total 8 refineries are equipped with a coker unit, 11 refineries have deep conversion possibilities.
- Striking is the amount of simple refineries, 26 in second category and 7 in the first. These are relatively small refineries, from about 6.000 b/d to 120.000 b/d, with 11 of them capacities below 60.000 b/d, only in Germany a large refinery (268.000 b/d) of this kind is found.
- Almost all refineries are equipped with thermal operations as visbreaking and thermal cracking.

It can be concluded that the centre of gravity is on the FCC type refinery, and thus on the production of gasoline. The shift from gasoline to diesel on the product market, pressure

the refinery to produce more diesel. The configuration is not suitable to produce large amounts of diesel, and therefore will need to shift towards more HCC capacity.
Another point of concern of the refinery configuration is the lack of units which reduce residual fuel. These are mostly expensive processes. The slacking demand of residual fuel oil, and a production which is increasing, there is more need reduce residual fuel production.

3.4.2 Refinery investments made in Europe

In total 179.000 b/d of HCC capacity is 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.

Country	Crude distillation	Hydrocracker (b/d)	FCC (b/d)	Coker
Finland		47.000 (2006)		
France		49.000 (2005)	2.000 (2005)	
Greece		37.000 (2005)		
Italy		24.000 (2005)		
Spain		50.000 (2005)		20.000 (2008)
Total		179.000	2.000	20.000
Percentage of total		18%	3,0%	

Table 31: Conversion process additions according to Oil and Gas Journal (2005)

Most investments made are in hydrotreating facilities, and some in hydrodesulphurization. Both processes can or are used to reduce sulphur content in blendstock for both gasoline and diesel. The following table show the number of treatment unit additions per country in Europe:

Country	Hydrotreater and hydrodesulphurization (b/d)		
	2005	2006	2007
France	79.000		
Greece	19.751		27.000
Italy	2.500	33.000	12.000
Turkey	60.400	73.700	28.300
Total	161.651	106.700	67.300
Increase (%)	1,6%	1,1%	0,7%

Table 32: Treating facilities capacity additions in Europe (OGJ 2005)

3.4.3 The development of the European refinery industry since 1996

The development of the refinery industry is explored from 1996 onward. The industry data published before does not contain information on sulphur production and coking capacity. Therefore, it is chosen to begin the trend analysis in 1996. The following remarks can be made:

- Hydrotreating capacity growth accelerated since 2000, from 1,3% annually in the 1996-2000 period to 7,5% since 2000. According to the OGJ construction update 2005, the growth will stabilize at the level before 2000.
- Growth of HCC capacity seems to grow in shocks, in 2000 a growth 26%, in 2003 12,3% and in 2006 18% extra capacity will be installed. Annually capacity grows with 4,4%.
- Distillation capacity is creeping up slowly, distilling capacity grew with about 0,8% per year (since 1996) and vacuum distillation by 1.3% per year (since 1996).
- Thermal operation and reformer capacity shrinks with respectively 0,9% and 0,2%.
- Coking and FCC capacity grow with 0,9% and 0,7% per year.
- FCC and reformer capacity have about the same volume of capacity.
- The sulphur production capacity grows relatively fast. A growth of 10,8% per year since 1997 has more than doubled the capacity.

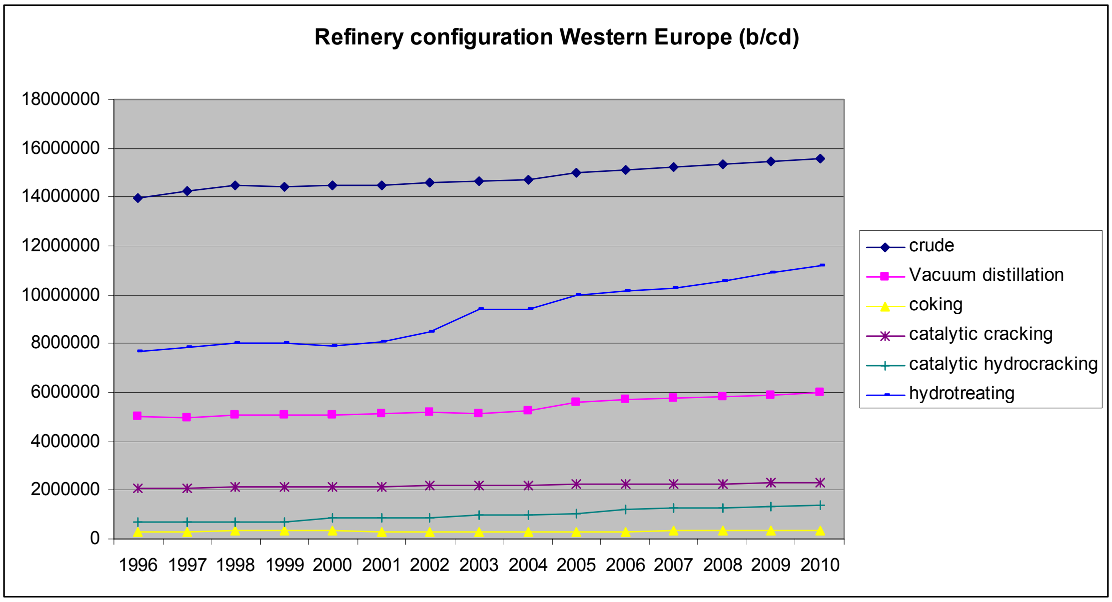


Figure 40: Trend lines refinery configuration Europe (OGJ 1996-2005).

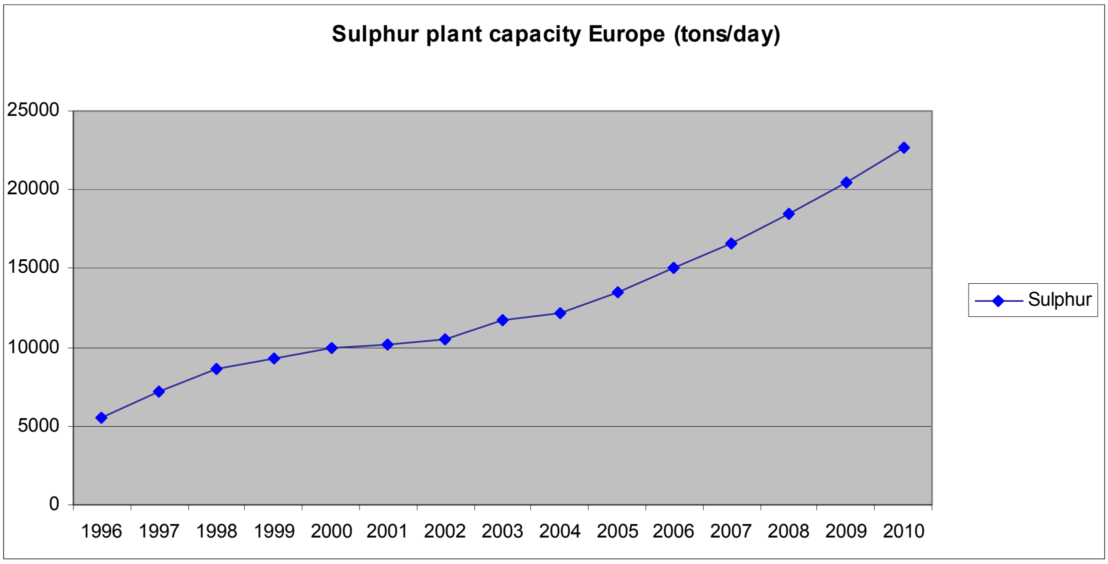


Figure 41: European sulphur plant capacity growth (ton per day) (OGJ 1996-2005).

By using data from paragraph 4.1 the potential additional middle distillate (gas/ diesel oil and kerosene) production can be approximated. Taking that 85% of HCC capacity will be used for production the middle distillate, it will add a potential of 152.150 b/d (7,4 million ton per year). With diesel consumption growing with a rate of about 2% per year, adding up 5,4 million ton of diesel consumption, this addition of capacity is sufficient to keep up the consumption growth, and could even make up some of the deficit (about 10 million ton in 2004).
Overall it can be said that the European refinery sector will get more complex the coming years. This is mainly due to HCC capacity additions without distilling capacity additions (approximately 1,5 may be added to the conversion ratio).

3.4.4 The North American refinery industry

The North American refinery industry is far more complex than the European. According ENI World Review 2005 the conversion ratio exceeds 70, which is twice as much as the European conversion ratio. The result of the refinery configuration tally is presented in the following table:

North America	refinery type							
Country	1	2	3a	3b	3c	4	4a	4b	4c
United States	8	10	41	5	7	3	24	2	29
Canada		1	7	3	5	1			3
Total	8	11	48	8	12	4	24	2	32

Table 33: North American Refinery sector configuration (OGJ Dec. 2005)

The following points stand out:

- With an average refinery capacity of 128.477 b/cd this is lower than the average size of a European refinery.

- The North American refinery industry has a lot of deep conversion units, in total 58 refineries have coking capacity, some have additional residual fuel hydro-cracking possibilities.
- Only 19 out of 149 refineries have no conversion capacity (category 1 and 2).
- There are only two refineries equipped with thermal cracking, with a total of 21.500 b/cd in the US and 138.550 b/d in Canada.
- More than 2/3 of the refineries are equipped with FCC, 116 in total (78%).
- In total 54 refineries are equipped with HCC.
- 8 refineries have HCC capacity without FCC capacity, of which three are situated in Canada.
- 3 out of 4 HCC refineries have FCC, and are able to produce a high quality diesel from cracking next to gasoline.
- The possibilities to process residual fuel are great, almost half of the refineries have access to coker capacity. Coke production is high.

Overall the North American refineries industry is focused on gasoline production. This is inline with the product market, which is focused on gasoline as well. Next to gasoline production, the refineries have great possibilities to reduce production of residual fuel. The result of reducing residual fuel is a large production of coke, which is exported over the whole world. The configuration is very suitable to process heavy crude from Canada and Latin America.

3.4.5 Refinery investments made in North America

Most of the capacity additions are in the planning or engineering phase, only three are under construction. Striking is the amount of hydrocrackers, compared to the FCC units, which are added. HCC units are capable to produce diesel of high quality, not gasoline which is the most wanted product.
In Canada investment in upgrading capacity are made. Upgrading facilities are used to produce synthetic-crude from tar-sands and bitumen, of which great amounts of reserves are found in Canada.

Country	Crude distillation	Hydrocracker	FCC	Coker
Canada	70 (2007)	32 (2010)		124 (2007)
	2 (Feb. 2006)			257 (2010)
United States	12 (2006)	15 (2005)	15 (2006)	15 (2007)
		36 (June 2006)	3 (2005)	14 (2007)
	32 (Nov 2006)	3 (Nov. 2005)		
	75.000 (2006)	35 (Nov. 2005)		
		10 (2007)		
Total	119 (by 2007) 70 (by 2008)	89 (by 2007) 10 (by 2008)	18 (by 2007)	153 (by 2008)

Table 34: Conversion process additions in 1000 b/d (OGJ 2005).

The next table presents the treating facilities added in North America. The amount of capacity planned 2006 corresponds with late investment to cope with regulation on sulphur content in transportation products. Canada has only little extra treating capacity planned.

In Canada regulation isn't initiated yet, this may be the reason for the lack of investment treating facilities. There are no investments done in reforming capacity.

Country	Hydrotreater and hydrodesulphurization (b/d)		
	2005	2006	2007
Canada		30.000	
U.S.A.	186.900	770.250	36.000
Total	186.900	800.250	36.000
Increase (%)	1,3%	5,6%	0,2%

Table 35: Treating capacity under construction in North America (OGJ 2005)

Overall it can be said that the conversion ratio in North America will increase the coming years. More conversion capacity than the distilling capacity is installed. This could mean a consumption of lower quality crude in the future.

3.4.6 The development of the North American refinery industry since 1996

The development of the North American refinery industry has resemblances with the European trends. The 2007 data is based on the information provided by the OGJ 2005 Refinery Construction Update and added to the 2006 data. The trend is extrapolated to 2010.

- Hydrotreating capacity grows 2,84% annually since 1996. Since 2002 the growth expanded from 1,4% annually to 4,7%. This trend will advance in 2006 and 2007.
- Coking capacity grows by 2,8% annually since 1996.
- Thermal operation and catalytic reforming capacity shrinks by respectively 2,8% and 0,3% annually.
- Other operations (CDU, FCC, vacuum distillation and HCC) grow with about 1-1,2% annually.
- HCC capacity will grow more in 2006 (3,1%) and 2007 (2,0%) than the years before (1,1%).

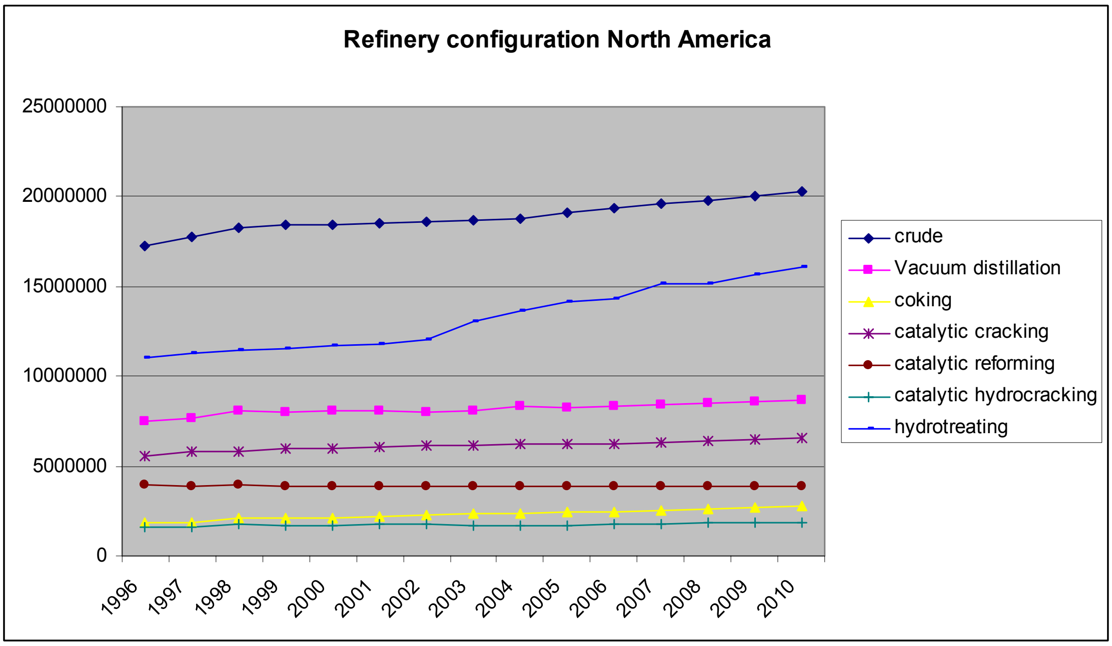


Figure 42: Trend lines refinery configuration North America in b/d (OGJ 1996-2005).

The sulphur plant capacity grew by 243% since 1996, with an average annual growth of 15,6%. If we ignore the extreme growths, the annual growth is corrected to 5,8% (taken from the years 1998-2003). This percentage was used to predict the capacity in 2010.

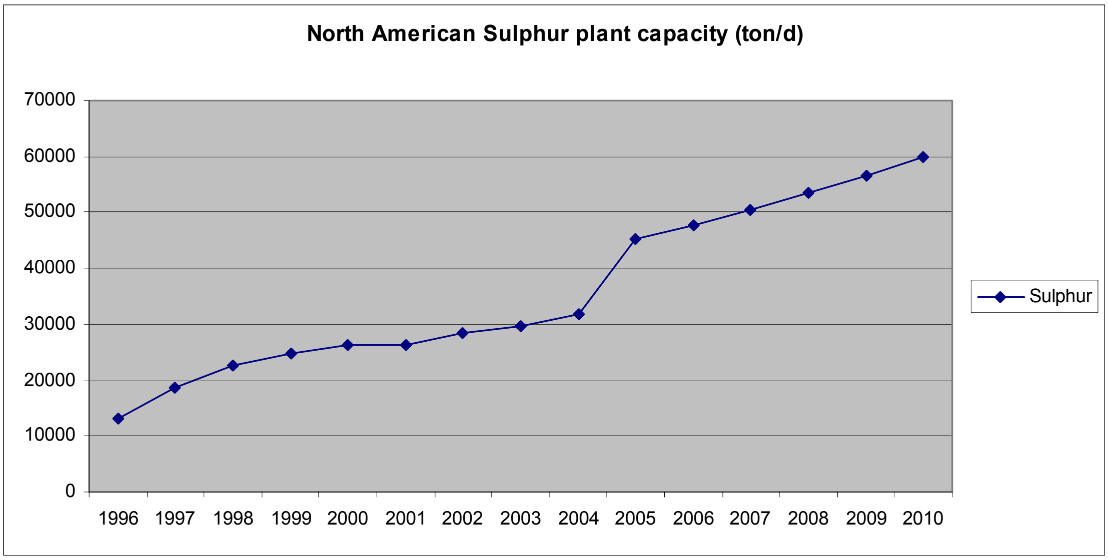


Figure 43: North American sulphur plant capacity (ton per day) (OGJ 1996-2005).

Investments in sulphur plant capacity seem to be postponed until the regulation came into effect. This indicates that a strategy of late investment is pursued.

3.4.7 The OECD Pacific refinery industry

OECD Pacific is some what more complex than Europe and less complex than North America. The conversion ratio in 2004 is 53% at a utility rate of 93%. The following table gives the result of the tally:

OECD Pacific Country	refinery type 1	2	3a	3b	3c	4	4a	4b	4c
Australia			6		1				
Japan	2	3	15	1	5		4		1
New Zealand				1					
South Korea		2	1				1	1	1
Total	2	5	22	2	6	0	5	1	2

Table 36: OECD Pacific Refinery sector configuration (OGJ Dec. 2005)

The following points stand out:

- OECD Pacific refinery industry is good equipped with FCC units, 37 refineries of a total of 45 refineries (82%).
- Ten refineries have at least 1 HCC unit (category 3 and 4 together).
- 2 refineries have RHCC units, they are put in the 4a class (they also have an FCC unit).
- Seven refineries are rather simple, of which one is able to produce lubes (Japan).

The most refineries are focused on the production of gasoline, most configurations have FCC capacity. Still, the ability to produce middle distillates is sufficient, though gasoline production falls short.

3.4.8 The development of the OECD Pacific refinery industry since 1996

In the OECD Pacific practically no investments are made in conversion capacity, only Japan has a FCC unit with unknown capacity under construction.

Country	Crude distillation	Hydrocracker (b/d)	FCC (b/d)	Coker
Japan			.. (2005)	

Table 37: Conversion process additions in the OECD Pacific (OGJ 2005)

Investments in treating facilities are being done. In Australia little capacity is added, which is not strange because regulation on sulphur content hasn't been set yet. In Japan a small addition in 2007 is expected. Japan already had regulation on sulphur, new rules come into effect in 2007. South Korea has most investments in desulphurization equipment, regulation comes into effect in 2006.

Country	Hydrotreater and hydrodesulphurization (b/d)		
	2005	2006	2007
Australia	3.000		
Japan			14.000
New Zealand	26.000		
South Korea	75.000	130.000	
Total	104.000	130.000	14.000
Increase (%)		5,9%	

Table 38: Treating capacity under construction in OECD Pacifc (OGJ 2005)

Remarks on the identified trends in the refinery industry in OECD pacific:

- Distilling capacity has been declining since 1998, now the capacity is at the same level as in 1996.
- Hydrocracking has an overall annual growth of 6,67% since 1997, of which most of the growth takes place in the period 1996-1998 (respectively with 34,41% in '96-'97 and 11,96% in '97-'98).
- Catalitic cracking capacity grows by 2% per year since 1996, the growth after 2002 declines to below 1%.
- Just as in Europe the catalytic cracker capacity is about the same as the reformer capacity.
- Hydrotreating capacity increases slowly, with most of the growth before 2002, 2002-2003 capacity declines, but is corrected in 2004-2005 and expected to grow to above 6 million b/d.

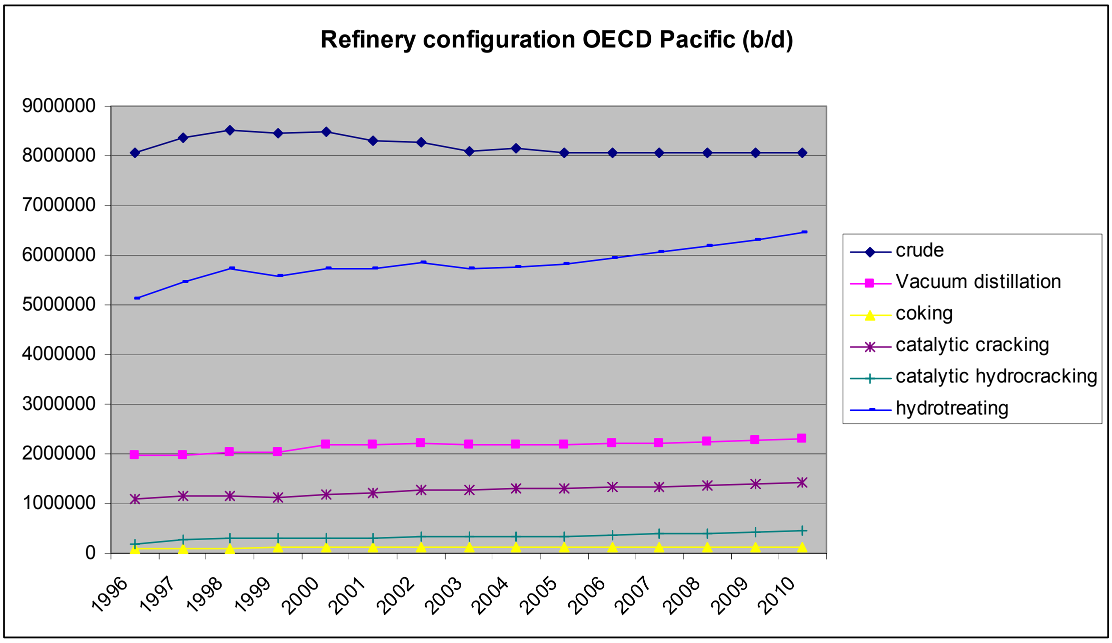


Figure 44: Trend lines refinery configuration OECD Pacific (OGJ 1996-2005).

The sulphur plant capacity almost doubled in 1996-1998 period and decreases a bit after 2002. The same trend can be seen at the hydrotreating and reforming capacity. This corresponds with the introduction of regulation in Japan, starting in 1997.

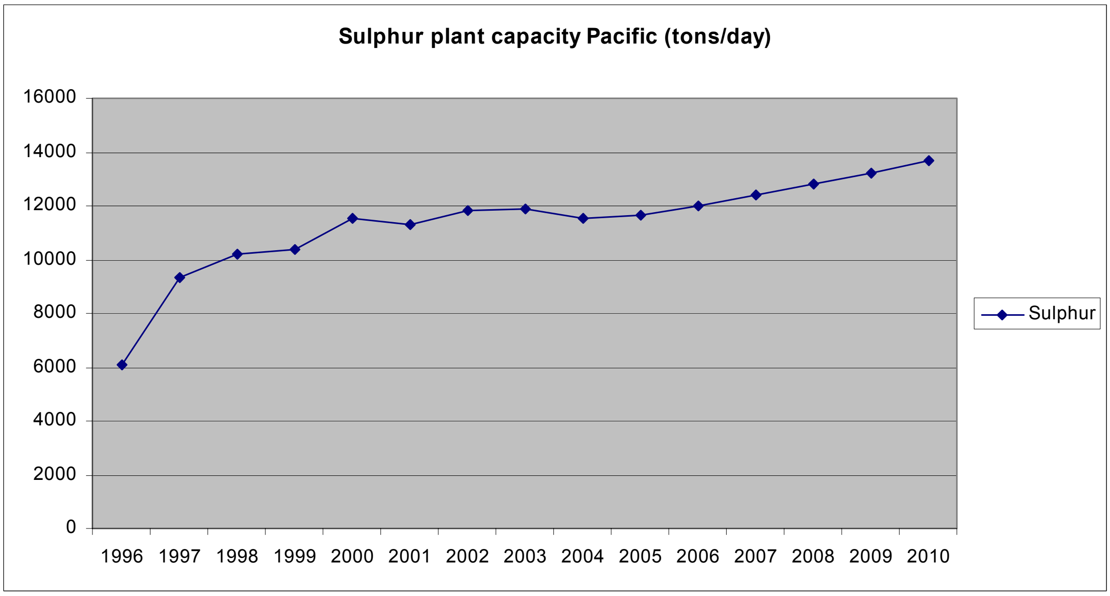


Figure 45: OECD Pacific sulphur plant capacity growth (ton per day) (OGJ 1996-2005).

With the primary capacity constant and growing conversion capacity, it is likely that the conversion ratio will increase relative to 2004. Though, conversions ratio growth will be small, for the amount of conversion added is small.

3.4.9 The refinery industry in the other regions

This paragraph will describe the other regions in an overview, Beginning with Africa, followed by Latin America, Other Asia, Other Europe, FSU and Middle East.

Other Regions	refinery type									Conversion Ratio
	1	2	3a	3b	3c	4	4a	4b	4c	
Africa	18	13	5	1	1	1	0	1	0	18%
Latin America	9	12	17	1	1	1	8	0	0	39%
Other Asia	42	13	18	3	4	5	11	1	7	35%
Other Europe	2	7	5	2	1	3	7	0	1	±20%
FSU	19	13	9	1	3	7	7	0	1	40%
Middle East	13	3	5	14	4	1	0	1	0	20%
Total	103	61	59	22	14	18	33	3	9	

Table 39: Other World Refinery sector configuration (OGJ Dec. 2005, ENI 2005)

Following points stand out:

- Africa has relatively simplest refinery configuration of the world, this is supported by a complexity ratio of 18% in 2004. Almost all refineries are simple.
- Latin America is better equipped to produce gasoline than diesel. Practically all refineries in category 3 and 4 have catalytic cracking capacity, except for one.
- In Latin America 21 of 50 refineries have no cracking capacity at all.
- In Latin America nine refineries (18% of total refineries) are equipped with coker, RFCC or RHCC equipment.

- Asia has the most refineries as well as the most residual reduction units, but also a great amount of simple refineries. This is mostly due to the amount of Chinese refineries with only a distilling unit (28 of 45 refineries), and almost no treating units.
- Asia is better equipped for producing gasoline than diesel, 40 of 104 refineries are equipped with a FCC unit, only 15 have hydrocracking capacity.
- Other Europe refinery industry is well suited to produce gasoline, it has emphasis on catalytic cracking.
- Other Europe has the best ability of these regions to reduce residual fuel, with 11 of total 28 refineries in the fourth category.
- The Middle East has focus on diesel production, 19 out of 41 refineries have HCC capacity. Only 9 refineries are equipped with catalytic cracker capacity.
- In the Middle East a small amount of refineries have coker, RFCC or RHCC equipment, only 2 refineries are classified in the fourth category.

Overall, Latin America has the most conversion possibilities, mostly to produce gasoline. A great amount of refineries have no conversion processes at all, 50% of total refineries. In Asia the amount of simple refineries is very big, all though the complexity ratio is quite high. Therefore it can be presumed the average size of these simple refineries is small. For example, 50% of China's refineries have no conversion capacity, still the conversion ratio in 2004 was 73% (ENI 2005) (though: OGJ World refinery capacities indicates that this conversion ratio is probably incorrect).

The following table summarizes the capacity addition of distillation and conversion capacity.

Region	Crude distillation	Hydrocracker (b/d)	FCC (b/d)	Coker
Africa	321.000 (2006)			
Latin America	34.983 (2007) 1.000.000 (2010)			61.856 (2006) 80.314 (2008-2009)
Other Asia	381.805 (2005) 2.117.100 (2010)	50.000 (2005) 79.500 (2006) 61.000 (2007)	52.000 (2005) 73.200 (2006)	77.000 (2005) 5.600 (2006)
Other Europe		40.000 (2005)	20.000 (2005)	
FSU	302.600 (2008)			
Middle East	116.400 (2007) 20.000 (2008) 250.000 (2009) 600.000 (2010)	215.000 (2006) 60.000 (2007)		

Table 40: Refinery process additions (OGJ 2005)

Remarks:

- Two residual FCC (RFCC) units are planned in Asia of a total capacity 73.000 b/d, coming into utility in 2007.
- In the Middle East and in Brazil 1 RFCC, due to be on stream in 2006 and 2005.
- Primary capacity is due to grow the coming years, with most growth expected in 2010. From 2005-2009 additions of 250.000-381.805 b/d per year is expected, in 2010 additions with a total of 3.717.100 b/d is expected.

- Of the conversion processes, hydrocrack capacity is to grow most, especially in Asia and the Middle East.

Region	Hydrotreater and hydrodesulphurization (b/d)				
	2005	2006	2007	2008	2009
Africa	4.000				
Latin America	138.399	56.063	74.000	54.283	394.176 (Brazil)
Other Asia	268.000	50.800	7.760	1.000	
Other Europe	7.600				
FSU	50.500	54.000			
Middle East	176.000	131.707	70.000		
Total	644.499	937069	151.760	55.283	394.176

Table 41: Treating capacity under construction in the other regions (OGJ 2005)

Hydrotreater and hydrodesulphurization capacity is added in all regions, but not in big amounts. China and India have very little treating possibilities, and these additions will not change this condition. Latin America has most additions in 2009, mainly in Brazil, in the short run the Middle East and Asia have most growth in treating capacity.
The Middle East mostly adds diesel desulphurization capacity, this is according to their capacity which is mainly suitable to produce diesel. The FSU has little progress in capacity of refineries, although complexity is low and exports to Europe seems logic. The same counts for the other European countries, but their refinery configuration is quite complex.

3.4.10 Conclusion

This paragraph will compare the different regions and will give short comment on the developments in the different regions. First comments on the configuration on the refinery sector will be given, than to the investments and last the trends.

First some remarks on the regions with sulphur regulation, mostly OECD countries:

- The North American and OECD Pacific refinery industry is focused on gasoline production, more than Europe's.
- The North American refinery industry has most coking capacity (2,6 million b/d), but have very little other thermal cracking capacity (the US only 21.500 b/d). OECD Pacific has no thermal cracking capacity and little coking capacity (112.400 b/d), but has RFCC and RHCC capacity. Europe has little coking capacity (313.470 million b/d) and high thermal cracking capacity (not coking) (1,4 million b/d) and some RHCC and RFCC capacity. Asia is worst of when looked at residual fuel reduction capacity, though the refineries are complex (conversion ratio of 53%) followed by Europe.
- The average refinery size in OECD Pacific is 178.968 b/d, which is larger than Europe (151.265 b/d) and North America (128.477 b/d).
- Europe has large thermal operations capacity compared to the other regions. North America and the Pacific have almost none.
- The emphasis of investment in Europe is on HCC capacity. North America invests more into HCC than in FCC capacity, but the emphasis is on coking capaci-

ty. Also some investments are done on distilling capacity, mostly in Canada. OECD Pacific has very little investment in conversion processes and distilling capacity.

- In North America the biggest amount of hydrotreatment capacity is added in 2006, more than in all the other regions, though in 2007 only little additions are expected. Europe and OECD Pacific are expected to increase their treating capacity more moderately.
- Europe had high growth of treating capacity in the period of 2000-2005 compared to North America and OECD Pacific.
- OECD Pacific has a stable hydrotreating capacity, growing very slowly.
- Sulphur production capacity in Europe and North America is growing fast the last couple of years. In the OECD Pacific the sulphur production capacity is stable with very little growth.
- The sulphur production capacity line approximately follows the treating capacity line, suggesting a correlation. This correlation can be seen in North America, Europe and in OECD Pacific.

The development of the refinery industry in the other regions:

- It seems that the Middle East is the only region which reacts on sulphur regulation, and mostly to the European. This can be derived from the investments made in diesel desulphurisation equipment.
- Relatively little treatment capacity is available in Asia, Africa and in a lesser extend Latin America.
- Big additions in refinery capacity are expected in these regions. Africa, the FSU and other Europe stay behind.
- Most investments in conversion processes are in HCC capacity.
- Investment in coking capacity is mostly done in Latin America and Asia.
- Asia and in a lesser extend other Europe invest in FCC equipment.

3.5 Specification of conversion ratio and sulphur ratio

3.5.1 Conversion ratio

The conversion ratio's given below are corrected with the utilization rate of the refinery, denoted by the crude runs. It was taken that the conversion processes were used on maximum capacity. When distilling units are not used in full, less vacuum gasoil (which is used as feedstock for FCC and HCC) and residual fuel oil is produced. To be able to run the conversion processes on maximum capacity the refineries are able to run lower quality crude. To be able to cancel out this effect the conversion ratio is corrected with the utility of the distilling unit. The original conversion ratio and refinery utilization rate can be found in Appendix 2, Table 71 and Table 72. The result of this calculation is given below.

Conversion incl. utilization rate	1993	1994	1996	1997	2000	2001	2004
NAM	**79**	**79**	**77**	**77**	**79**	**80**	**81**
US	81	80	79	78	81	82	83
Canada	62	62	60	58	57	57	61
EU-15	**35**	**35**	**36**	**35**	**37**	**39**	**38**
EU-15+	**35**	**35**	**36**	**35**	**37**	**39**	**39**
Belgium	25	29	26	24	24	28	26
France	25	30	26	28	24	30	26
Germany	41	41	41	41	41	44	43
Italy	38	41	41	40	37	45	43
Netherlands	29	31	32	34	38	38	38
Spain	31	29	29	29	31	34	36
Turkey	12	20	19	26	29	27	26
UK	47	48	48	48	49	51	51
Japan	33	32	37	38	41	43	44
Korea	8	8	19	23	26	27	29
Austalia	59	60	59	58	62	72	77
Pacific[7]	**26**	**26**	**31**	**33**	**35**	**37**	**39**

Table 42: Conversion ratio of the investigated regions (ENI 2005 and 2006)

Overall the conversion ratio increases over the years. Only in the mid '90 it declined in Europe and North America. This is due to a higher utilization rate of distilling capacity. North American refinery industry is most complex.

Conversion ratio	1993	1994	1996	1997	2000	2001	2004	2005
Central Asia	38	50	55	55	57	59	59	59
Middle East	19	21	22	21	23	23	25	23
Africa	14	12	15	13	16	18	24	24
Other Asia	38	42	43	49	61	63	57	61
Latin America	35	38	40	43	42	45	48	48
Central Europe	48	48	46	47	52	55	60	60
Eastern Europe	18	21	25	24	23	22	22	24

Table 43: Conversion ratio with utilization rate correction (ENI 2005 and 2006)

The high conversion ratio in Central Asia and Central Europe is due to a low utility of the distilling capacity. The high complexity ratio of other Asia is due to a high conversion ratio in China, which is according ENI 2005 and 2006 73%. The conversion ratio of China can be questioned. The Worldwide refinery capacities published by Oil and Gas Journal do not underpin this number. Canada, for example, has a lower conversion ratio than China, still it has more conversion capacity and less distilling capacity according to OGJ 2006.China has more than half of the production capacity, and is therefore an important factor in the refinery industry in Asia.

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[7] Australia is not taken into account. The crude quality calculated in the next chapter is incorrect, and therefore it is taken out.

3.5.2 Sulphur ratio

The sulphur ratio is calculated by dividing the capacity of the sulphur plant (ton) by the capacity of the distilling unit (ton). This ratio gives more insight in the ability of refinery to be able to reduce the sulphur in products, thus in the ability to remove sulphur. The sulphur plant is taken as an indicator. It is taken that the sulphur plant capacity is adapted the abilities (or ambition) of the refinery to remove sulphur. This table clearly shows an increase in the ability to produce sulphur relative to the distilling capacity. Only the Pacific behaves differently (except for Japan).

It must be noted that the sulphur ratio is indicator on the ability to remove sulphur, this by it self cannot predict the sulphur content of the crude used. The level of regulation on sulphur content of fuels influences the amount of sulphur which needs to be removed. To be able to compare countries or regions on the crude quality used, this must be taken into account. Also the share taken by regulated products is of importance. If the share of transportation fuels is relatively low, less desulphurization of these products is needed.

Sulphur ratio	1996	1997	2000	2001	2004	2005
NAM	**0,56%**	**0,80%**	**1,08%**	**1,04%**	**1,24%**	**1,73%**
US	0,60%	0,86%	1,16%	1,10%	1,32%	1,87%
Canada	0,24%	0,28%	0,45%	0,52%	0,55%	0,54%
EU-15	**0,29%**	**0,38%**	**0,53%**	**0,53%**	**0,63%**	**0,71%**
EU-15 plus	**0,28%**	**0,36%**	**0,50%**	**0,50%**	**0,60%**	**0,67%**
Belgium	0,55%	0,53%	1,22%	1,12%	1,09%	1,07%
France	0,37%	0,26%	0,33%	0,32%	0,41%	0,51%
Germany	0,38%	0,67%	0,89%	0,83%	0,83%	0,99%
Italy	0,18%	0,37%	0,52%	0,51%	0,56%	0,57%
Netherlands	0,39%	0,49%	0,48%	0,44%	0,59%	0,95%
Spain	0,00%	0,14%	0,36%	0,36%	0,92%	0,90%
Turkey	0,34%	0,34%	0,32%	0,32%	0,32%	0,33%
UK	0,29%	0,29%	0,28%	0,30%	0,30%	0,30%
Japan	0,67%	1,03%	1,17%	1,15%	1,27%	1,35%
Korea	0,64%	0,63%	0,76%	0,76%	0,66%	0,66%
Australia	0,05%	0,02%	0,16%	0,15%	0,10%	0,11%
Pacific	**0,63%**	**0,81%**	**0,94%**	**0,74%**	**0,71%**	**0,72%**

Table 44: Sulphur ratio (OGJ 1997-2006, ENI 2005 and 2006)

3.5.3 Conclusion

Taking the conversion ratio and sulphur ratio, Europe will probably consume the highest quality crude, followed by the Pacific and North America. North America is able to consume the heaviest and the most sour crude compared to the other two regions. These regions and countries are comparable, because they have about the same level sulphur regulation. Sulphur regulation came to effect in 2004-2005-2006 and in Japan since 1997.

3.6 Conclusion on developments in the refinery industry per region

The complexity of refinery sector is increasing. The utilization rate of the distilling capacity influences the conversion ratio, but because of the high utilization rate of production, this only has limited impact. The configuration of the refineries in North America, Pacific and Europe differ.

- Europe is the only region which uses thermal cracking.
- Compared to the Pacific and Europe, Cokers are widely used in North America, little residual FCC and HCC units are found here. Europe and the Pacific have little coking or residual cracking capacity available compared to North America.
- Based on the conversion ratio: Europe and the Pacific will use lighter quality crude feedstock than North America.
- Based on the sulphur ratio: Europe and the Pacific will use sweeter quality crude as feedstock than North America.

According to the tally performed in paragraph 3.4 the European refinery industry is focused in gasoline production. But, there is a significant amount of diesel producing capacity. This is historically set (Reinaud 2005). Although more FCC units are available and capacity is bigger, more diesel than gasoline is produced. This is due to a relative higher yield of diesel from HCC units than of gasoline by FCC units. Therefore less HCC capacity is needed to produce the same amounts of diesel as a FCC unit produces gasoline.

Residual fuel production capacity is limited; only 11 residual fuel reduction units are available out 99 refineries. 26 refineries have no conversion capacity at all.
The investments made in Europe are focused on sulphur extraction units and HCC. The refinery industry is adapting to the changing product market. Still, investment in residual fuel reduction is small.

The North American refinery sector is far more complex. The amount of refineries is large (149). The amount of coker units (62) is big compared to the other regions. Thermal conversion is almost non existent. The amount of simple refineries (18) is small, the amount of FCC refineries is big (116). The amount of HCC units is significant as well (54), most of them are included in refineries which have everything available: FCC, HCC and coking (32).
The refinery industry is focused on gasoline production, but the ability to produce middle distillates with HCC is available. The ability to reduce residual fuel is very large. The investments are focused on HCC, coker and distilling units. The additions will increase the conversion ratio. The capacity of conversion added surpasses the addition of distilling capacity.

The OECD Pacific refinery sector is focused on gasoline production. The number of FCC units surpasses the amount of HCC units (35 FCC, 11 HCC of a total of 45 refineries). The amount of deep conversion units is average (compared to North America and Europe), 8 refineries have some sort of deep conversion capacity.

	refinery type								
Region	1	2	3a	3b	3c	4	4a	4b	4c
EU-15 plus	7%	26%	33%	10%	12%	1%	4%	2%	4%
North America	5%	7%	32%	5%	8%	3%	16%	1%	21%
Pacific	4%	11%	49%	4%	13%	0%	11%	2%	4%

Table 45: Share of refinery types in Europe, North America and the Pacific

Europe is equipped best to produce middle distillates as diesel, followed by the Pacific. North America and Europe have about the same amount of refineries of the 3a type (FCC), but Europe is surpassed by the relatively big amount of FCC (and HCC) with coker refineries (4a and 4c). Europe falls short in deep conversion capacity compared to the other two regions.

Based on the deep conversion capacity and the amount of simple refineries, Europe will need to consume the best quality crude, followed by the Pacific. North America has the most complex refinery sector of the three. All have focus on gasoline production.

The refinery sector will advance to more HCC and treatment capacity, together with some deep conversion additions.

4 Crude/ petroleum Market

'Petroleum is a naturally occurring mixture of hydrocarbons, generally in a liquid state, that may also include compounds of sulphur, nitrogen, oxygen, metals, and other elements.' (ASTM D-4175, from JG Speight, 2001) There is a wide variation of compositions of petroleum, this is mainly field specific. This chapter will try to map the different qualities of crude to the producing countries.
The causal diagram presented below denotes a part of the causal diagram given in the introduction. The red circles are assessed. The paragraphs in this chapter will address these parameters up to down.

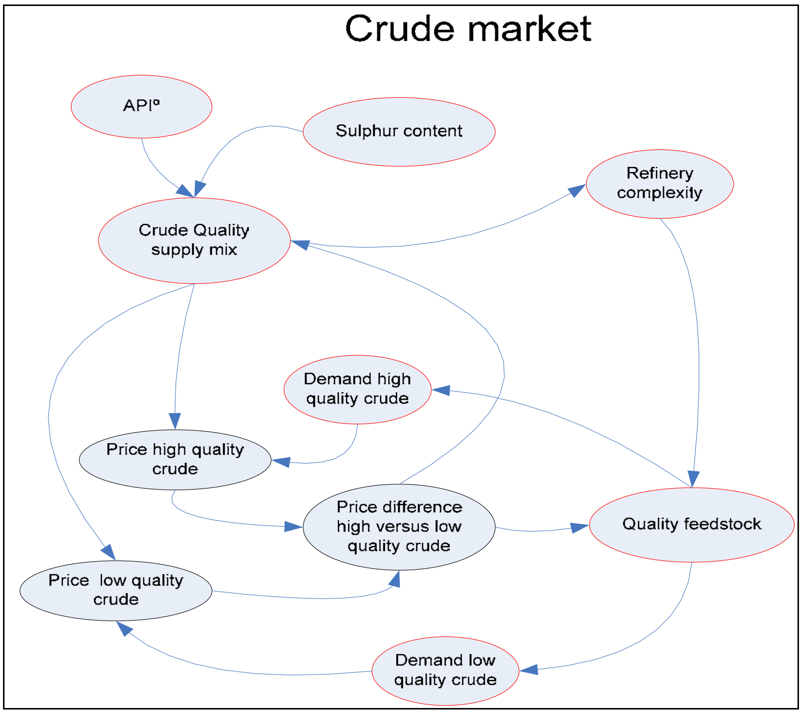

Figure 46: Causal diagram crude market

The first paragraph will describe the indicators for the quality of crude, API° and sulphur. API° is a measure for the specific weight of crude. There will be a description of the classification of different crudes according these two parameters.
The second paragraph will describe producing countries/ regions, with attention on quality and production. As a result the crude quality supply mix will be known. At the end of the paragraph the average world quality will be given.
In paragraph 3 the crude streams will be described, focused on the regions Europe, North America and the OECD Pacific. These regions are chosen because the availability of data on import origins.

The quality of the import origins are used to calculate the weighted average of the crude consumed in the assessed country/ region in paragraph 4. By this analysis the crude quality feedstock of the refineries are known.

4.1 Classification of crude

There are heavy and light crudes. Heavy oil is more viscous than light and has a bigger high boiling point fraction. 'The most important properties of a whole crude oil are its boiling-point distribution, its density (or API gravity), and its viscosity.' Viscosity is an indication on the content of 'undesirable residual material', which resists the crude to flow (JG Speight, 2001). The boiling point distribution and the viscosity is a difficult notion to find information on, but a good indicator is the API°, which is widely used. The three notions are strongly related and thus taking the API° is a simplification suitable for this report. Sulphur content is a crucial characteristic for crude (JG Speight, 2001), especially because regulation on sulphur content in products is introduced. Higher sulphur crude implies higher cost for refining (Birch e.a. 2000).
This paragraph starts with defining the classification on specific weight (API°) in paragraph 5.1.1. Than the classification of crude on the basis of sulphur content will be described. In the third part the methods used and demarcation will be given to analyze the crude market with focus on quality.

4.1.1 Specific weight of hydrocarbon resources

Classification of crude can be done in several ways, first step made is based by type of resources:

1. 'naturally occurring resources (petroleum, heavy oil, natural gas and natural waxes); and
2. hydrocarbon sources (bitumen, oil shale, and coal) that may be made to generate hydrocarbons by the application of conversion processes.' (JG Speight, 2001)

Here category 1 is researched, but only petroleum and heavy oil. Category 2 is incorporated side ways, as syn-crudes. No further attention will be given on this matter.
A classification on petroleum and heavy oil is needed. This will be done by looking at the API°, as a measure for density. API gravity is a widely used notion in databases, and therefore easy to use for comparison and classification purposes. Note that the higher the API° the lighter the crude.

The API° is calculated by the formula:

$$^{o}API = {}^{141.5}/_{\text{specific gravity}} - 131.5$$

Leffler gives three characteristics of API:

1. 'Water has a specific gravity of 1 and a gravity of 10°
2. the higher the API gravity, the lighter the compound
3. The reverse is true for the specific gravity' (Leffler 2000; 15-16)

Different notions are given to different API° ranges. Speight (2001) uses the classification:

1. bitumen and tar-sands have smaller APIº than 10º
2. heavy oil till 20 APIº, with a typical range 15º-10º
3. above 20º API crudes are called conventional (JG Speight 2001).

Speight denotes crude with an APIº lower than 20 to be unconventional, and above 20 conventional.

The conventional range needs to be further classified to be useful. Favennec (2001; 122) distinguishes two classes in the conventional range, and denotes the heavy crude and the tarsand/ bitumen in one group:

1. 'Light crude oils, with gravities higher than 33º API;
2. medium crude oils, with gravities between 22 and 33º API;
3. heavy crude oils, with gravities less than 22º API.'

Taking these classifications to gether the following classification can be taken:

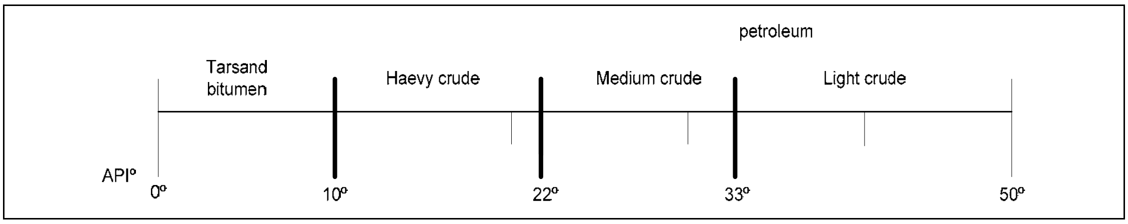

Figure 47: Crude classification based on ºAPI

In this range, the Favennec classification is used for the petroleum part and the Speight classification for the tarsand/ bitumen and heavy crude part. So, tarsands and bitumen ranges from 0-10º API, heavy oil from 10-22º API, medium heavy/ light crude ranges from 22-33º API and light crude is ranged from 33-50º API.
For example, Brent blend (North Sea) is a light crude with an APIº of 38, Urals (Russia) is medium crude with an APIº of 31-32, and Maya (Mexico) is a heavy crude with an APIº of 21.

4.1.2 Sulphur content

Crude can be sweet or sour, depending on the amount of sulphur crude contains. Sweet crude has little amounts of sulphur, sour crude has higher amounts of sulphur. Because sulphur is most found in the heavier fractions of crude, heavy crude tend to contain more sulphur in w% than lighter crude.
'Today sweet crudes typically have 0.5% sulfur content or less, sour 1.5% or more. The area in between is sometimes called intermediate sweet or intermediate sour, but the distinction is not clear.' (p17 Leffler, 2000) In this report the terms sweet, intermediate sweet or sour and sour will be used. The range of 0.5% - 1.0% will be called intermediate sweet, and the range 1.0% - 0.5 % will be called intermediate sour.

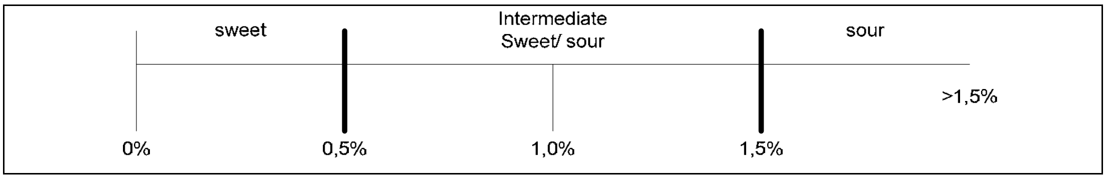

Figure 48: Sulphur content – sweet to sour range

4.1.3 More quality indicators

Another characteristic of crude oil is its acid content. Acidity is 'measured by the total acid number (TAN), an aggregate index that includes various types of acid.'(Worldbank, October 2004) If the TAN index is above 0.5 the price of crude is affected. A crude is called high acid (HAC) when the TAN is above 1.0. TAN is not a real good measure, because it is a basket of acids including naphtenic acids which are the most corrosive for refineries, (Anne Chafizadeh e.a. 2003) thus the TAN number is not always a sufficient quality indicator. Acidity is mostly important due to its corrosive characteristics to refining equipment, leading to more maintenance or adaptation by using better quality materials for refining.

High Acidity Crudes (HAC) are growing in importance because of its growing availability. It is expected that the share of HAC will be 13% by 2006, from only 1 percent in 2001. Since the usually used characteristics for the quality of crude is API and sulphur content, of which information is available, and lack of information on the ability of refiners to process HAC, TAN will not be used as quality indicator in this report.

4.1.4 Conclusion

The following table contains all the possible combinations and thus classes derived from sulphur content and API°. Tarsand/ Bitumen are out of the scope of this report, because it needs to be pre processed into 'syn-crude' (synthetical crude). Intermediate sweet/ sour can be taken together in one group (Favennec 2001, Leffler 2000).

Crude	Sweet	Intermediate sweet	Intermediate sour	sour
Heavy	Heavy-Sweet	Heavy-Inter. Sweet	Heavy-Inter. Sour	Heavy-Sour
Medium	Medium-sweet	Medium-Inter. Sweet	Medium-Inter Sour	Medium-Sour
Light	Light-Sweet	Light-Inter. Sweet	Light-Inter. Sour	Light-Sour

Table 46: crude classification

Not all classes will occur in the same amounts. Heavy-sweet is an example which will not occur often, the same counts for light-sour. Sulphur is mostly located at the heavier ends of the crude, therefore heavier crudes generally contain more sulphur.

Trend analysis on the quality of crude consumed in the regions is performed, but not extrapolated to the year 2010. Crude production and crude quality is extrapolated to 2010.

4.2 Crude quality and production

The major crude export regions are Africa (North and West Africa), Latin America (Venezuela, Mexico and Brazil), FSU (former Soviet Union) and the Middle East (Saudi Arabia, Kuwait, Iran etc.). These regions produce different qualities of crude in different amounts. This paragraph will look into the production abilities and the qualities of crude on the basis of API° and sulphur content. The sulphur content is calculated on the qualities given of different crudes by Haverly website. The crude API° is taken from the IEA (if available), other sources are used to back the qualities given.
Different sources are used to assess the future production. Some data is in b/d others in tons. This thesis uses tons main unit, therefore growth percentages of prediction are calculated and used on data from IEA data cd-rom 2005 data which use tons to report production levels.
It must be noted that the API° results will be different depending on the use of barrels or tons. Lighter crude have more volume per ton than heavy crude. Therefore calculating with barrels will yield a higher average API° than calculation on the basis of tons. Also, increase of production of light crudes in barrels is higher than increase of production in tons. So depending on the scheme used, the result is different. Both were done, in Appendix 4 tables can be found of the average qualities crude produced in barrels, in this chapter tons are used, consistent with the rest of the report.

4.2.1 African crude production and quality

The African continent has two production regions, North Africa, consisting of Algeria, Libya, Egypt, Tunisia and Morocco. The West African production is dominated by Nigeria and Angola. The North African region is situated in the Mediterranean area and therefore important for supply of Europe. Nigerian oil is mostly exported to the US.

Country	Production 2004 (1.000 ton)		Percentage of total production		API°		Sulphur (wt%)		TAN
	2004	2010	2004	2010					
Algeria	85627	99156	17%	17%	51		0,1		Low
Angola	48535	67379	10%	12%	35		0,2		Low
Libya	76431	82237	15%	14%	39		1,2		Low
Egypt	33104	28969	7%	5%	32		2,2		Low
Sudan	15057	15057	3%	3%	32-34		0,1		High
Nigeria	128663	147471	26%	26%	37		0,1		Low
Other Africa	77606	88291	16%	15%	40		0,5		
Total/ weighted average	498555	571577			‘04	‘10	‘04	‘10	
					39	39	0,5	0,5	

Table 47: Crude production and quality in Africa (BP 2005, Haverly 2005, IEA 2005)

Crude quality

Algeria produces a relative light and sweet crude. There is a great amount of condensates and natural gas production. The average API of crude produced is 47,55° (Haverly data-

base), according to the IEA 51 API° (includes condensates) and the sulphur content is approximately 0,08 wt% (Haverly database).
Angola produces about the same amounts of oil as Algeria. With an average API of 35,4° (IEA) and a sulphur content of 0,24 wt%, it produces a light-sweet crude. The total acidity number of the major crude (Cabinda), and some other crudes, is very low and therefore not a problem.
Libya produces more oil than Algeria and Angola. Production is nearing 1,7 million b/d (see below), most of the crude produced is of high quality (light-sweet). It's average crude quality ranges from 39°API according the IEA , 36° API according to own calculations (Haverly data base) and 35°-37° API (Simmons 2004). The average sulphur content is 0,40 wt% (Haverly database).
Egypt's crude production has passed its peak and is declining. Its quality is not as good as the other North African crudes, 32° API (IEA 2005) and a sulphur content of 2,18 wt% (Haverly database).
Sudan is a relatively new producer of crude oil. It mainly exports the Nile Blend, with an API of 32-34°. Sudanese crude are paraffinic (waxi) and therefore very suitable to produce lubricating oils, but also high acid, with a TAN above 1,0. The sulphur content is about 0.06 wt%, which is very low.
Nigerian (West Africa) crude is of good quality, 37API gravity (IEA 2005) and a sulphur content of approximately 0,12 wt% (Haverly 2005). Nigerian crude is valued because of the gasoline content and the small amount of impurities, making it very suitable for the North American crude market (high quality gasoline demand). Europe imports Nigerian crude to produce diesel and export the gasoline surplus yield (www.genocidewatch.org/NigeriaOilMarch22.htm).

Crude production

According to the EIA Algeria is under-explored and therefore can increase there reserves in future. There are 11,8 billion barrels of proven reserves, according to BP production is 1,9 million b/d in 2004 (Includes crude oil, shale oil, oil sands and NGLs (natural gas liquids - the liquid content of natural gas where this is recovered separately) (BP 2005)). IEA predicts a steady growth of crude production from 1,9 million b/d to 2,2 million b/d in 2010. The growth percentage is taken and applied to values in tons taken from IEA 2005, resulting in a growth of 86 to 99 million ton in 2010.
IEA predicts further decline of production in Egypt (IEA Outlook 2005). The trend of -1,6% is taken for future production until 2010.
The reserves found in Libya are mostly from the 1959-1970 period. In 2004 the proven reserve is 39,5 billion barrels (BP 2005). Production costs are low, exploration has been minimal the last decades and infrastructure is available; therefore '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.' (IEA 2004)
It is taken that Sudan can increase there reserves because the country is still 'under' explored (www.mbendi.com). In this report it is taken that production will grow at the same pace of 10% per year. Production started in 1996 and grew to 12 thousand ton in 2002 (IEA 2004), now production is at about 350.000 b/d (Tchilinguirian 2006).

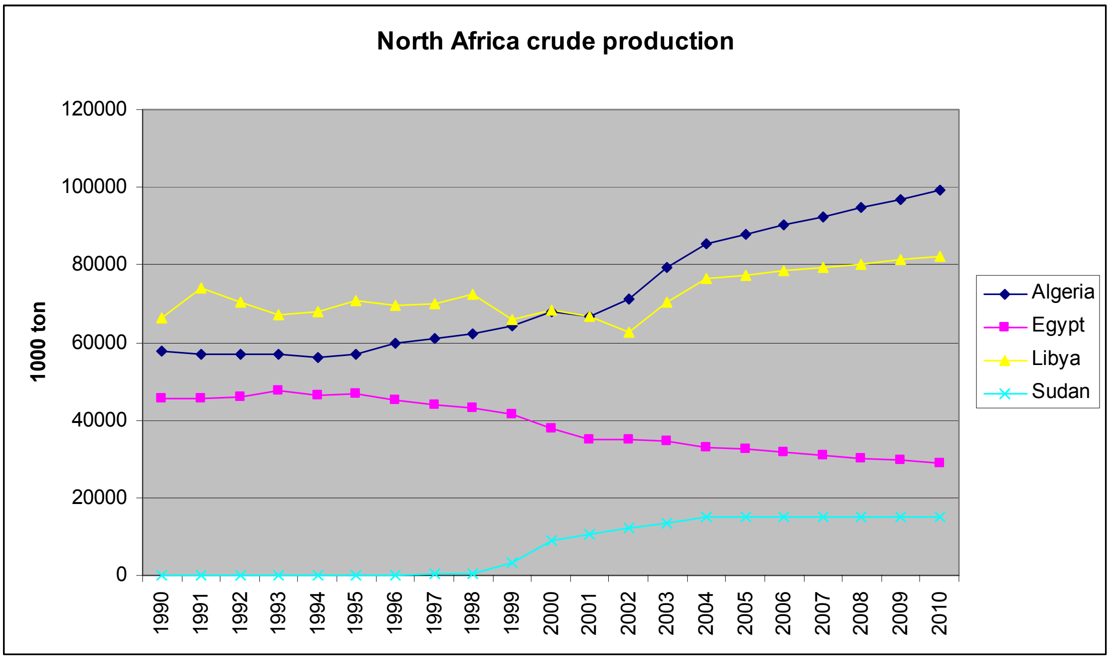

Figure 49: North African crude production outlook until 2010 (IEA 2005).

Off-shore Angola has great opportunities for exploration and production. Angola produced 44 million ton of crude in 2002 (IEA 2004), which is about 900.000 b/d. Now production has just passed 1,4 million b/d (see left) (0,9 million b/d in 2004 according to BP). Estimated reserves are 8,8 billion barrels (BP 2005). New finds in deep water offshore boosts production at least until 2008, but higher decline rates at older fields will slow growth down (IEA 2004).

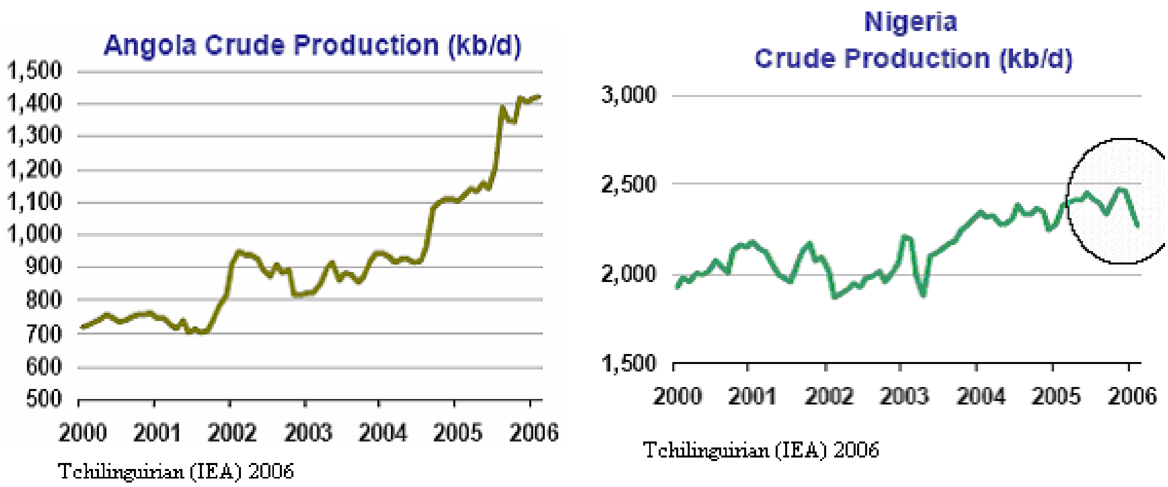

Figure 50: Angola and Nigeriona crude production (IEA 2006)

Nigerian production is high, but social unrest pressures production. The Nigerian government is ambitious, wanting to boost production to 4,1 mb/d in 2006 (IEA 2004), this goal will most probably not be reached. It is difficult to predict future production because of social unrest. Therefore production has been growing with an average of 2,3% annually from 1990-2004, and is projected to do so until 2010 to 2,8 mb/d.

Equatorial Guinea started production in 1995. Production has grown to 350.000 b/d in 2004 with an average growth of 25.000 b/d. It is taken that growth will grow in the same pace to 500.000 b/d in 2010.
Other producing countries are Gabon, Congo and Tunisia with declining crude production. Chad has just starting up production (since 2003) (Tchilinguirian 2006).

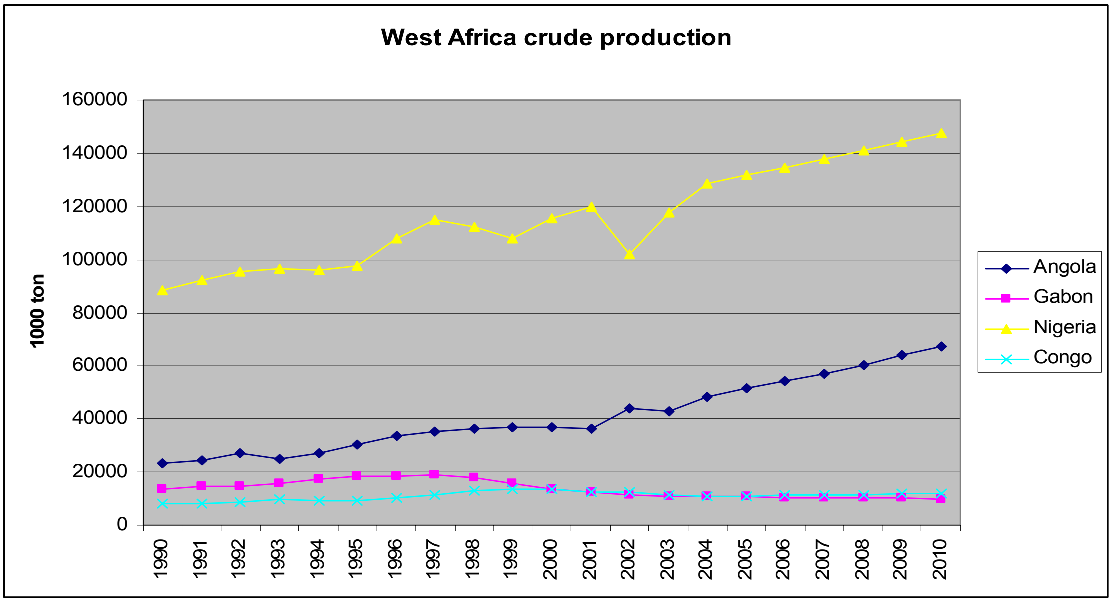

Figure 51: Projections of crude production till 2010 in West Africa (IEA 2005).

Conclusion

Overall quality in Africa is light and sweet, thus very suitable for production of light products with low sulphur content. There are exploration possibilities. The main countries in North Africa are taken to be underexplored. Recent finds may support this, taking the development of reserves denoted in the BP statistical review 2005. Giving the fact that:

- the crude reserves are present,
- investment climates are getting better (Simmons 2004),
- the price of crude is high,
- the geographical position at the Mediterranean and West Coast is good for export to Europe but also to the United States and China (Chad and Sudan mostly)
- the quality is very good,

a prosperous future crude production will occur, filling up future crude deficits.
China is trying to get more influence on the crude production in especially Sudan and Nigeria. Algeria has great amount of condensate production, knowing that in several countries the natural gas production did not receive much attention (Simmons 2004), condensate[8] production may be taken up, for example in Libya.

[8] Condensate is also called natural gas liquids. It is mostly 5produced together with crude or natural gas.

4.2.2 Latin American crude production and quality

The major crude producers in Latin America are Venezuela, Brazil, Argentina, Colombia, Ecuador, Peru, Trinidad & Tobago and Venezuela. Mexico is assessed here as well. The following table presents the production as well as the quality indicators for the average grade of crude produced.

Country	Production (1.000 ton)		Percentage of total production		API°		Sulphur (wt%)	
	2004	2010	2004	2010				
Mexico	191697	213355	29%	27%	25		2,1	
Venezuela	152950	176339	23%	22%	24		1,9	
Brazil	77319	114690	12%	14%	27		0,5	
Argentina	38124	45321	6%	6%	29		0,2	
Colombia	27402	30582	4%	4%	28		0,7	
Ecuador	27376	35880	4%	5%	27		1,2	
Other	1309040	1424680	23%	22%	25		1,5	
Total/ weighted average					'04	'10	'04	'10
	667818	792505	100%	100%	25	25	1,5	1,4

Table 48: Crude production and quality in Latin America. (Haverly 2005, IEA 2005)

On average, the crude produced is medium heavy and sour. Only Argentina produces sweet crude. The bulk of crude produced is near the heavy crude border. Next to desulphurization, conversion is needed to be able to produce suitable products. These crudes are mostly available with big discounts compared to high quality crude.

Figure 52 denotes the production over the years in this region. Production is taken since 1990.

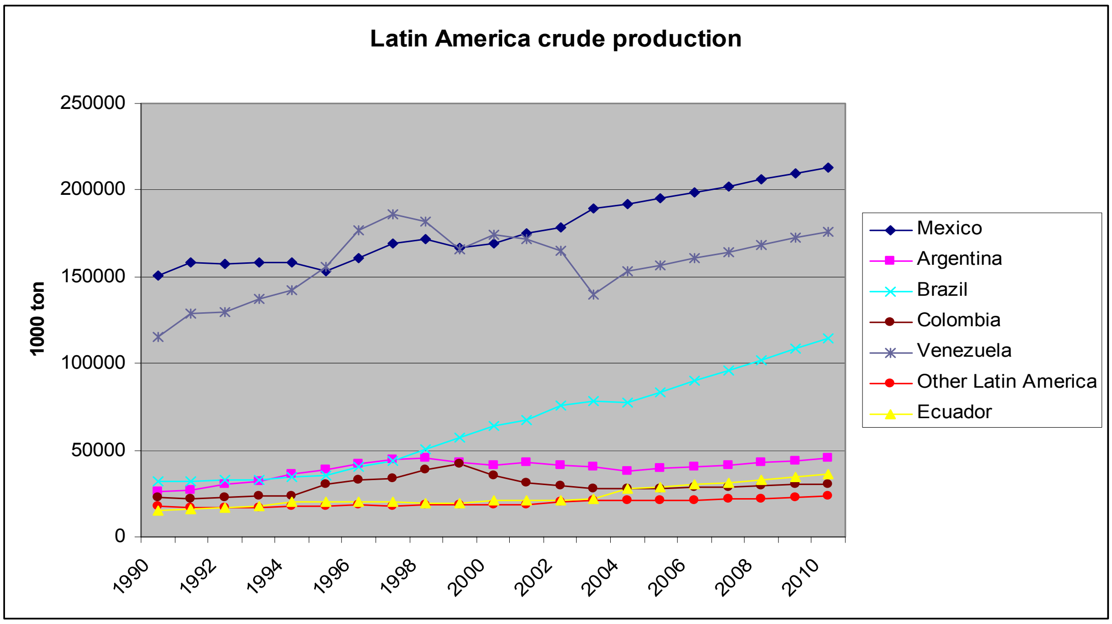

Figure 52: Latin America crude production from 1990-2010 (IEA 2005, IEA 2004)

Mexico has the largest production. It produces a wide range of crude, but emphasis is on heavy crude, mostly Maya (high viscous low wax crude). Production is slowly increasing, with a little dip around 1999. IEA 2004 projects that production will reach 4,2 million b/d in 2010 and than flattens. This increase is according the regression of the growth since 1990, with an average production growth 1,8%.
Venezuela's crude production is declining since 1998. A sharp decline is seen in 2003, with a correction in 2004, it is taken that production will increase with 2,4% per year. Brazils production has an overall trend of increasing production, just as the production of Ecuador. Brazils production is projected to increase to 2,3 mb/d in 2010 (1,5 mb/d in 2004). Production in Argentina, Colombia and Peru is declining. The other nations have rather stable production. Total production in 2004 was 9,8 million b/d and is expected to grow to 13,1 million b/d.

Latin American countries export most crude to the US. The refinery capacity in the US is most suitable for processing these grades of crude. Europe and Asia are small importers of these grades, because they lack the capacity to process large quantities of heavy sour crude.

4.2.3 North American crude production and quality

Canada has great potential in increasing there crude production. Great amounts of oil sands and bitumen are found. These hydrocarbons are upgraded into syn-crudes. Canada invests vast amounts of crude upgraders.
The United States crude production has passed its peak. Declining petroleum production and increasing consumption leads to growing crude imports. Most crude is imported from: Latin America including Mexico, and Canada.

Country	Production (1.000 ton)		Percentage of total production		API°		Sulphur (wt%)	
	2004	2010	2004	2010	2004	2010	2004	2010
USA	145777	177130	30%	37%	35		1,1	
Canada	337382	308134	70%	63%	30		1,1	
Total/ weighted average					'04	'10	'04	'10
	483159	485263			34	33	1,1	1,1

Table 49: Crude production and quality in North America (BP 2005, Haverly 2005, IEA 2005).

The trend in the US is a declining crude production of 1,5% per year (since 1990). This decline is taken for the years 2005-2010. Canada production will grow with 3,3% per year. Eventually the production rate in North America will approximately stay the same until 2010. If crude qualities stay the same within the countries, the average API° will decline to 33° in 2010 because the share of the more heavy Canadian crude will increase.

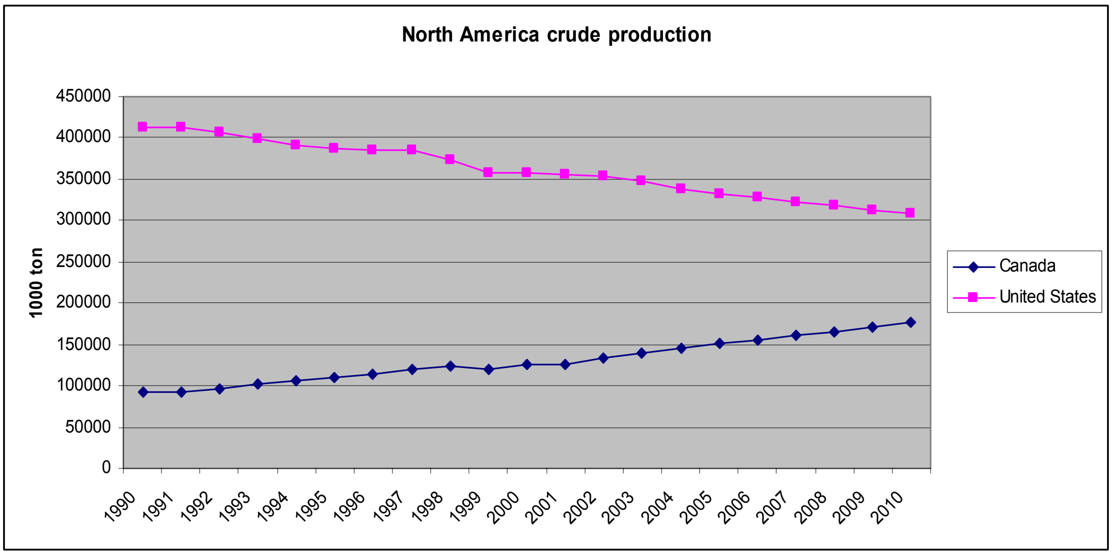

Figure 53: North America crude production from 1990-2004 (IEA 2005)

4.2.4 European crude production and quality

The European crude production is mainly located at the North Sea. North Sea crudes are of high quality. Brent is the most important crude, not because of the amounts produced, but because it is the benchmark crude for the price of other crudes. Overall, the quality will stay high the coming years, all though North Sea crude production is declining. API° has an average of 39, and the sulphur content is 0,3%, this will stay this will until at least 2010.

Country	Production 2004 (1.000 b/d)		Percentage of total production		API°		Sulphur (wt%)	
	2004	2010	2004	2010				
Norway	150929	133699	53%	56%	40		0,2	
UK	95433	61744	33%	26%	38		0,5	
Denmark	19825	22983	7%	10%	35		0,3	
Italy	6725	8122	2%	3%	33		>0,5	
Other Europe	12213	11237	4%	5%				
					‘04	‘10	‘04	‘10
Total/ weighted average	285125	237785	100%	100%	39	38	0,3	0,3

Table 50: Crude production and quality in Europe (BP 2005, Haverly 2005, IEA 2005)

The European trend is a declining crude production. The decline started in 1999 for the UK and in 2001 for Norway. The graph below takes this downward trend in regression until 2010. IEA (2005) predicts that the European production will decline from 2004 level (5,7 million b/d) to 4,9 million b/d in 2010 (IEA 2004 predicts 4,8 million b/d in 2010). The graph is based on a production decline in the UK of 7% and 2% for Nroway. These trends are only recently set, and therefore not reliable. New finds and new investments could lead to a slower decline of production. Denmark’s production is increasing, this trend is followed and results in a production of 0,7 million b/d in 2010.

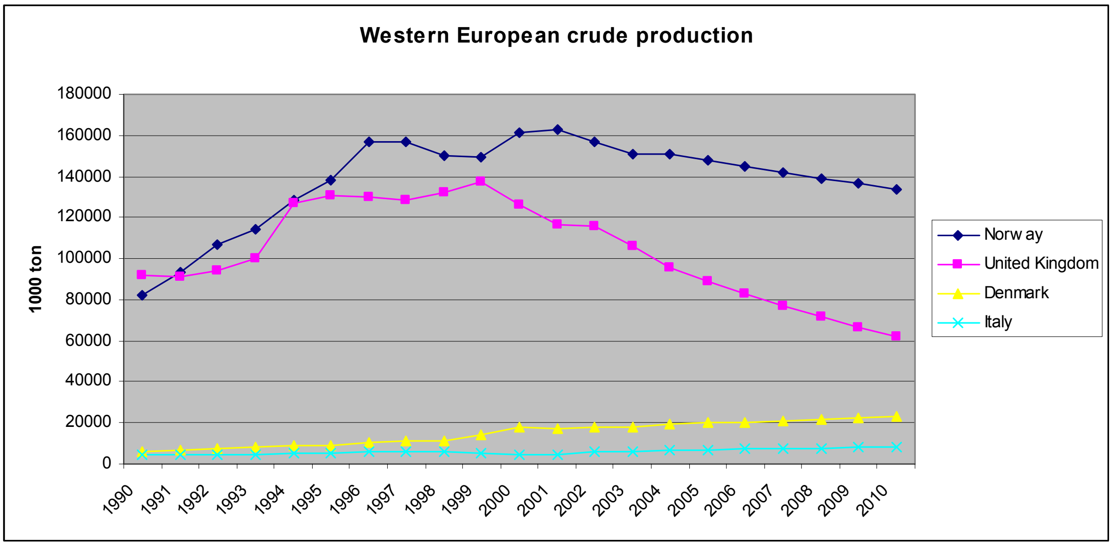

Figure 54: European crude production from 1990-2004 (IEA 2005)

4.2.5 FSU crude production

There are different crude production regions in the FSU. Basically Siberia and Caspian Sea regions are most important. The Caspian region is a relatively new crude production area. Kazakhstan is the biggest producer of Caspian crude. Next to Kazakhstan, Russia, Turkmenistan and Azerbijan benefit from Caspian oil.
Transportation of crude to export ports is the biggest problem. Pipelines are essential, but need to pass Russia. Transneft uses its monopoly power to influence politics. The alternative through Russia is rail, but this is very expensive. The BTC pipeline is a good alternative to transport Caspian crude; it runs through Turkey and not through Russia.
Next to scarcity of pipeline capacity, port capacity is limited. The Bosporus Street is the only passage to the Mediterranean. Bosporus street runs through Istanbul, is very narrow and difficult to maneuver. Therefore the amounts of ships and their size is limited.
Russia's potential of increasing production is good, but exporting is a problem because of lack of capacity. Pipelines run over their maximum capacity and are beyond their life span (30-40 years). Investments from third parties are difficult because of the monopoly of Transneft. New pipelines to the east coast are planned, and being build.
Next to transport over land, transport over water is difficult. The street of Bosporus on the one site and the ice packs in winter in the Baltic limits exporting capacity. Moermansk, which is ice free through the year, could take up the role of export port, but is not connected to the pipeline system

FSU crude is of medium quality. The Russian Federation has the bulk of crude production, and the main crude produced is the Ural blend (mixture of Ural and Siberian crude) which is transported through pipelines to Europe, Black Sea and Baltic Sea (Druzbha pipelines).
Production from the Caspian Sea region has other export routes: the CPC pipeline (to Black Sea) and the Baku-Ceyhan (Mediterranean). Overall, Caspian crude is light, (in-

termediate) sweet and TAN is low, Tengiz and Kashagan are examples of crudes from this region.

Country	Production 2004 (1.000 ton)		Percentage of total production		API°		Sulphur (wt%)	
	2004	2010	2004	2010				
Russia	456335	496763	82%	77%	31		1,3	
Kazakhstan	59435	92679	11%	14%	41		0,6	
Azerbaijan	15399	18266	3%	3%	32		0,2	
Uzbekistan	7320	11527	1%	2%	33		>1,3	
Other FSU	16443	21918	3%	3%				
					‘04	‘10	‘04	‘10
Total/ weighted average	554932	641153	100%	100%	32	33	1,2	1,2

Table 51: Crude production and quality in the FSU (BP 2005, Haverly 2005, IEA 2005).

The production capacity growth of Russia is predicted (by the IEA 2005) to slow down to 10,7 million b/d in 2010. Kazakh crude production had an average growth of 6,8% annually from 1990-2004, it is taken that this growth will continue till 2010.

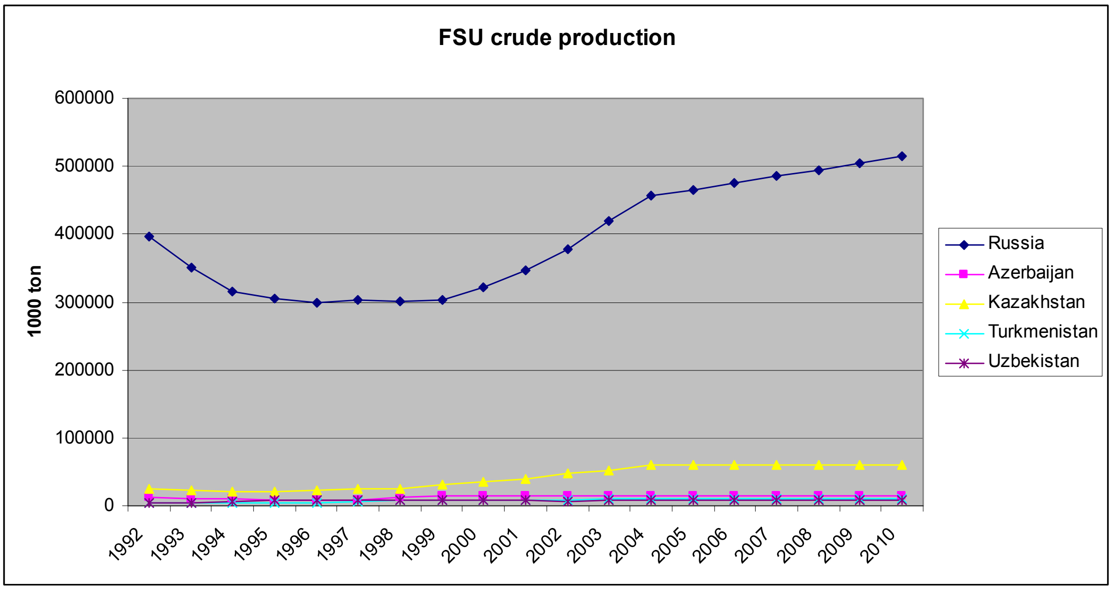

Figure 55: FSU crude production from 1990-2004 (IEA 2005)

4.2.6 Middle East crude production

On average, crude from the Middle East is light and sour. Most production, from Saudi Arabia, is light, but almost medium heavy, and sour. Only Yemen produces a high quality crude with low sulphur content high API°. On average crude quality will stay the same until 2010, taking that the quality produced by individual countries will stay the same.

Country	Production 2004 (1.000 b/d)		Percentage of total production		API°	Sulphur (wt%)
	2004	2010	2004	2010		
Saudi Arabia	492303	519814	42%	37%	33	2,1
Iran	202966	228735	17%	16%	34	1,7
UAE	124978	144264	11%	10%	39	1,0
Kuwait	119941	130483	10%	9%	32	3,0
Iraq	98990	213574	8%	15%	36	2,2
Other Middle East	138601	156763	12%	11%	34	1,9
Total/ weighted average	1177779	1393634	100%	100%	34*	1,9*

Table 52: Crude production and quality in the Middle East (BP 2005, Haverly 2005, IEA 2005).

***This number represents the value for 2004 as well as for 2010.**

Middle East production is growing. In Figure 56the trend lines are presented. The IEA (2005) predicts a production of 26,6 million b/d in 2010, without natural gas liquids (NGL) (BP includes NGL production where its produced separately). All predictions on production in 2010 are based on the trend seen from 1990 onwards. The following exceptions are made:

- ‘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 many wars fought in this country, trend analysis is not possible. Therefore this prospect is taken, although NGL production is probably not included.
- The Kuwaiti trend is taken after production recovered from the Iraqi invasion in 1990.
- Saudi Arabia growth percentage in 1990 is not taken into account because it doesn’t seem to reflect the growth over the complete period (1990-2004) (this was very strong rise of production, Saudi Arabia is not taken into the graph because the production is more than twice as big and reduces readability of other countries).
- ‘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.’(Global Research 2005) The growth of production in Qatar will 250.000 b/d. This amount will be added to the production reported by BP in 2004, 990.000 b/d, this amount includes NGL.
- In total the Middle East will produce 28,2 million b/d, a difference of 1,6 million b/d with IEA prediction. This can be explained by a NGL/ condensate production which is taken into account by BP and not by the IEA.

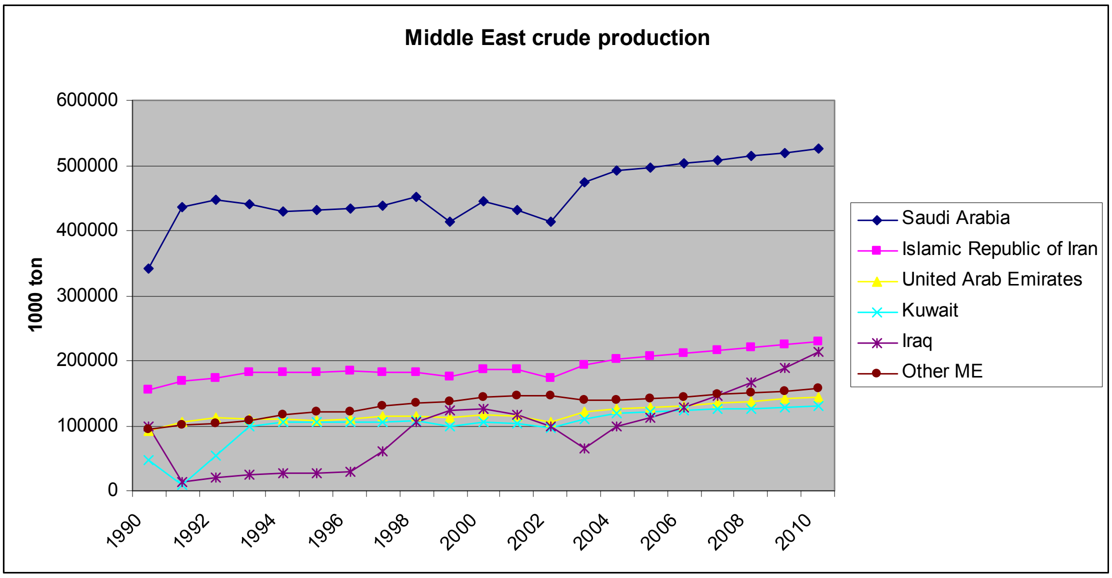

Figure 56: Middle East crude production from 1990-2010 (BP 2005, IEA 2005, Global research 2005)

4.2.7 Asia Pacific crude production

On average, Asia – Pacific crude production is of good quality. It has low sulphur content and above average API°. The following table presents the different quantities and qualities of crude produced in the countries in this region. The quality of crude will stay the same until at least 2010.

Country	Production 2004 (1.000 b/d)		Percentage of total production		API°	Sulphur (wt%)
	2004	2010	2004	2010		
China	174030	174030	50%	49%	33	0,2
Indonesia	56784	51382	16%	14%	33	0,2
Malyasia	40434	44178	12%	12%	43	0,1
Australia	24690	24621	7%	7%	46	0,1
Vietnam	19834	20834	6%	6%	36	0,2
Other Asia	33975	42007	10%	12%	43	0,1
Total/ weighted average	349747	357051	100%	100%	35*	0,1*

Table 53: Crude production and quality in the Middle East (BP 2005, Haverly 2005, IEA 2005)

***This number represents the value for 2004 as well as for 2010.**

Asia petroleum production is projected to stay constant until 2010. Some new fields will come into production, while production of other fields will diminish. It is difficult to find any projections of the crude production in 2010 of the different countries individually. The following remarks are of importance:

- China productions levels at about 3,5 mb/d (IEA 2005), China is taken out of the graph for readability reasons.

- Malaysia, Vietnam and Thailand production is calculated by adding the average absolute growth since 1990 until 2010. This is done because production growth is more realistic and on the careful side.

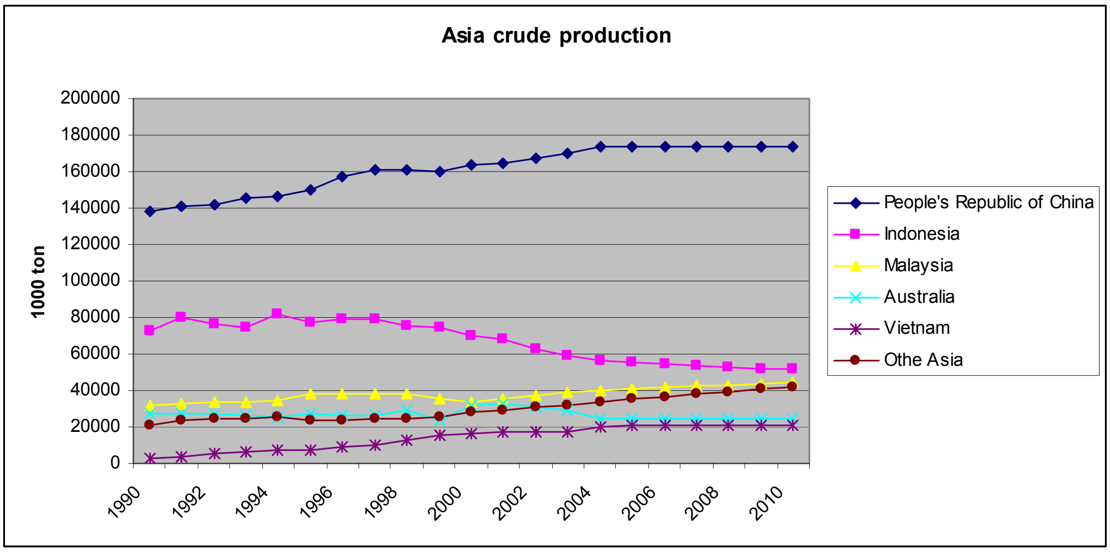

Figure 57: Asia – Pacific crude production from 1990-2004 (IEA 2005)

4.2.8 Conclusion

- Consuming regions have the smallest increase of production or even a decreasing production.
- The Middle East, Latin America and Africa have the most production growth potential.
- African and European crude is on average of high quality.
- Latin American crude has on average the lowest quality.
- Middle East, North American, FSU and Asia crude is of intermediate quality.
- Asia and Europe has crude of sweet quality.
- Overall quality of crude stays about the same. In 2010 crude is some what lighter but also slightly sourer.

Country	Production 2004 (1.000 b/d)		API°		Sulphur (wt%)	
	2004	2010	2004	2010	2004	2010
Africa	498.555	571.577	40	40	0,5	0,5
Latin America	667.818	792.505	25	25	1,5	1,4
North America	483.159	485.263	34	33	1,1	1,1
Europe	285.125	237.785	39	39	0,3	0,3
FSU	554.932	641.153	32	33	1,2	1,2
Middle East	1.177.779	1.393.634	34	34	1,9	1,9
Asia-Pacific	349.747	357.051	35	35	0,1	0,1
Total/ weighted average	*4.017.115*	*4.478.969*	*33,6*	*33,5*	*1,2*	*1,2*

Table 54: World crude production with projection on 2010 (IEA 2005)

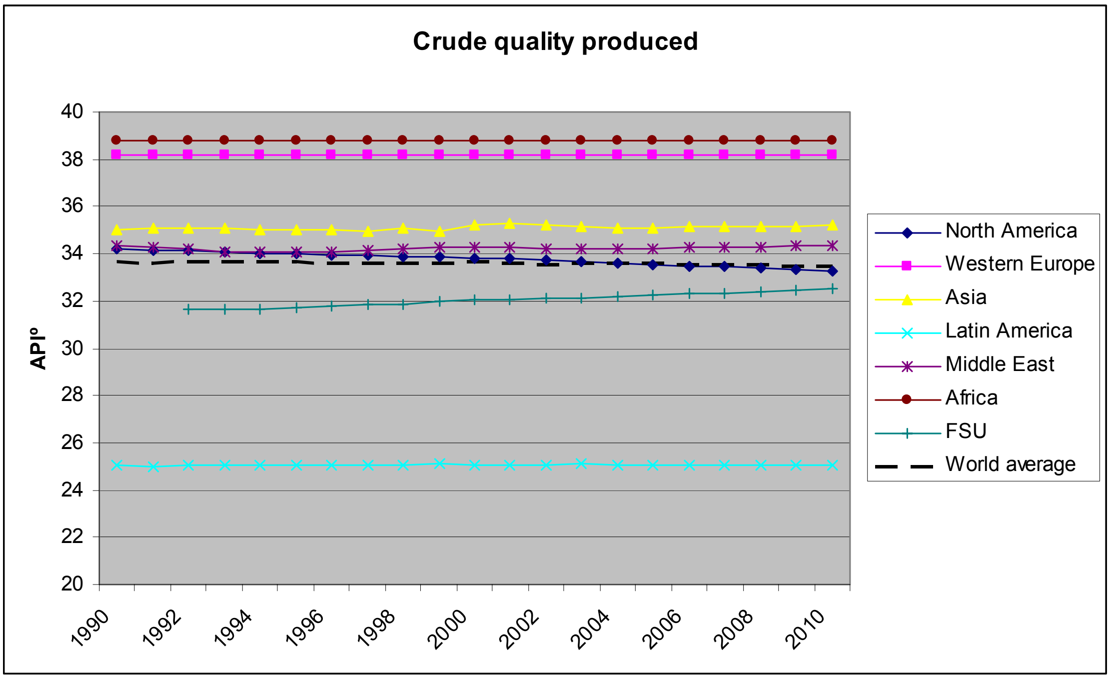

Figure 58: Average quality of crude produced in the regions (IEA 2005).

It must be noted that this calculation is based on the weighted average of the production in tons. If the weighted average in barrels is taken, the quality would be higher, the quality would stay approximately the same. This is due to the difference in weight of a light and a heavy barrel. A ton of heavy crude yields less barrels than a ton of light crude.

Therefore, in barrels relatively more light crude is produced compared to heavy crude than in tons, resulting in a different average quality of crude.

4.3 Crude streams to the consuming regions

This paragraph will describe 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 per origin country is used, when this is unknown the average API of the origin region is used. First the crude streams and quality to Europe is described, than North America, and OECD Asia. The other regions are less interesting because the quality requirements and demand mix of products is significantly different and are mostly producing, and therefore these regions will have a different crude quality demand.

4.3.1 Crude streams to Europe

The consumption of domestic crude is declining relative to imports. Since 1999 actual domestic consumption is declining from 2,3 to 1,9 million ton. Overall consumption was decreasing from 1999 till 2003 and recovered to above 6 million ton in 2004.

The biggest share of the refinery through put is from domestic production. In the beginning of the nineties Europe was most dependent on Middle East oil, mostly Saudi Arabian and Iranian crude. This dependence has shifted to FSU crude, which now takes the biggest proportion of crude supplies. Mostly all regions have declining shares in crude imports of Europe. This is first due to increasing domestic production and after domestic production declined the imports from the FSU increases. Overall, there are four different sources of crude to Europe: domestic, FSU, Middle East and North Africa.

	1990	1993	1996	2000	2004
Non Specified/Other	0%	0%	0%	1%	1%
Latin America	5%	4%	2%	3%	2%
Middle East	32%	35%	27%	27%	22%
West Africa	8%	7%	7%	5%	4%
North Africa	16%	13%	13%	12%	13%
FSU	10%	9%	10%	15%	25%
Domestic	29%	32%	39%	37%	33%

Table 55: Share of crude refinery throughput per origin in Europe (IEA 2005)

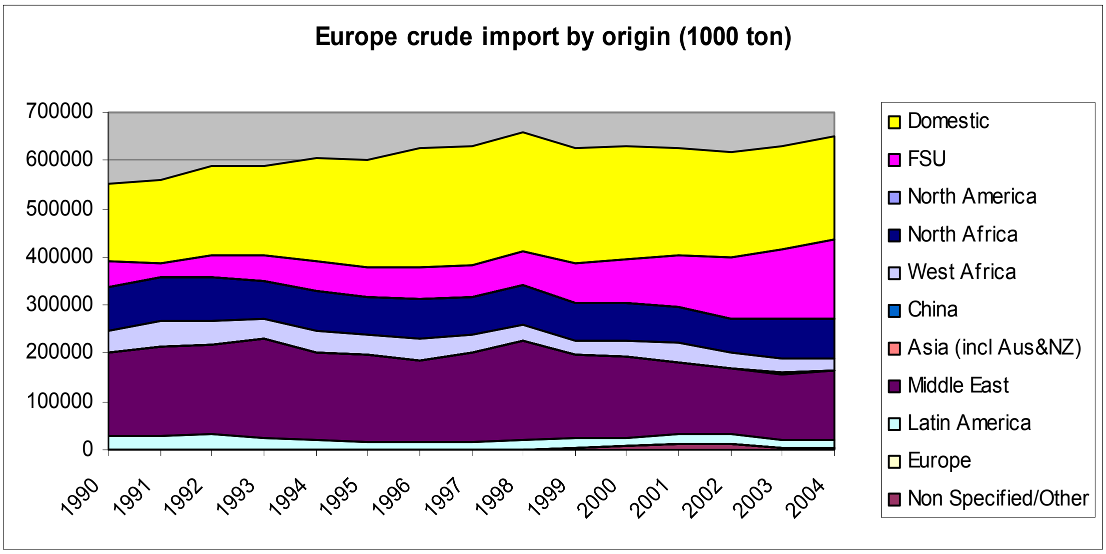

Figure 59: Crude consumption per origin region for Europe.

Consumption grew with an average of 1,22% per year 1990 until 2004. Extrapolating this trend, the consumption in 2010 will be 699 million ton. This is 49 million ton more than consumed in 2004.

4.3.2 Crude streams to North America

In North America 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 in increasing with small dips in 1999 and 2002. It is expected that more crude is imported because of declining domestic crude production and a growing demand for oil products.

	1990	1993	1996	2000	2004
Europe	4%	5%	6%	7%	5%
Latin America	12%	16%	21%	21%	23%
Middle East	14%	13%	11%	15%	15%
Asia (incl Aus&NZ)	1%	1%	1%	1%	1%
West Africa	8%	9%	9%	9%	9%
North Africa	1%	1%	1%	1%	3%
FSU	0%	0%	0%	0%	1%
Domestic	59%	55%	51%	46%	44%

Table 56: Share of crude refinery throughput per origin in North America (IEA 2005)

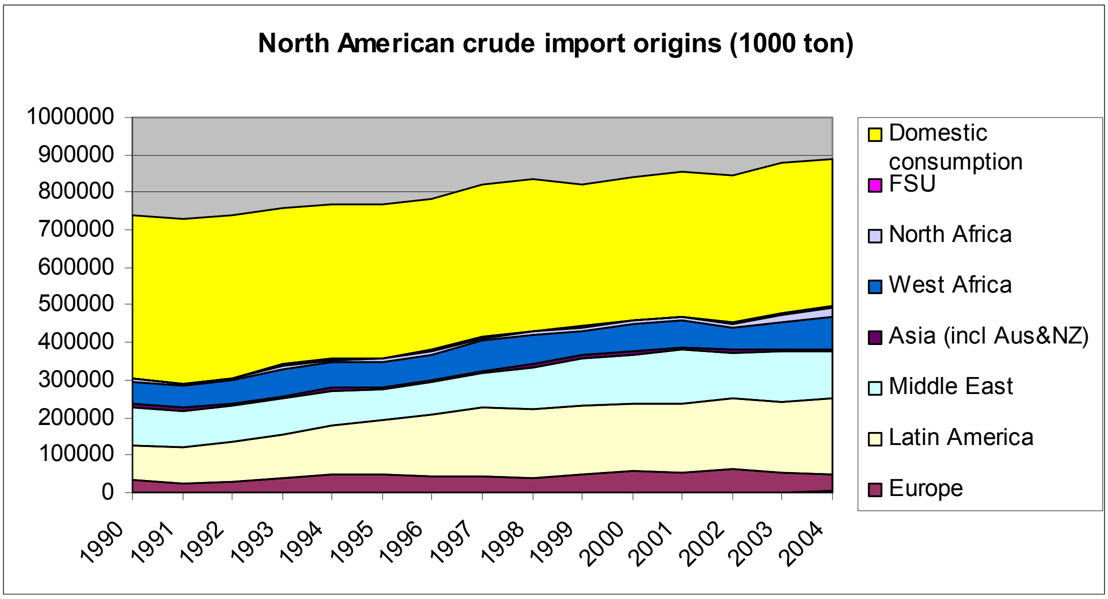

Figure 60: Crude consumption per origin region in North America (IEA 2005).

4.3.3 Crude streams to OECD Pacific

The OECD Pacific countries are in a large extend dependent on Middle East crude. Taking 56% of all consumption in 1990, in 2004 this share has grown to almost 80%. Asia, mostly Indonesia provides another 12%. If we look at the non specified/ other category, it seems logic the lions share of these imports are from the Middle East, because the other origins seem quite stable in there import share. Overall consumption is declining the last decade.

	1990	1993	1996	2000	2004
Non Specified/Other	16%	24%	0%	0%	0%
Latin America	3%	1%	2%	1%	1%
Middle East	57%	55%	74%	78%	79%
Asia	14%	11%	13%	13%	12%
China	5%	4%	4%	1%	1%
West Africa	0%	1%	2%	2%	2%
North Africa	0%	0%	0%	1%	2%
FSU	0%	0%	0%	0%	1%
Domestic	5%	3%	5%	3%	3%

Table 57: Crude consumption per origin in the OECD Pacific (IEA 2005)

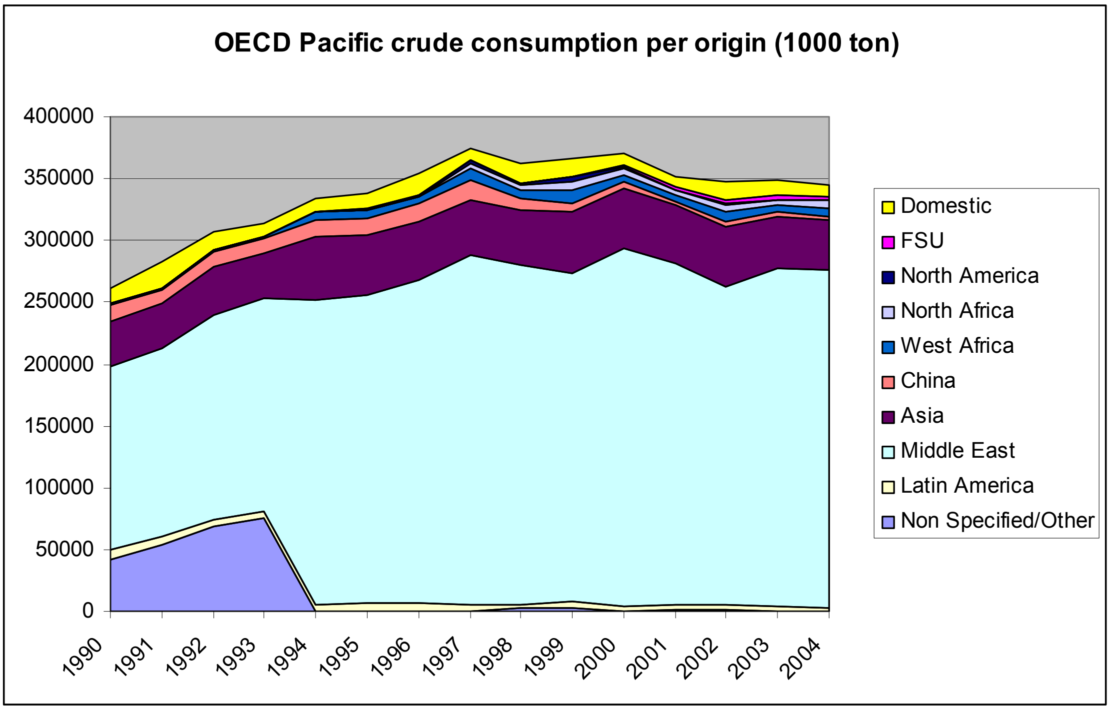

Figure 61: OECD Pacific crude consumption (IEA 2005)

4.3.4 Conclusion

- The origins of European imports are mostly the FSU, Middle East and (North) Africa. Geographically speaking this is what can be expected.
- The origins of North American imports are Latin America, the Middle East and West Africa. Geographically speaking the Middle East seems far away, but merely because of the amount production situated in this region, it is understandable. West Africa and Latin America are more obvious import origins.
- The OECD Pacific region is focused on Middle East crude. Almost 80% of all crude consumed is produced in the Middle East. The FSU may be a new supplier of crude on the long run, when pipelines are finished to the East Coast of Russia.

4.4 Crude Quality in the assessed regions

This paragraph will describe the crude quality consumed in the consuming regions. The years 1990-2004 will be assessed. The average quality of world crude production is added to the figures. The weighted average is used to calculate the qualities.

4.4.1 Crude quality

Average quality of the crude used as refinery feedstock in Europe is relatively high compared to the average world production. Europe consumes a relative light average crude of above 36º API. The development of the average API follows about the same trend as the share domestic crude consumed. The average weight of crude processed in Pacific refineries is some what heavier than the European crude processed. In 1990 the API is almost 36º declining to an average of 34,5º to 35º. North American crude consumption has a declining APIº between 1990 and 1998, after 1999 the average API almost levels around between 32,5.

	1993	1994	1996	1997	2000	2001	2004
NAM	**32,96**	**32,89**	**32,53**	**32,39**	**32,55**	**32,52**	**32,45**
US	32,96	32,87	32,41	32,26	32,37	32,34	32,24
Canada	32,99	33,15	33,80	33,77	34,33	34,29	34,52
EU-15	**35,88**	**36,14**	**36,45**	**36,34**	**36,25**	**36,04**	**35,83**
EU-15+	**35,91**	**36,19**	**36,54**	**36,39**	**36,29**	**36,07**	**35,88**
Belgium	35,29	35,89	35,71	35,65	35,86	35,53	33,85
France	35,08	35,89	36,44	36,68	36,85	36,91	36,56
Germany	36,89	36,80	36,71	36,87	36,48	36,21	35,90
Italy	35,49	35,60	36,16	36,04	35,95	35,62	35,94
Netherlands	34,56	35,05	35,62	35,46	35,54	35,50	34,50
Spain	33,08	33,39	34,53	34,27	33,97	33,67	34,27
Turkey	33,65	34,44	35,97	34,81	34,25	34,05	34,38
UK	34,23	33,65	33,86	33,85	34,78	34,72	35,21
Japan	34,77	34,78	34,88	34,85	34,70	34,78	35,10
Korea	0,00	34,14	33,92	34,12	33,08	32,98	33,20
Austalia	41,19	40,49	39,47	38,87	37,62	36,92	38,21
Pacific	**35,55**	**35,15**	**34,99**	**34,95**	**34,42**	**34,35**	**34,73**

Table 58: APIº calculated by the weighted average of the quality of the import and domestic consumption

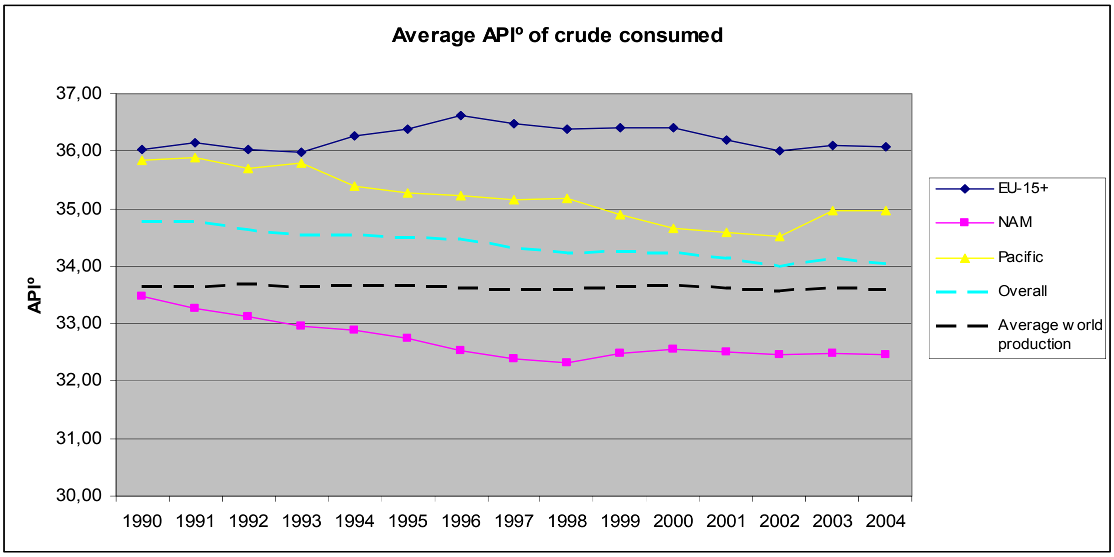

Figure 62: Average API° consumed in the regions assessed (IEA 2005)

In Europe, 50% (in 2004, in 1996 this was 59%) of the crude processed is sweet, the other half tends to be intermediate sour (FSU crude) to sour (Middle East) crude. The crude consumption turns sweeter together with growing domestic crude consumption and vice versa. Overall the sulphur content stays between 1,1% and 1,0%, with mostly a down ward trend.

North American and Pacific crude consumption tend to get sourer, but growth levels in 2001. For North America this is because domestic crude production decline is substituted by North African crude instead of Middle Eastern or Latin American crude. For the Pacific there is a decline in consumption, giving a greater share of domestic crude consumption and less Middle East crude.

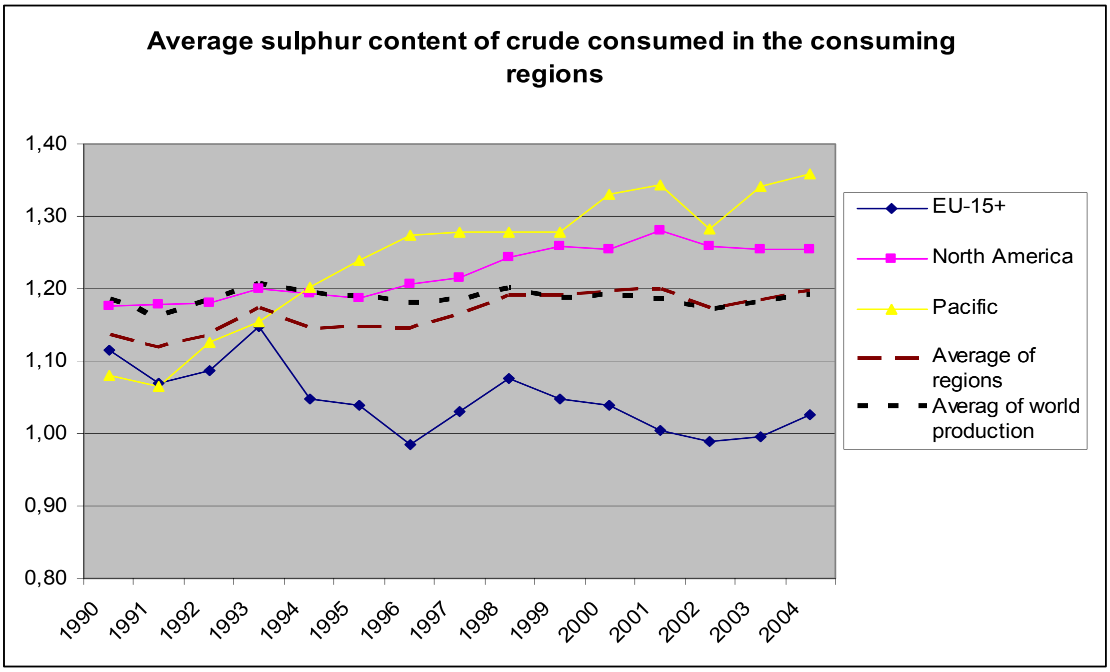

Figure 63: Average sulphur content of crude consumed (IEA 2005)

4.4.2 Conclusion

- When looked at both graphs, it can be noticed that when average sulphur content increases, the average API° decreases. This illustrates that the heavier the crude the more sulphur it contains.
- North American crude quality seems most constant compared to the other two regions.
- The sulphur content of crude used at the Pacific seems volatile after it increased fast from 1990-1996.
- The sulphur content of the crude used in European is volatile over the complete period. This could mean European refiners are able to process crude with different sweetness. This may be because it processes a relatively sweet crude on average. Another explanation may be that the availability of sweet crude is good relative to the other regions.
- In all three regions sulphur content grows in the 2003-2004, although the API° stay relative the same.
- The average API° of crude produced is about 33,58°, this hasn't changed much over the years. It is expected to drop to 33,47 in 2010. Both the Pacific and Europe consume crude with an average above the world average. North America consumes crude below this API°. The average API° of crude consumed in these three regions in 2004 is just above this average, 34,04° API. This means the other regions consume relative heavy crude.
- The average sulphur content of world crude is 1,19%. Both the Pacific and North America process sourer crude, while Europe tends to use sweeter crude. So, on both sides, Europe use relatively light and sweet crude for their refineries.

4.5 Conclusion

Overall it can be concluded that:

- Africa produces the best qualities crude and has potential for increasing production
- Overall, the worst quality crude is produced in the America's.
- Middle East crude is of average quality.
- The FSU mostly exports its crude to Europe, but it is expanding its export capabilities to other regions as Asia. Therefore there will be more competition for attaining FSU crude. Europe may need to shift imports from the FSU to other regions like the Middle East and Africa.
- Asia is almost completely dependent on Middle East exports.
- United States and European production is declining, while demand is growing and therefore import reliabilities grow.
- If Europe wants to maintain the same quality of crude for consumption, the best option is to increase imports from North Africa and the Caspian sea region instead of Middle East and Russian crude (Ural blend). Declining production and growing consumption may be compensated by exporting less to North America.
- The United States processes relative low quality crude. Latin America is their biggest supplier. Production in Latin America will grow, but if this crude is suitable to substitute for the declining share of domestic crude consumption is doubtful. US production is of better quality, therefore substituting domestic declining production with Latin American and Canadian crude will pressure average quality of the crude consumed. Imports from West/ North Africa, the FSU and Middle East to keep average crude quality up as well as increase refinery complexity are options to cope with declining endogenous production.
- The consuming regions seem to have adapted their refinery configuration to the regions quality of crude.
- When average sulphur content increases, the average API° decreases. This illustrates that the heavier the crude the more sulphur it contains.
- North American crude quality seems most constant compared to the other two regions.
- The sulphur content of crude used at the Pacific seems volatile after it increased fast from 1990-1996.
- The sulphur content of the crude used in European is volatile over the complete period. This could mean European refiners are able to process crude with different sweetness. This may be because it processes a relatively sweet crude on average. Another explanation may be that the availability of sweet crude is good relative to the other regions.
- In all three regions sulphur content grows in the 2003-2004, although the API° stay relative the same.
- The average API° of crude produced is about 33,68°, this hasn't changed much over the years. It is expected to stay about the same. Both the Pacific and Europe uses crude with an average above the world average. North America uses crude below this API°. The average API° of crude consumed in these three regions in

2004 is just above this average, 34,04º API. This means the other regions consume a relatively heavy crude.

- The average sulphur content of world crude is 1,19%. Both the Pacific and North America process sourer crude, while Europe tends to use sweeter crude. So, on both sides, Europe use relatively light and sweet crude for their refineries.

5 Model to assess the quality of crude demand in 2010

The goal of this chapter is giving more insight in the quality of crude demand in the world by creating a model. This model is needed for the estimation of the crude quality demand in the not assessed regions of chapter 5 to calculate the average quality of world crude demand. These were not assessed because of lack of information.
Two indicators will be used: refinery complexity (conversion ratio), the crude quality (API°) and the production of residual fuel as percentage of total production of products (RFPS). By building a model, an estimate will be made on the quality of crude consumed in the past, present and the future.
This chapter will start with the framework on which the model is based, describing the effect of the first indicator, the conversion ratio. The second paragraph will describe the second indicator, residual fuel production share of total product production. These two indicators are put into a model in paragraph 3, to predict the quality of crude consumed by refiners denoted in API°. Many attempts were made to create such model, these attempts are summarized and their insights are described. These insights are used to tune the model to more satisfactory results. Eventually the normalized API° is created which cancels the effect of different product market structures in the model.

5.1 Conversion ratio and crude quality

To be able to predict the API° of crude consumed by refiners, the conversion ratio is used as indicator. The conversion ratio was described in chapter 3. The conversion ratio is set against the API° used by the refiners in the specified countries and regions. The result is scatter plot, which shows a weak correlation. Still this plot gives an indication on the correctness of the average API° calculated by the weighted average of the API° of the imports. The different dots are countries within the regions and the regions themselves. Information of the years 1993, 1994, 1996, 1997, 2000, 2001 and 2004 are used due to conversion ratios available. Below Figure 64 some remarks are made on specific countries.

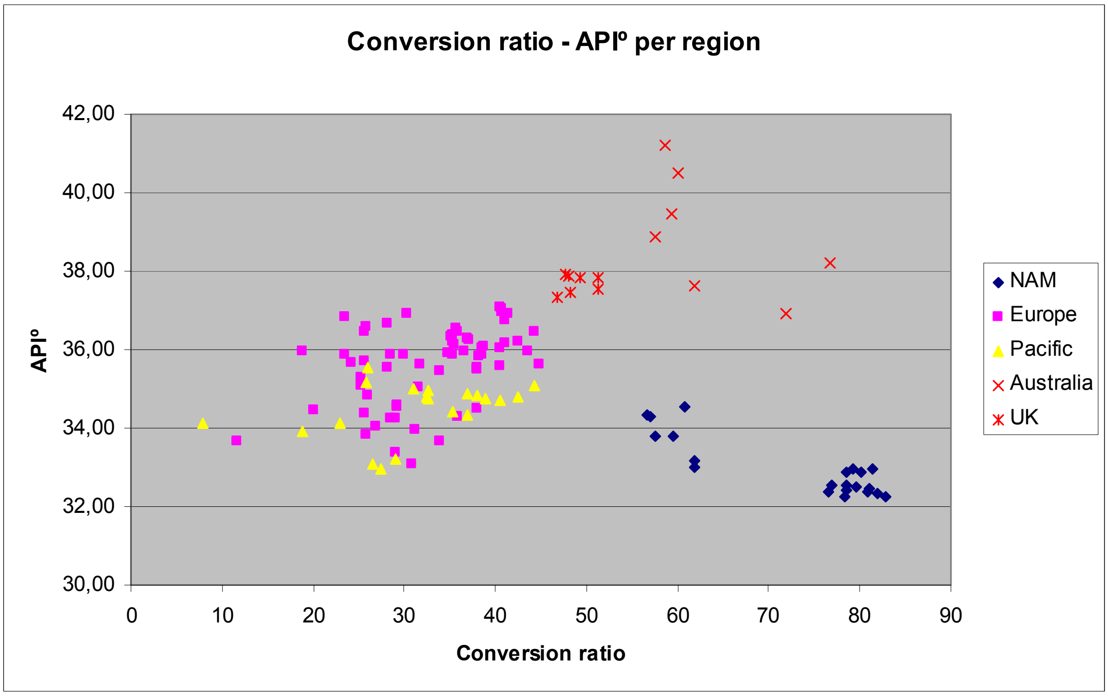

Figure 64: Scatter plot of the conversion ratio and API° per region (IEA 2005, ENI 2005/ 2006).

The API° of Australia is relatively too high for the conversion ratio of the refinery sector (red crosses at the top right corner of the figure). By investigating the crude quality run by Australian refineries, it must be concluded that the API° is incorrect. 'Australia's refineries have conversion plant to handle medium/heavy sour crudes.' (Yappy, 2006). An API° of around 40° is light, and by no means medium to heavy. Therefore Australia imports more heavy crude for "yield balancing" purposes (heavy crude yield more vacuum gas oil which is feed to conversion processes) (Yappy, 2006). Australian domestic production is light.

Because the calculation of the average API° of Australia is presumed false, Australia is taken out of the model and the Pacific data recalculated. The Pacific average crude quality consumed is corrected downwards.

The quality of crude processed in the UK (group of red stars against the 38° API line) is too high for the conversion possibilities of the refinery sector and residual fuel production. The crude produced in the UK is on average of high quality. The amount of medium and heavy crudes produced is about 32% (OGJ 2004). This is about the amount of domestic crude which is processed by its own refineries. It cannot be taken that the complete proportion of non- light crude is consumed by UK it self. Therefore a moderate API° of 32° is taken for the domestic crude. The API° of crude used in the UK is more reasonable.

According to Han de Krom (2006) there is an incentive to sell high value crude and process low value crude instead. Both countries are characterized by a crude production which is relatively of high quality.

Germany consumes a great deal of Russian crude, mainly provided by the Druzbha pipeline, providing Ural blend. The Ural blend has lower quality crude than the average FSU crude. Therefore the quality of the Russian imports is corrected to an API of 31º (average Ural blend APIº) instead of 32,72º. This lowers the average APIº consumed in Germany, fitting better to the abilities of conversion by the refiners.
The same counts for the consumption of crude by all countries in the North West Europe region, knowingly Belgium, Netherlands and the UK. The countries connected to the Mediterranean are more likely to import a mix of crudes from the FSU, as Kazakhstan's Tengiz grade and Ural blend from Russia (Tengiz is high APIº crude of about 39º).

North West Europe refineries import Ural blend from Russia, therefore the characteristics of Ural blend is taken instead of the average of FSU crudes. APIº is lowered from 32,7º to 31º, which lowers the weighted average of APIº in these countries.

As a result the following APIs are used for further assessment:

	1993	1994	1996	1997	2000	2001	2004
NAM	**32,96**	**32,89**	**32,53**	**32,39**	**32,55**	**32,52**	**32,45**
US	32,96	32,87	32,41	32,26	32,37	32,34	32,24
Canada	32,99	33,15	33,80	33,77	34,33	34,29	34,52
EU-15	**35,14**	**35,52**	**36,07**	**35,88**	**35,74**	**35,57**	**35,38**
EU-15+	**35,22**	**35,61**	**36,19**	**35,96**	**35,82**	**35,64**	**35,47**
Belgium	**35,22**	**35,84**	**35,62**	**35,58**	**35,70**	**35,37**	**33,44**
France	35,08	35,89	36,44	36,68	36,85	36,91	36,56
Germany	**36,72**	**36,59**	**36,46**	**36,62**	**36,15**	**35,87**	**35,49**
Italy	35,49	35,60	36,16	36,04	35,95	35,62	35,94
Netherlands	**34,53**	**35,00**	**35,57**	**35,42**	**35,46**	**35,38**	**34,20**
Spain	33,08	33,39	34,53	34,27	33,97	33,67	34,27
Turkey	33,65	34,44	35,97	34,81	34,25	34,05	34,38
UK	**35,02**	**34,61**	**34,88**	**34,86**	**35,53**	**35,40**	**35,81**
Japan	34,77	34,78	34,88	34,85	34,70	34,78	35,10
Korea		34,14	33,92	34,12	33,08	32,98	33,20
Pacific	**34,77**	**34,61**	**34,56**	**34,58**	**34,10**	**34,11**	**34,41**

Table 59: APIº corrected with the above given corrections, Australia is taken out

Resulting in the following scatter plot:

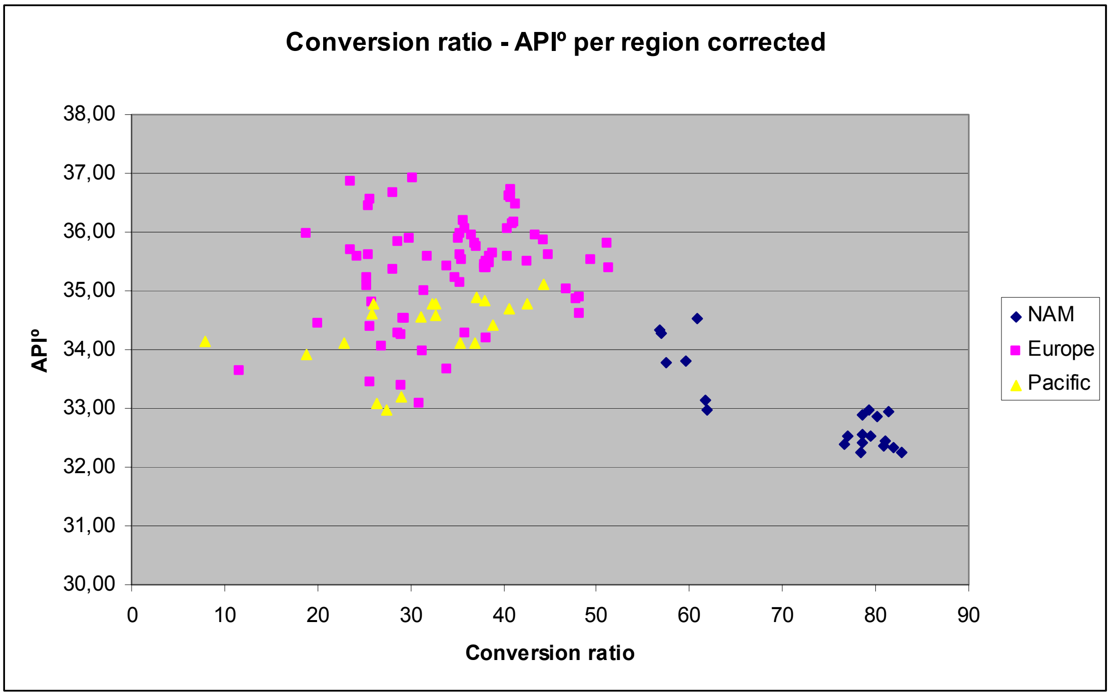

Figure 65: Scatter plot of the conversion ratio and API° corrected per region (IEA 2005, ENI 2005/ 2006)

The scatter plot shows a correlation between the conversion ratio and the API° of crude consumed. But this correlation is not enough to predict crude quality consumed by the not assessed regions and not enough to look into the future.

As noticed before, a different product market asks a different structure of the refinery sector or a different quality feedstock. Therefore the values need to be normalized according the structure of the product markets. As noticed before, residual fuel production depends on the weight of the crude produced. This relation will be used in the next paragraph.

5.2 Residual fuel production share

This paragraph will start with a concept model to introduce the residual fuel production share in relation with the conversion ratio and the API°. Then an assessment is made to get more insight of the effect of the residual fuel production share on the data.

5.2.1 Concept model incorporating the Residual fuel production

The share of residual fuel production (RFPS) of total is tested as indicator for the API° consumed by refiners. The conversion ratio is an indicator of the ability to produce light products and reduce residual fuel (vacuum gasoil is blended in with residual fuel when not further processed). It was taken that the conversion processes are used in full potential, but this does not mean all refineries pursuit the same amount of residual fuel production. Lower quality crude will produce more residual fuel, the conversion ratio determines the amount of residual fuel which is converted into light products and therefore the amount of residue left over. Therefore the conversion ratio is not enough an indicator to find a correlation with the crude quality, as shown in the former paragraph.

The following theorem must suffice to incorporate the residual fuel production:
1. the lower the API° the higher the RFPS
2. the higher the conversion ratio the lower the RFPS

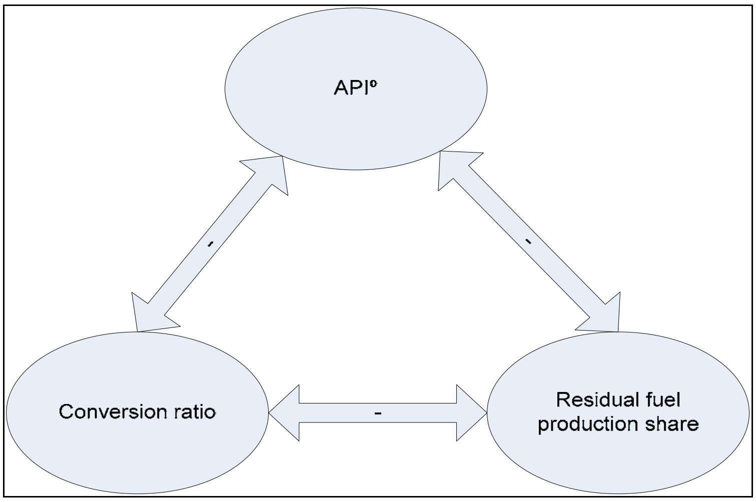

Figure 66: API° - Conversion ratio – residual fuel production share

The Figure 66 is a causal diagram of the system at hand here. A higher API° contains less residual fuel. Residual fuel can be reduced by conversion, denoted in the conversion ratio. The higher the conversion ratio with the same quality crude, the lower the amount of residual fuel produced. To produce the same amount of residual fuel while the conversion ratio increases, the API° of the crude used needs to be lowered. As noticed before, some refineries chose to produce relatively more residual fuel by lowering the API° of crude. Generally speaking, refiners avoid producing residual fuel which yields a low price.

5.2.2 Residual fuel in relation with the conversion ratio

The following table presents the residual fuel production share in the assessed countries and regions:

RFPS	1993	1994	1996	1997	2000	2001	2004
NAM	**6,9%**	**6,7%**	**5,7%**	**5,5%**	**5,4%**	**5,5%**	**4,9%**
US	6,8%	6,6%	5,6%	5,3%	5,2%	5,2%	4,5%
Canada	8,2%	7,5%	7,3%	7,6%	7,0%	7,6%	8,2%
EU-15	**19,4%**	**17,8%**	**17,2%**	**17,2%**	**16,8%**	**16,4%**	**16,1%**
EU-15+	**19,9%**	**18,3%**	**17,8%**	**17,7%**	**17,2%**	**16,9%**	**16,5%**
Belgium	21,1%	16,9%	19,5%	20,3%	21,0%	17,6%	19,4%
France	15,4%	13,3%	12,3%	12,1%	12,5%	12,5%	13,2%
Germany	12,3%	11,7%	11,6%	11,0%	11,3%	11,5%	11,7%
Italy	23,9%	22,8%	20,6%	20,2%	20,5%	20,1%	18,6%
Netherlands	20,3%	16,9%	16,7%	16,7%	13,9%	13,2%	15,7%
Spain	27,1%	25,6%	23,3%	24,0%	21,9%	20,4%	15,3%
Turkey	36,3%	34,7%	34,1%	33,2%	33,8%	33,3%	30,2%
UK	16,2%	14,9%	14,3%	14,5%	13,5%	14,5%	14,6%
Japan	21,6%	22,3%	19,3%	19,4%	17,4%	15,6%	15,7%
Korea	39,1%	38,7%	33,3%	29,0%	27,8%	28,0%	25,7%
Pacific	**26,4%**	**26,7%**	**23,8%**	**22,9%**	**21,3%**	**20,2%**	**19,4%**

Table 60: Residual fuel production share in the assessed countries, the yellow countries are taken out in the <20% residual fuel share (IEA 2005).

The Figure 67 shows the relation between the conversion ratio and the residual fuel production share. There is a correlation between the two. This illustrates that the conversion possibilities influence the residual fuel production more than the quality of crude. Still, it was concluded that the quality of crude has an influence. Combining the two should give a better result.

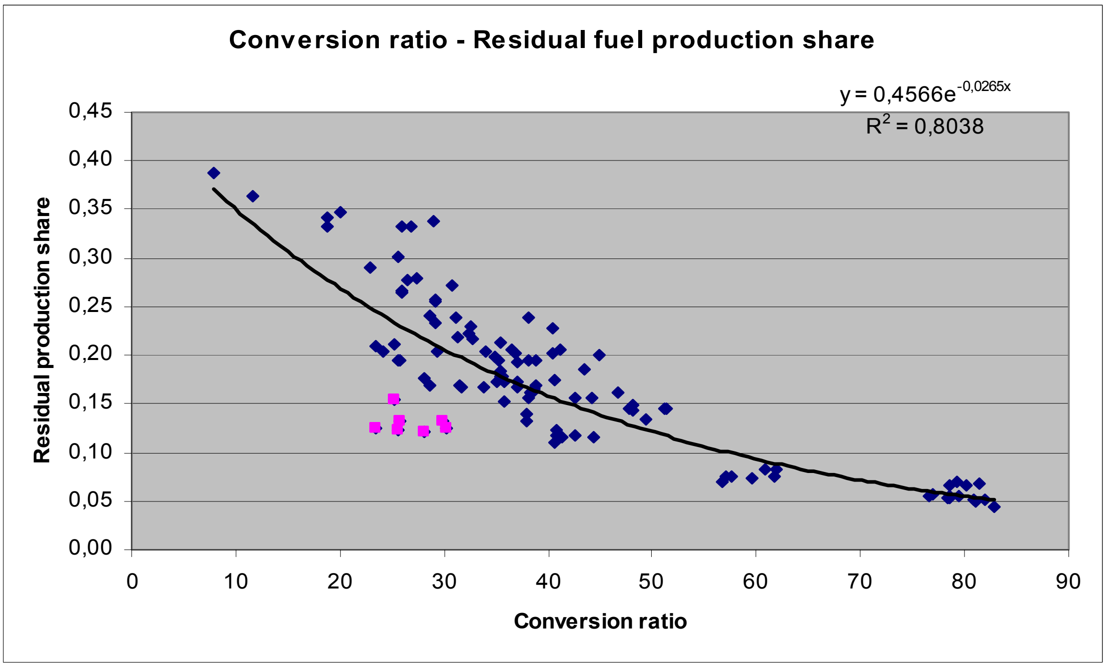

Figure 67: Conversion ratio – residual fuel production share, the purple dots resemble France (IEA 2005, ENI 2005/ 2006)

5.2.3 Eliminating data by incorporating the RFPS

To create more insight in the consumption of different qualities of crude, countries, regions and years are selected by residual fuel production share. First, countries with a higher production of residual fuel than 20% of total are leaved out (Model attempts and validation on data, Figure 78). The RFPS is reduced to eventually 15%. The chart below shows the scatter plot of countries with a production of residual fuel lower than 15%. This assessment shows that there is a relation between the conversion ratio and the quality of crude when the residual fuel production is at similar level.

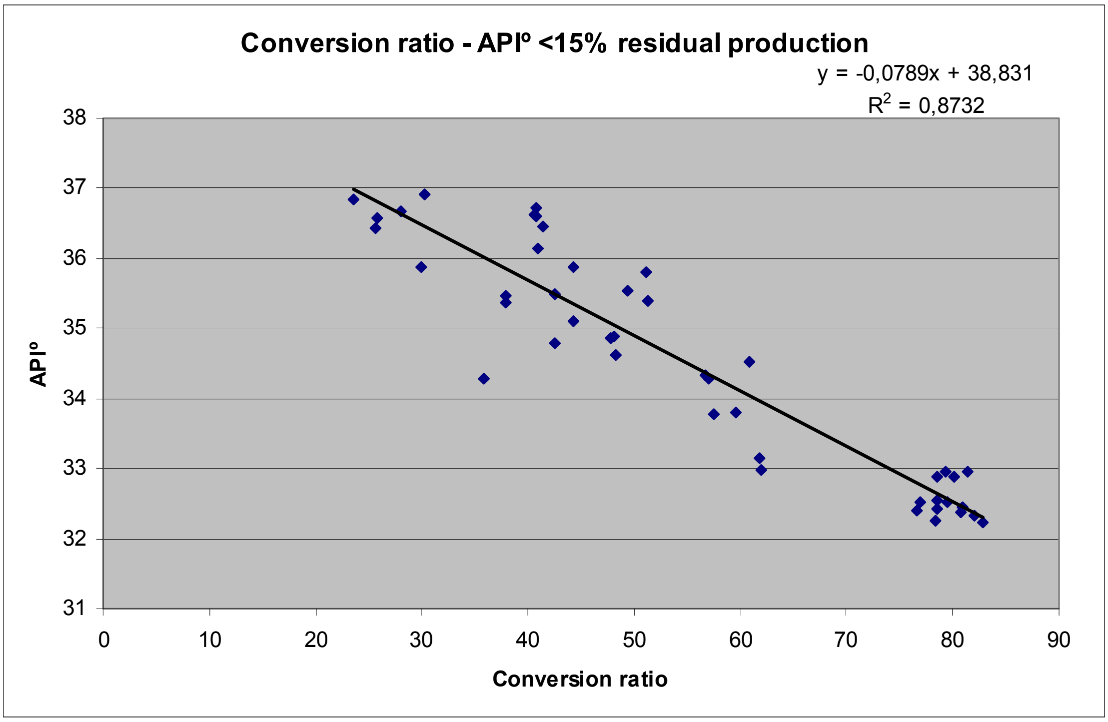

Figure 68: Scatter plot of the conversion ratio and APIº corrected per region and residual fuel production lower than 15% of total

5.3 Incorporating the residual fuel share into the graph

Several attempts were made to incorporate the residual fuel. The resulting graphs which do not work can be found in Appendix 4 Figure 79 to Figure 82. The problem with most of these attempts is using the formula to calculate the APIº, none of them had satisfactory results. Still, these attempts were useful for getting insight in the correctness of the data used. Therefore these insights will be described in the first part, than the attempt with good results will be described. Eventually a normalized APIº gave good results, the formula will given in 6.3.2.

5.3.1 Insights taken from the unsatisfactory attempts

Attempts of linking the three parameters were focused on creating equations which could be used to calculate the API°. Some did not suffice the logics which were presented in former chapters, and theorem above. Still, these attempts created extra insight in the correctness of API° calculated in chapter 5. The plots which were made can be found in 8.5Appendix 5. The following attempts were made

- API° - RFPS: Turkey and in a lesser extend Korea are located above all the other points, the residual production is high for the API° of the crude used. In the early years the low conversion ratio can explain this symptom, but the conversion ratio of Turkey develops with no result on a lower residual fuel production share all though the quality of crude stays approximately the same.
- Conversion ratio – API°/ RFPS: France, Germany and Canada are situated above the trend line drawn, and therefore differ from the other points. This graph does not suffice the theorem given above.
- Conversion ratio – Specific weight / RFPS: a better fit than the previous graph, still, recalculating the API° with the equation found, gave unsatisfactory result. US and North America (NAM) 1993-94 and Canada deviate.
- RFPS – Specific weight/ conversion ratio: France and the US 1993-94 deviate.

These attempts show a deviation in the values of France, Turkey, Canada except for 2001 and 2004 and 1993-94 North America and the US. This could explain deviations in later calculations and the initial data used.

5.3.2 Creating an equation: normalized API°

With combining these two relations, conversion ratio – API° and RFPS, in a single graph can lead to a better insight in the API° used. The attempts described in the former paragraph have unsatisfactory results. This attempt will try to correct the API° to the conversion ratio so that all refineries have comparable residual production.

The API° of the crude consumed needs to be corrected by the amount of residual fuel the refinery produces. Taking that:

- the heavier the crude the more residual fuel is produced
- the conversion capacity is run on its maximum

Knowing that the conversion ratio is used in full, refineries need to produce enough vacuum gas oil (feed for HCC and FCC) and residual fuel to serve this capacity. As noticed before, the higher the API° the less residual fuel is produced, the less feed for the conversion processes. Therefore the API° of crude is limited by the amount of residual fuel and vacuum gas oil the conversion processes need to use full capacity. If crude is used with an API° which is too high, the conversion processes won’t be used in full, which is a suboptimal situation. This system is visualized in the figure below.

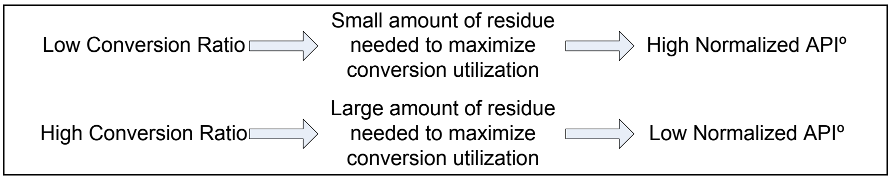

Figure 69: Conversion ratio – residual share - Normalized API°

To correct the API° this formula is introduced:

Normalized API° = API° * RFPS + API°

This formula normalizes the amount of residual fuel produced relative to the conversion ratio. This API° represents the limit API° which yields enough feed for the conversion processes to be used in full. In theory no residual fuel is produced when crude of the quality of the normalized API° is consumed. In the table below the normalized API° is given.

Norm. API°	1993	1994	1996	1997	2000	2001	2004
NAM	35,23	35,10	34,39	34,17	34,30	34,30	34,04
US	35,20	35,04	34,23	33,97	34,06	34,02	33,69
Canada	35,69	35,63	36,27	36,34	36,74	36,89	37,36
EU-15	42,84	42,58	42,72	42,60	42,34	41,95	41,59
EU-15+	43,05	42,82	43,04	42,83	42,53	42,16	41,80
Belgium	42,73	41,95	42,67	42,89	43,39	41,78	40,41
France	40,48	40,66	40,92	41,11	41,46	41,52	41,39
Germany	41,58	41,29	41,19	41,15	40,89	40,66	40,46
Italy	43,98	43,71	43,61	43,33	43,32	42,78	42,62
Netherlands	41,58	40,97	41,57	41,39	40,48	40,19	39,92
Spain	42,04	41,94	42,58	42,50	41,41	40,53	39,52
Turkey	45,86	46,39	48,23	46,37	45,82	45,39	44,77
UK	43,39	43,02	43,31	43,40	42,93	42,97	43,37
Japan	42,28	42,53	41,61	41,61	40,74	40,21	40,61
Korea	0,00	47,36	45,21	44,02	42,28	42,21	41,74
Austalia	50,09	49,53	47,08	46,41	44,17	42,68	44,21
Pacific	44,94	44,53	43,32	42,96	41,75	41,29	41,47

Table 61: Normalized API° by using the equation: API° * Residual share + API°

Refineries with a high conversion ratio, consuming average quality crude will produce less residual fuel than refineries with a low conversion ratio. Therefore the RFPS of the low conversion refinery will be higher and the API° of the crude will increase more than of the high conversion refinery. This is according the statements in Figure 69.
Countries with a low residual fuel production have their API° of crude increased less than countries with high residual fuel production.

5.3.3 The correlation between the normalized API° and the conversion ratio

By the scheme described above the effect of different levels of residue fuel production is corrected and a correlation may be found between the conversion ratio and the normalized API°. This is done below:

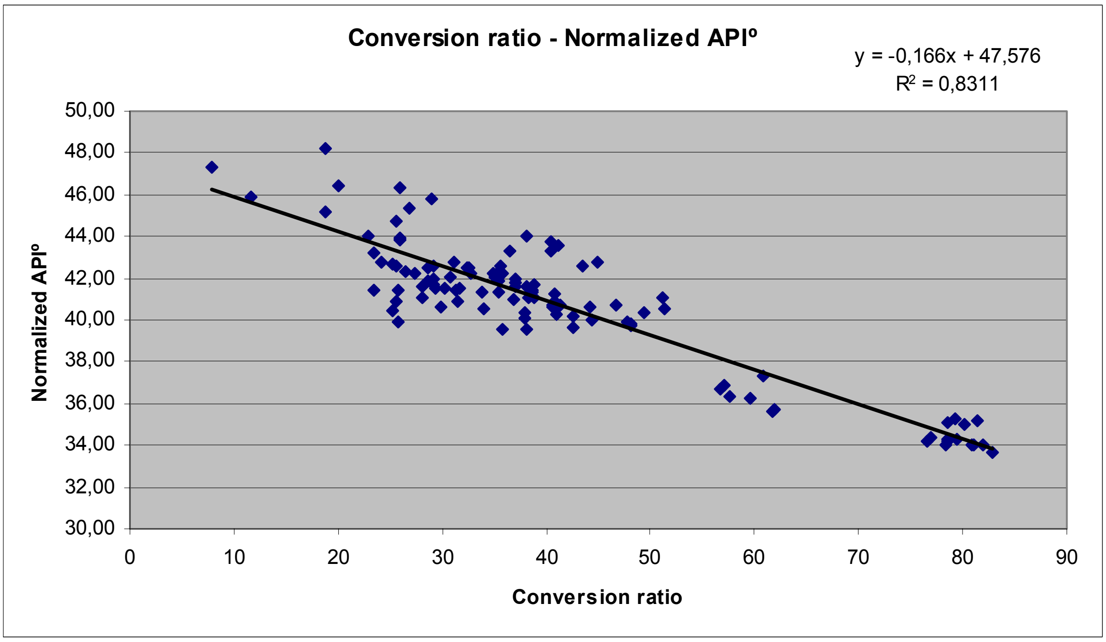

Figure 70: Conversion ratio – Normalized API° (IEA 2005, ENI 2005 and 2006)

This figure shows a correlation between the normalized API° and the conversion ratio.

The formula of the trend line drawn in the plot in combination with the formula for the normalized API, is used to recalculate the API°. The results can be found in 8.5Appendix 6.

To test if the formula of the trend line drawn in the plot can be used to calculate the API°, the results are compared with the measured results. In 8.5Appendix 6 the results of the test can be found.

The difference between the calculated and the measured API° are small, with a maximum average difference of assessed years is 2,7%. France deviated in earlier measurements, again its difference is relatively large, the same counts for Canada and Italy. In paragraph 5.2, it was striking that Italy fall out of the measurement because of a high residual fuel production (>20%), all though the conversion ratio and API° were in line with the countries with a residual fuel production lower than 15% (Appendix 4, Figure 84 underlines this observation).

In the next graph the same values are used but without the countries, regions and/or years which are presumed to be wrong. It is taken that the countries and years with an difference of 3,5% or higher are wrong and taken out the second equation. Taken out are: Turkey, Italy, France, Canada except 2004, Belgium 2004, UK 2001-2004, Spain 2004 and

Netherlands 1994 and 2004. Notice that only Spain of the Mediterranean is still present in this plot. The following graph is the result:

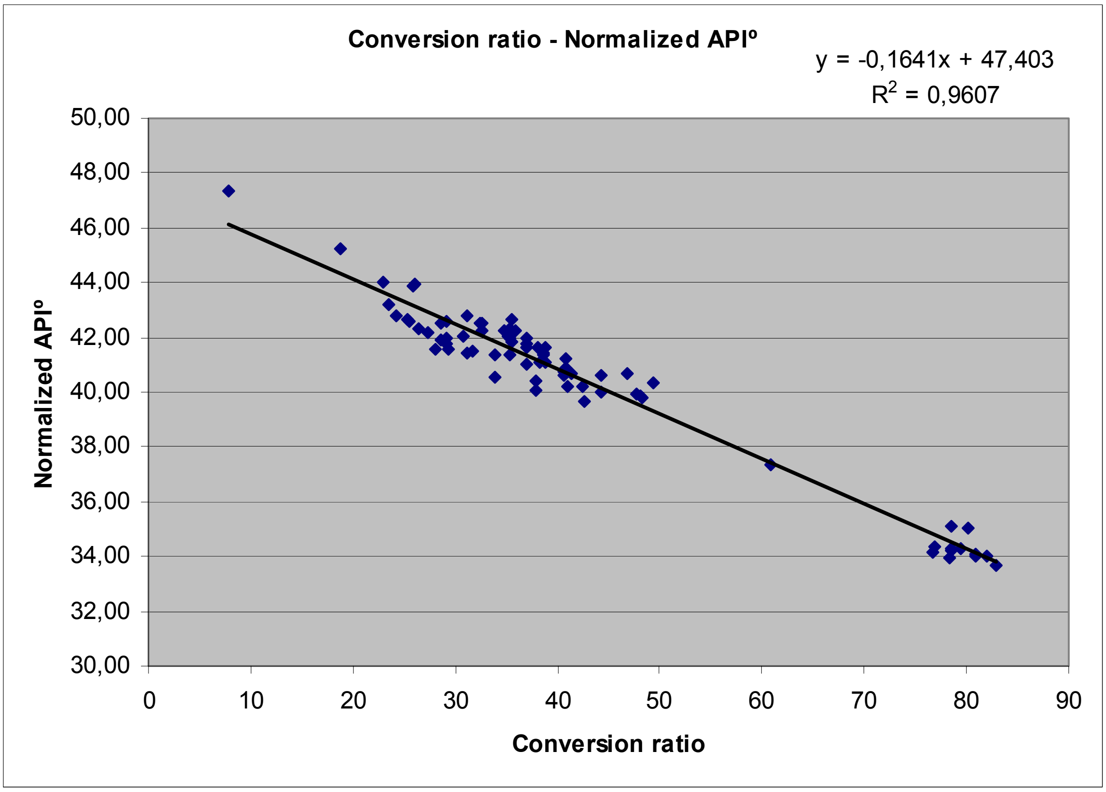

Figure 71: Conversion ratio – normalized API° better fit (IEA 2005, ENI 2005 and 2006)

As can be expected the error is smaller. In the next chapter this equation together with the normalized API° will be used to assess the present and future quality of crude consumed. The blanks in the table below represent the countries and years taken out the plot above, to enhance the R^2 to 0,95. Some are based on the analysis given above other are just taken out because they differ too much from the mean (the equation in this case). In total 78 points instead of 112 were used in this plot.

	1993	1994	1996	1997	2000	2001	2004
NAM	2,40%	1,66%	1,13%	1,91%	0,63%	0,14%	0,23%
US	3,27%	2,23%	0,82%	1,66%	0,25%	0,22%	0,34%
Canada							0,17%
EU-15	0,82%	0,61%	1,76%	0,97%	1,00%	0,80%	0,13%
EU-15+	1,28%	1,26%	2,51%	1,73%	1,52%	1,50%	0,61%
Belgium	1,41%	1,95%	1,52%	1,44%	0,81%	2,86%	
France							
Germany	1,27%	0,37%	0,19%	0,24%	1,10%	0,32%	1,96%
Italy							
Netherlands	2,55%		1,65%	1,22%	1,95%	2,82%	
Spain	0,70%	1,64%	0,08%	0,51%	2,09%	3,21%	
Turkey							
UK	2,37%	0,69%	0,88%	0,87%	2,56%		
Japan	0,55%	1,05%	0,68%	1,07%	0,02%	0,55%	1,15%
Korea		2,64%	1,98%	0,84%	1,85%	1,67%	2,14%
Pacific	1,84%	1,58%	1,12%	1,07%	0,57%	0,84%	0,13%
Average	**1,68%**	**1,42%**	**1,19%**	**1,13%**	**1,20%**	**1,36%**	**0,76%**

Table 62: Difference between the measured API° and calculated API° by equation 2

The table below presents the calculated API° of the second equation denoted in Figure 71.

API	1993	1994	1996	1997	2000	2001	2004
NAM	**32,15**	**32,33**	**32,88**	**32,99**	**32,76**	**32,56**	**32,50**
US	31,88	32,13	32,67	32,79	32,45	32,26	32,34
Canada	34,40	34,65	35,05	35,26	35,58	35,34	34,56
EU-15	**34,81**	**35,27**	**35,40**	**35,50**	**35,35**	**35,25**	**35,39**
EU-15+	**34,74**	**35,12**	**35,26**	**35,32**	**35,22**	**35,07**	**35,22**
Belgium	35,68	36,50	36,11	36,05	35,95	36,34	36,12
France	37,44	37,47	38,43	38,13	38,66	37,68	38,10
Germany	36,22	36,42	36,36	36,67	36,51	35,96	36,15
Italy	33,18	33,16	33,68	33,88	34,32	33,32	33,92
Netherlands	35,37	36,09	36,12	35,82	36,11	36,34	35,54
Spain	33,27	33,90	34,52	34,41	34,64	34,71	35,98
Turkey	33,34	32,71	33,01	32,36	31,83	32,21	33,14
UK	34,16	34,34	34,54	34,53	34,60	34,02	34,01
Japan	34,54	34,38	34,61	34,44	34,67	34,94	34,67
Korea	33,08	33,20	33,20	33,79	33,66	33,49	33,88
Austalia	31,05	30,69	31,55	31,77	31,73	30,79	30,09
Pacific	**34,71**	**34,65**	**34,70**	**34,73**	**34,79**	**34,83**	**34,82**

Table 63: Results of the second equation.

Taking these results, the world crude quality demand now and in the future can be estimated.

5.4 Conclusion

The following equations are good estimators for the API° of crude consumed by the refineries on the basis of conversion ratio and residual fuel production:

Normalized API° = API° * RFPS + API°

The Normalized API° is correlated to the conversion ratio with following equation as a result:

Normalized API° = -0,1641 * conversion ratio + 47,403

As a result the calculation of the API° on the basis of conversion ratio and the residual duel production share the following equation can be used:

$$API^{o} = {}^{(-0,1641 \text{ * conversion ratio } + 47,403)}/_{(RFPS + 1)}$$

These equations are used to estimate the world crude quality demanded denoted in API°. Note that this model not only can predict the API°, but also the conversion ratio and residual production share, as long as two of the parameters are known.

Some API° calculated by the equation deviate more from the API° calculated in chapter 5 than others. Most of these deviations are noticed before the equation was set.
Several comments to this result need to be made:

- The initial calculation of the API° is a raw approximation of the feedstock used in refineries, improving the reliability improves the results of this research. Improvement can be achieved when more detailed information on the actual quality of crude imported instead of (weighted) averages of the imports.
- No statistical research is done. To be able to assess reliability of this method this would be useful.
- Other factors may have an influence as well, incorporating these in the calculation will improve the estimation, the following factors may have an influence:
    - The amount of light products, gasoline, diesel and LPG, may have influence on the conversion and API° of the crude used.
    - Other feedstock than crude used by refiners, for exapmple residual fuel oil or gasoil from other refiners.
    - More insight in the configuration of refineries and there yields may improve the result, more insight in the conversion ratio will be useful.

For a better result of this model the following additional research is useful:

- A statistics analysis on the model, to optimize the coefficient and to assess the value of this model.
- Research on individual refineries and there conversion ratio's, residual fuel production and feedstock to predict feedstock on a smaller scale. Case studies are useful here.

- Better data on the actual crude quality used. More data on the quality of crude produced in countries would improve the results. Most gain can be found on the average API° of crude of countries not reported by the IEA (in this report these qualities are based on the regions average).
- Data on the quality of crude in the different producing countries in the past years can enhance the result of the average quality of crude consumed. The crude quality differs from year to year, which is not incorporated in this report. Past years can be corrected by using older IEA data-cd- roms with average qualities of crude produced in the producing countries.
- Incorporating the change in conversion ratio by incorporating future utility of distilling equipment and the conversion processes added.
- Expanding the model to predict future product yield of for example diesel and gasoline by incorporating different refinery configurations and their typical yields in the conversion ratio.
- Incorporating the ability to increase quality of products, within this model or with other indicators as the sulphur plant capacity, desulphurization capacity etc. to be able to predict the sulphur content of the feedstock.
- Research in demand of particular qualities of crude instead of averages from export countries. The plot given in paragraph 6.1 can be used for this research.
- The following graph may be useful to incorporate the residual fuel within this framework. The diagonal lines represent the level of residual fuel production in percentages. Note that this is a concept, conclusions can not be drawn from this graph.

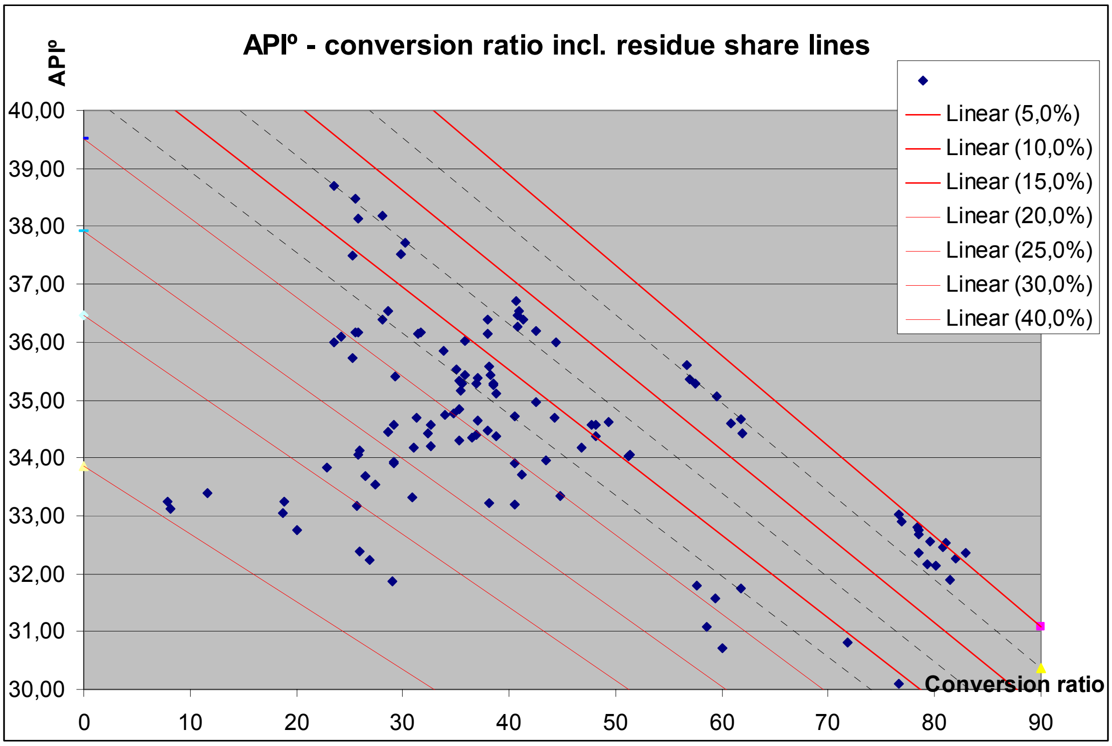

Figure 72: Conversion ratio – API° with the residual fuel production to have more insight in the amounts demanded of particular qualities of crude.

6 The impact of the product market and the refinery industry on the crude market

This chapter will give an overview of the complete value chain. The three of the five strategies for the refinery industry will be assessed to create more insight of the impact these strategies have on the crude market.
First the model of the former chapter will be used to assess the world quality crude consumption taking that the refinery industry is adapting the crude diet to cope with the product market. Than (paragraph 2) the model will be used, but with an outlook on the conversion ratio change, based on the capacity additions described in chapter 4.

6.1 Future world crude quality consumption by changing crude diet

6.1.1 Method used

To estimate the world consumption of crude focused on quality, the two parameters (conversion ratio and residual fuel production share) need to be known for the other regions: Latin America, other Asia, FSU, Central Europe, Middle East and Africa. These regions as such are chosen on the basis of the data available on the conversion ratio.
The IEA reports the production of petroleum products of non-OECD countries until 2002. To be able to perform this analysis and predict the quality of crude consumed in 2010, the residual fuel production and total product production is extrapolated from 1990 to 2010.
It is taken that the conversion ratio will stay the same from 2005 onward, according to the strategy of changing crude diet. The next paragraph will incorporate the new conversion capacity additions.
The production of residual fuel may not decrease as expected here, only the trend is followed. No extra analyses are performed on this matter. Additional analysis on the outlook for consumption of products in the other regions could lead to more optimized results. In 0Table 85 the results of this trend analysis can be found.

6.1.2 The results

Using the equation of chapter 5 the following results are found:

	1993	1994	1996	1997	2000	2001	2004	2005	2010
Asia	32,09	31,99	32,77	32,26	31,83	31,86	*33,39*	*33,02*	*34,02*
Latin America	33,25	31,84	31,86	31,77	31,79	31,28	*31,19*	*31,15*	*31,61*
Africa	34,57	34,71	34,62	34,89	34,50	34,74	*35,23*	*34,04*	*34,37*
Middle East	33,09	33,43	32,97	33,10	33,18	33,28	*33,21*	*33,57*	*33,98*
Central Europe	29,88	30,41	30,89	30,67	30,11	29,81	*29,29*	*29,31*	*29,78*
FSU	31,53	31,03	30,54	30,84	32,17	32,40	32,50	*32,46*	*33,16*
Western Europe	34,77	35,16	35,28	35,35	35,24	35,14	35,25	*35,25*	*35,64*
NAM	32,13	32,34	32,87	33,00	32,81	32,56	32,51	*32,34*	*32,53*
Pacific	34,52	34,41	34,69	34,72	34,69	34,45	34,31	*34,55*	*34,92*
World	**33,22**	**33,32**	**33,53**	**33,57**	**33,51**	**33,36**	***33,67***	***33,69***	***34,34***

Table 64: Results of world quality of crude demanded, the italic qualities are based on predictions of residue production (IEA 2004/2005, ENI 2005/2006)

The following graph shows the quality of crude demand in the different regions, the average quality produced is added to the graph:

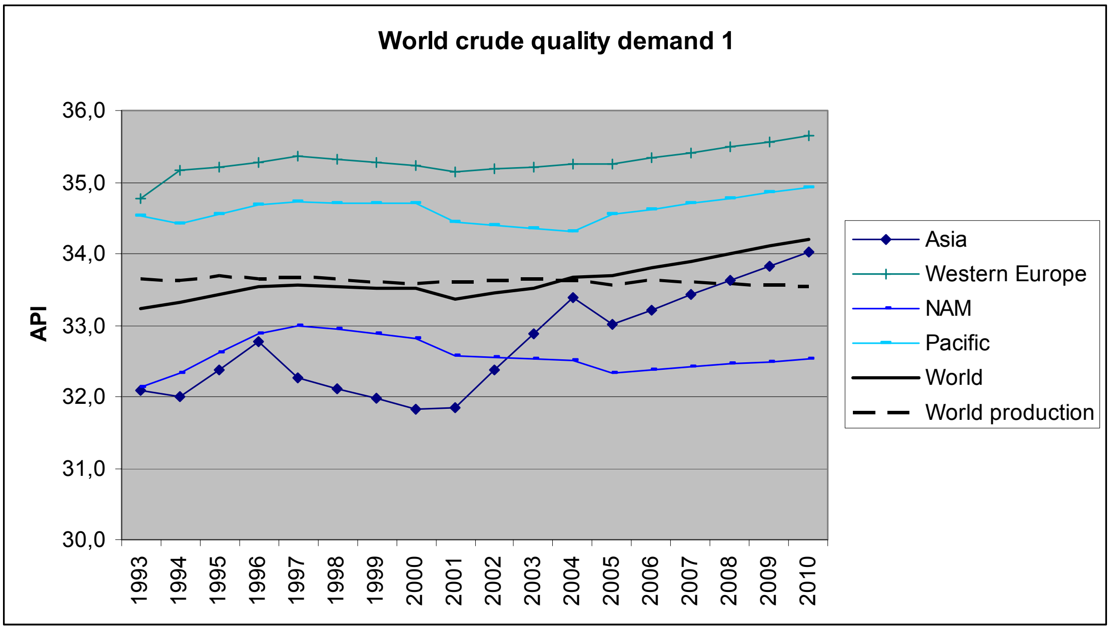

Figure 73: Crude quality demand and average world production

Figure 73 show a higher quality demanded than produced since 2004, this when the outlook starts.

The demand for crude will grow lighter. On average the crude demanded in 2010 will have an API° of 34,3°. The average quality of crude demanded in 2005 was 33,7° when refiners chose to change their crude diet to cope with product market change.

6.1.3 Conclusion

The strategy of changing the crude diet shows a growth in demand of higher quality crude. Moderately the quality of crude consumed is growing. The following remarks can be made:

- Especially Asia demands a higher quality of crude than they used to. The decreasing production of residual fuel and increasing demand of light products have big effects. Increasing the conversion ratio may limit the increase of the quality demanded.
- The consumption, according to this calculation, is of higher quality than produced (chapter 4). Therefore it can be presumed that more residual fuel was produced in 2004 and 2005 than projected by the trend analyses performed on this product.
- In Western Europe, Central Europe, NAM and the Pacific the quality of crude consumed stabilize or rise small amounts.
- Latin America and Africa have a stable quality demand.

6.2 Impact of conversion ratio change on future crude demand

As noticed in chapter 3 the product market structure is changing. More demand of light products and less demand for residual fuel drive refiners to convert more or use lighter feedstock. In addition, regulation on the quality of fuel products has an impact on the product market.
The question addressed here is what change of conversion ratio is needed to avoid increase of the crude quality demand and what the expected change of the conversion ratio has on the crude quality demanded.

6.2.1 The desired and expected conversion ratio in 2010

The desired conversion ratio, sufficing the RFPS in 2010 with the same quality crude as now, can be calculated by using the equation of the model of chapter 5. The crude quality as consumed in 2005 is taken for the year 2010, the estimate of the RFPS was calculated extrapolating the trend since 1990 to the year 2010. The table below denotes the results on the conversion ratio:

Conversion ratio	2005	2010	Difference
Asia	61,0	67,8	6,7
Latin America	48,5	51,5	3,0
Africa	24,2	26,5	2,3
Middle East	22,9	26,2	3,3
Central Europe	60,3	63,9	3,6
FSU	31,1	36,5	5,4
NAM	82,4	83,6	1,2
Western Europe	39,3	42,0	2,7
Pacific	41,7	44,4	2,7
World	**51,4**	**55,5**	**4**

Table 65: The desired conversion ratio (ENI 2005, IEA 2005 & 2004)

The possible increase of the conversion ratio is calculated by the following scheme:

- relative increase of the capacity in barrels is calculated
- relative increase is added to the capacity in tons
- the utilization rate of 2005 is used to calculate the crude runs in 2005
- the conversion ratio is calculated on the basis of tons, the equivalents and the formula of the conversion ratio given in chapter 3 are used.

Treating facilities and revamps of conversion processes are not taken into account. These calculations are approximations to give insight, not to predict the conversion ratio in the future.

Conversion ratio	2005	2010	Added
Asia	61,0	65	4
Latin America	48,5	45	-3.5
Africa	24,2	24	0
Middle East	22,9	27	4
Central Europe	60,3	60	0
FSU	31,1	24	-7
NAM	82,4	86	4
Western Europe	39,3	41	2
Pacific	41,7	42	0
World	**51**	**54**	**3**

Table 66: Expected 2010 conversion ratio (ENI 2005, OGJ 2005)

6.2.2 Results of the conversion ratio change on future crude quality demand

The crude consumed in 2010 is tending to be heavier than the crude consumed now. This is because the conversion ratio does not keep up the slacking demand of residual fuel. To compensate the conversion capacity shortage lighter crude needs to be processed or it must be accepted that more residual fuel is produced than demanded.

The average API° of crude produced is lower than the demand, the conversion ratio will increase with small amounts, therefore it can be expected that the production of residual fuel will grow, and the price of light crude will stay high.

Residual exports to Asia will be more difficult knowing that the indigenous production of this region will grow relative to the demand, needing less import. Other regions may have problems dumping the surplus of residue, and need to enhance their conversion ratio or process lighter crudes. Lighter crudes are not available or very expensive.

Taking the increase of the conversion ratio estimated above, the following crude demand can be expected:

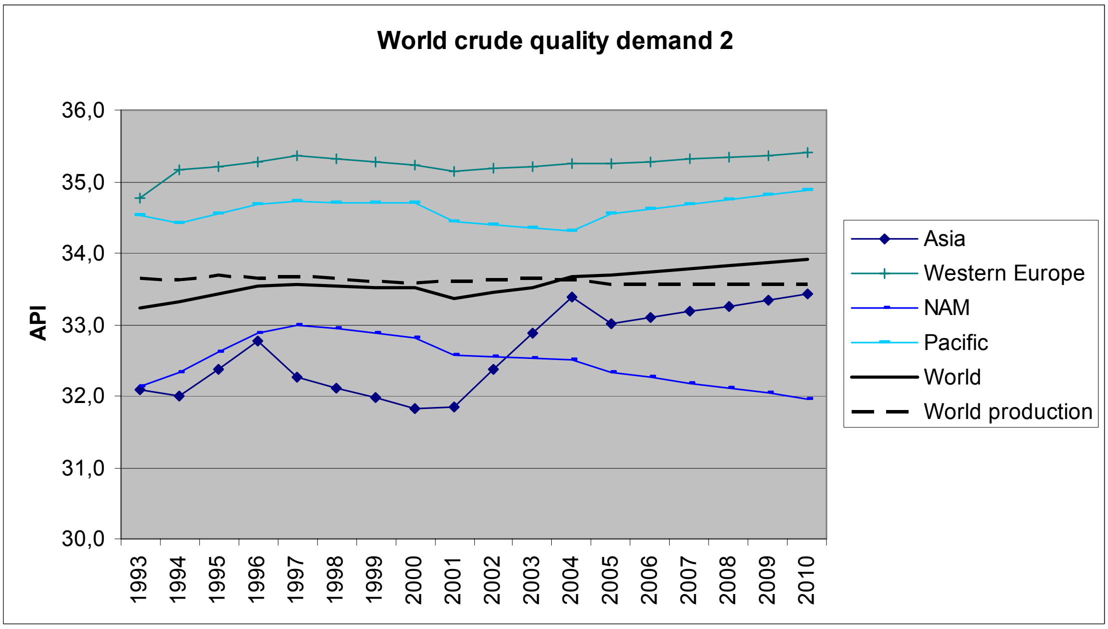

Figure 74: Result of conversion ratio revisit on the crude quality demand in 2010.

API°	2005	2010
Asia	33,02	33,43
Latin America	31,15	32,00
Africa	34,04	34,37
Middle East	33,57	33,47
Central Europe	29,31	29,82
FSU	32,46	34,06
Western Europe	35,25	35,40
NAM	32,34	31,96
Pacific	34,55	34,88
World	**33,69**	**33,91**

Table 67: Average crude quality in 2005 and 2010

The FSU will consume lighter crude than it does now. The average quality of the production is some what heavier, but it is not expected that import of lighter crudes from other regions will occur. This could mean the export will get heavier if the lighter crudes are consumed domestically. This has implications on the import of Europe.

North America and Latin America have less to worry about. The consumption of crude is already heavy. The Middle East demand the quality they produce, therefore no problem in supply can be expected in this region.

6.2.3 The effect on the residual fuel trade streams

The streams for Western Europe, North America and OECD Pacific were analyzed. The streams of the other regions need to be analyzed to give a complete picture on the residual fuel streams. This is not done here. Interpretations are made on the production of residual fuel and import and export streams of the regions which are assessed.

Europe exports most of its surplus production of residual fuel to North America. This will be no problem in the future, if the balances keep the same. It was concluded that North America is able to reduce residual fuel production further and therefore will import residual fuel in the future. Some competition can be expected with Latin America, but European residual fuel might be of better quality because the crude used is of better quality (less contaminants as sulphur and heavy metals).

OECD Pacific has potentially a problem selling its residual fuel. If Asia wants to reduce its residual fuel production it will need to do big investments or process lighter crudes. If these lighter crudes are not found, the residual fuel production will increase, needing less import. The export market for the OECD Pacific is Asia, and therefore this could impose problems. OECD Pacific will need to invest in conversion capacity to reduce the amount of residue produced. More insight in the developments of the product market in Asia is needed to say more about the export possibilities of the OECD Pacific in the future.

North America is the other option for exports. To assess this, more insight in the demand of residue on the West Coast is needed. Europe exports to North America are, more logically, directed towards the East coast and the demand in this region. Competition between Europe and the Pacific is not expected. Competition with Latin America is more likely.

North America will stay a net importer of residual fuel. Several sources may provide the North America with this product.

6.2.4 Conversion ratio and crude demand

Crude quality produced and demanded are approximately the same. Therefore it can be concluded that little surplus of higher quality crude will be supplied. Therefore the swing capacity will of low quality crude, yielding less light products and more residual fuel oil, needing more swing capacity.

The reason for the tight high quality crude market is lack of conversion capacity. Disruptions in the refinery industry have therefore an impact on the crude market. If, for example, the Gulf of Mexico is hit by a hurricane, a large amount of the US refinery capacity and crude production may be disrupted. These refineries are of high conversion, and therefore next to a large amount of distilling capacity a large amount of conversion capacity is not available.

This results in an increase of demand of crude: the conversion capacity must be taken over by distilling capacity with heavier than usual crude (swing capacity from elsewhere). Demand for crude will increase, pressuring the crude production. But since less distilling capacity is available and the distilling capacity is tight, the pressure of demand will be on light crude, which is available, driving the price up even further.

6.3 The effect of product regulation on the value chain

Regulation, demand and production were described in chapter 2, types of refineries were given in chapter 3. In the first section the impact of diesel regulation on the refinery industry and crude market will given, in the second section the same will be done for gasoline. In the third section more insight will given in the developments of regulation on bunker fuels and heavy fuels for inland consumption. In the last section the conclusion will be given.

6.3.1 Diesel: impact of regulation

This report focused on the sulphur content of transportation fuels. Diesel is an important fuel in Europe and in a lesser extend in OECD Pacific. Europe does not produce enough diesel to serve their own market. Imports are needed. To be able to export to Europe, countries must be capable to produce these qualities, or Europe needs to be capable to upgrade imported diesel.

Most imports of diesel are from the FSU and the Middle East. As can been seen from the investments done in treating facilities, it seems that both are adapting their capacity to remove more sulphur. Also the investment in diesel producing equipment (HCC) in the Middle East is striking. The Middle East seems to adapt their capacities to the high world demand of diesel.

Taking that HCC is able to remove vast quantities of sulphur, the Middle East is probably capable of producing a very high quality diesel. The FSU has little HCC capacity, therefore much diesel is probably straight run diesel from the many simple refineries. This diesel needs further treatment, needing additional treating capacity. Taking that Europe imports vast amounts from the FSU, it can be taken that this treatment is done in Europe.
It is difficult to estimate, from this information, if the treating equipment is sufficient to suffice the product quality. Different qualities of crude are used with different amounts of sulphur. HCC processes tend to reduce sulphur anyways, but the amounts are not clear, the same counts for treating fascilities. Not all diesel need to be desulphurized, some can be blended in etc. This makes it very difficult to estimate if the production can suffice the demand of diesel in the future, since so many (mixes of) solutions are possible.

It seems that the Middle East is better capable of producing high quality diesel than the FSU. It is more likely that FSU diesel is further treated than the Middle East diesel. Another option is importing gasoil from the FSU to serve as bunker fuel, to suffice regulation on sulphur content for fuels used in the North Sea and the East Sea and for inland use.

6.3.2 Gasoline: impact of regulation

North America is the major gasoline consumer, importing great amounts from Europe and Latin America. In 2004 24 million tons were net imported. Europe has similar regulation on gasoline as North America, therefore it is more likely that European refineries are able to suffice the regulation for gasoline. Also, Europe consumes a relative light and sweet crude compared to other regions, naturally, the gasoline produced yield less sulphur and need less treating.

Latin America is the second origin of gasoline for North America. It is less likely they will suffice the sulphur restrictions. Only small investments on treating facilities are done. Taking that the crude consumed in this region is sour, much desulphurization is needed to suffice the regulation. North America will probably need to blend in or treat the imported gasoline from Latin America.

Gasoline naturally contains less sulphur than diesel, but gasoline is not produced by the HCC process, but typically by a FCC unit. FCC units do not reduce sulphur content.
Large amounts of treating capacity are added in the US, more than in any region. This seems logic with a crude consumption which is heavy and sour.

6.3.3 Bunker and heavy fuel oil: impact of regulation

As described in chapter 2, regulation on sulphur content in fuel oil for shipping and inland use can have effect on the demand mix of products. As noticed earlier, the heavier the product the more sulphur it contains, therefore HFO contains relatively most sulphur. To remove sulphur is expensive, and often treated fuel oil is used as feed for conversion units to produce low sulphur diesel and gasoline.

Supply of low fuel oil may fall short, but alternatives as marine gasoil, which contain less sulphur because this product is lighter, are present. Marine gasoil is more economical in use (for burning), contains less sulphur and wears out the engine less than fuel oil, saving in maintanance. The result is less demand of HFO or residual fuel. This slacking demand is one of the reasons refineries need to increase their conversion capacity or consume lighter and sweeter crudes. From chapter 4 it can be concluded that most regions consume increasingly more sour crudes, except for Europe. What can be noticed in this respect, is that since the growth of domestic production the crude consumption became sweeter, and since the domestic production is declining the tendency is to consume sourer crude. Anyways, investment in treating fascilities is needed. All regions adapt to the new sulphur regulation, especially Europe, North America, Middle East, Asia and Latin America.

6.3.4 The Sulphur plant capacity as indicator

The trend analysis on sulphur plant capacity shows an increase of sulphur plant capacity at moments that new sulphur regulation is introduced. In North America a clear increase of sulphur plant capacity can be noticed in 2004-2005. The same occurred in Europe before 2000 (1999) and 2005 (2004). The same trend can be noticed in the hydrotreating capacity.

The trend of the sweetness of crude has a similar path as the hydrotreating facilities and the sulphur plant capacity. The increase of sulphur yield of the crude consumed in North America occurs around the same time sulphur plant and the hydrotreating capacity is added. The relationship between the four indicators, regulation introduction, treatment and sulphur plant capacity and sweetness of crude, presented here needs further research.
A start point may be the sulphur plant capacity relative to the primary capacity and the production of diesel and gasoline. The sulphur pant capacity can be a usefull indicator on

the amount of sulphur which can be removed, the amount of gasoline and diesel produced indicates the influence of regulation on the processes and the amounts which need to be removed.

6.3.5 Conclusion

There is an impact of regulation on the investment decisions made. Many investments are made in treating fascilities and the sulphur plant capacity has been growing constantly. Some other regions seem to adapt to the regulation in North America and Europe. Still, Europe and North America will import gasoline and diesel which will need further treatment or blending in with low sulphur blend components. For Europe it seems likely that marine gasoils are imported from Russia and road diesel is produced by their own refineries.
There are no direct signs that sweeter crude is processed to cope with sulphur regulation in Europe. Europe even demands more sour crude than they used to. The sulphur content in crude demanded by North America stay approximately the same, with small tendency to decrease since 2001

6.4 Conclusion

The average API° of the feedstock will grow lighter, if the possibilities are available. The production of crude is not getting lighter, which constraints the demand. Conversion capacity additions will be not enough to cope with trend of lowering the production of residual fuel. The demand of residual fuel will be slacking.

The combination of the constrained of the average quality crude produced and moderate increase of conversion ratio, the residual fuel production will grow, or at least be higher than the demand. This will drive the price of residual fuel down.

The difference between the demand of low quality crude and high quality crude will drive the difference in price up. This difference gives an incentive to sell high quality crude first and use low quality crude as swing production to take care of peaks in demand.

Refineries, which need to cope with product demand, need to increase production in these periods. Light crude yields more light products, and relatively little amount of residue. Taking no swing conversion capacity and no swing capacity of high quality crude are available, relatively more crude needs to be processed to be able to suffice light product demand. Therefore more distilling capacity is needed and therefore more residual fuel is produced.

Little extra distilling capacity is available. Therefore there might be not enough distilling capacity to cope with peak product demand. The refinery industry is vulnerable for production disruptions. In 2010 distilling capacity is added in big amounts. After 2010 some extra swing capacity will relax the market somewhat. The extra distilling capacity may partly be used as swing capacity with the price of increase of residual fuel oil.

There is lack of conversion capacity relative to the quality of the crude produced. The crude demanded is of higher quality in the future than now. The tight refinery capacity in the distilling part increases the difficulties. Therefore extra attention should be given to conversion capacity in the future to temper crude demand growth and avoid a surplus of residual fuel on the market.

OECD Pacific will have most problems selling residual fuel. The Asian residual fuel market will be slacking and will be producing relatively more residual fuel because of the small supply of high quality crude compared to the demand. The Asia crude market drives the quality of crude demand up.

The impact of regulation on refiners can be noticed from the investments made in sulphur plant capacity and hydrotreating facilities. A correlation is noticed the capacities added with the time frame of introduction of regulation. More investment in treatment sulphur plant capacity can be expected around 2007 in North America and 2010 in Europe and Asia.

The impact, of regulation, on the crude quality consumed seems limited, all though some indication are there that the demand in North America is getting some what sweeter. The same may occur in Western Europe and OECD Pacific in 2010.

7 Patterns of change: the questions answered

This chapter will give answers to the questions asked in the introduction. The following questions were asked:

Main question:
What patterns of change can be identified in the regional petroleum product markets and how will this affect the future capability of the refining industry to provide the products in demand and regional crude demand with emphasis on crude quality?

Sub-questions:

4. What is the current relation between the demand structure of the products markets, the production capabilities of the refinery industry and the supply of crude oil?
5. What trends can be identified in the product market, refinery industry and the crude market?
6. What challenges do these trends pose to the operations of the petroleum industry in the different world regions?

First the sub-questions will be answered, followed by the main question and a short evaluation on the results. The answers will be given per world region. Then some recommendation on further research will given followed by a short evaluation of the results.

7.1 Relations between the sub-systems in the value chain

The most important regions are described separately per sub-system (product demand, refinery capabilities and the crude market). The question addressed is the following:
What is the current relation between the demand structure of the products markets, the production capabilities of the refinery industry and the supply of crude oil?
First Western Europe will be described, followed by North America and Asia. Every description will begin with the structure of the product market followed by the refinery industry and the crude supply.

7.1.1 Western Europe

Europe has a diesel oriented product market, followed by gasoline and residual fuel demand. Gasoline and residual fuel demand take about the same share of total product demand. This market structure needs a HCC focussed refinery industry.

The refinery industry is both able to produce gasoline as well as diesel. The HCC and FCC capacity is approximately the same. There is little deep conversion capacity, but a large amount of thermal cracking capacity. Because the percentage of middle distillates produced by a HCC unit (78%, chapter 3.1.3) is higher than the percentage of gasoline (49%) produced by the FCC unit, the diesel production is theoretically higher than gasoline production.

The complexity of the refinery industry is below world average. This corresponds with the crude quality available and the product mix demanded. The share of residual fuel oil is high (16% compared to 6% in North America), and the crude quality in the vicinity is high (North Sea and Africa). The refinery complexity corresponds with the crude quality available and consumed, and the product demand in this region.

The sulphur content of the crude consumed is low. This can be explained by the high API° of the crude consumed, the higher the API° the less sulphur crude (and therefore the petroleum products) contains. If the API° of the crude diet lowers, investment in treating units is necessary.

The major crude suppliers are the Middle East, FSU and North Africa. FSU and the Middle East have average to below average crude quality. Africa on the other hand has relative high quality crude, and balances, together with domestic production, the quality of the barrel. Africa and domestic crude supply disruptions will have more effect on the average API° of the crude diet, because it is more difficult to import light crude than the other qualities.

Overall the petroleum industry in this region seems quite stable.

7.1.2 North America

North American product market is focused on gasoline. Next to gasoline, diesel and other products take an important position. The amount of fuel oil demanded is relatively low. The refinery industry needs to produce a little amount of residual fuel and a large amount of gasoline, needing coker or residual cracking and FCC units.

The refinery industry has a large FCC capacity in combination with high coker capacity. There is relative small capacity of HCC. The gasoline production and residual fuel destruction based refinery industry has the flexibility to consume medium to heavy crude. This corresponds with the region's medium to heavy crude supply.

The major suppliers of crude to North America are Latin America, the Middle East and West Africa. Latin American crude is of low quality, Middle East of average and West Africa crude is of high quality. On average, the domestic crude is of relatively high quality. West Africa crude is important to increase the average API° of the crude diet.

The average sulphur content consumed is high. This corresponds with a high sulphur production capacity.

Overall the petroleum industry seems stable. Decreasing domestic high quality crude supply, which balances the weight of the barrel, needs measures.

7.1.3 OECD Pacific

OECD Pacific product market is focused on diesel. Demand for gasoline and naphtha together is higher than diesel demand. Enough diesel/ gas oil is produced, while a shortage of gasoline and especially naphtha is apparent, needing FCC capacity.

The OECD Pacific refinery capacity has a large capacity of FCC relative to HCC capacity. Future investments should be focussed on increasing FCC capacity. Still the development of the middle distillate products (gas/ diesel oil and kerosene) must be kept in mind.

A small amount of coker capacity, but more capacity of other deep conversion units as the residual FCC is available.

The refinery industries complexity corresponds with the amount of residue (bunker fuel) demanded and the crude consumed.

The crude supplier is the Middle East. Supply disruptions from the Middle East will have a great effect on the crude supply of this region. Diversification of the crude suppliers should be on the agenda. Crude supply may therefore be an issue.

7.1.4 The Other Regions

The other regions are: other Asia, Latin America, the FSU, the Middle East and Africa. The product market in these regions was not assessed, except for the residual production share. Using insights from the model described in chapter 5, the relations are described. The following comments are of interest:

Asia: Conversion ratio is above world average, the share of residual fuel production is below average and crude quality consumption is close to average production.
The conversion capacity seems not fit to produce the amount of residue it wants with crude available in the region (Middle East mostly). Therefore this region seems unstable in its crude demand. This region is unable to match product demand with the current refinery capacity and future investments, and therefore imports increasingly higher quality crude.

Latin America: Conversion ratio is somewhat below world average, residual fuel production share is ample above average and the crude processed is below average. This fits with regions crude supply, which is low quality. Therefore this region seems stable and balanced in respect to residue production, conversion ratio and crude diet.

FSU: Conversion ratio is relatively low, residual fuel production is relatively high, the crude quality consumed is below average which fits with the quality of crude the FSU produces. The crude quality demanded is the average it produces.

Middle East: Conversion ratio is relatively low, residue production is relatively high, the crude diet is according the local production. This region seems ba-

	lanced with respect to crude diet and refinery complexity and residue demand.
Africa:	Conversion ratio is lowest of all regions. Residual fuel production is therefore relatively high, but the crude diet is below the average quality of domestic production. Therefore this region is able to export the more expensive high quality crude and process the lower qualities themselves.

7.1.5 Overall implications of the relations

It can be said that the conversion ratio needs to be increased to cope with the growing demand of light products relative to heavy products. This is most important for the two Asian regions.

North America and Europe are able to diversify its crude origins, Asia may have security of supply problems in the future.

Production of light crude focuses on Africa and Central Asia. These two regions (will) have a key role in the crude market: supply to Asia, North America and Europe to balance the weight of the barrel.

7.2 Trends in the product market, refinery industry and the crude market

This paragraph will address the question: *What trends can be identified in the product market, refinery industry and the crude market?* The paragraph will start with a description of Western Europe, followed by North America and the OECD Pacific. The rest of the world will be addressed last followed by general conclusion of the trends in the world.

7.2.1 Western Europe

Europe has a producing deficit of diesel, which needs to be filled with imports. The demand of transportation fuel slowly shifted from gasoline to diesel. The refinery industry is slowly adapting to the product mix change, all though the production of gasoline is too high for the demand, resulting in a surplus. Still, Europe has a relative high HCC capacity compared to the other assessed regions, which equals the FCC capacity.

The coming year (2007) the autonomous growth of diesel consumption can be compensated by blending 2% bio-diesel in transportation diesel. This is according to regulation in the EU. Increase of HCC capacity will not be necessary to keep up demand, but is necessary to over take demand and reduce the deficit. Imports will not increase.

The traditional origin of diesel is Russia, some is imported from Eastern Europe, North America and Africa. The Middle East made significant investments in treating and diesel production facilities as diesel desulphurisation and HCC. In the future imports from the Middle East may grow.

Regulations on product standards focus on sulphur regulation. The refinery industry focuses investments on treating and desulphurization units.

Because the described shift in the product market, too much FCC capacity is available. Most of the surplus of gasoline produced is exported to North America. Old FCC units which need replacement are replaced by HCC units. FCC capacity will decline in the future, replaced by HCC capacity.

The growth of production of residual fuel, while demand is declining, indicates that the conversion possibilities are used in full, and additional light products are straight run. This can be avoided by processing lighter crudes, which is, apparently, less beneficial than producing more residual fuel.

Regulation on sulphur content in transportation fuels pressures refiners to process sweeter crudes or invest in treating facilities. Investments in treating facilities are done inline with the expected regulation. The trend of sulphur content of crude shows an overall decrease, with the increasing content in 2003-2004, this is not according the introduction dates of regulation, and therefore it seems enough treating facilities are installed.

Domestic crude production is declining, increasing the net crude imports.

7.2.2 North America

Gasoline demand is slowly increasing, just as diesel and other products. Residual fuel demand is slowly decreasing, therefore the demand is getting increasingly lighter.

The refinery industry is investing in HCC and coker capacity. HCC is useful for the production of diesel and desulphurization, not for gasoline production.

Cokers reduce the amount of residual fuel. There are possibilities to process lower quality crudes in the future, and reduce residual fuel production.

To cope with gasoline deficits imports are done. These imports are from Europe and Latin America. These imports will grow in the future because of lack in FCC investments.

Regulation on sulphur content in products may have an effect on the sulphur content in the crude consumed. The crude became sourer, at least since 1990, until 2000. Now the crude consumed is sweeter than in 2000. To keep processing heavier crude, treatment needs to increase to remove the sulphur. It can be expected this will be done to keep the conversion capacity occupied.

7.2.3 OECD Pacific

The OECD Pacific is shifting towards lighter products. Diesel, naphtha, gasoline and kerosene demand grow, residual fuel demand decreases.

Overall, the refinery industry invests little in conversion capacity. The only growth noticed is due to capacity creep. Some investments are done in treating facilities. It seems that most of the investments were already made, when looked at the development of the conversion ratio. The conversion ratio grew rapidly from 30% in 1993 to 54% in 2005, while the utilization grew as well. These investments were made to decrease residue fuel production rather than decreasing crude quality. Residue demand decreased fast during the nineties, the crude diet stayed at same quality level.

The crude quality consumed in this region is above world average, and is quite stable around 34,5º API. It is expected to increase to almost 35º API.

The sulphur content has increased until 2002, than dropped and recovered in 2003 to 2001 level. This is inline with sulphur regulation in Japan.

Crude demand is growing, domestic production will stay approximately the same, increasing imports. These imports need to be of increasing quality to cope with declining residual fuel production. The major supplier is the Middle East which has an average APIº which is lower than demanded. To keep the same quality as of now, imports will need to be of higher quality: from Africa, Central Asia or domestic. The conversion ratio will not increase the coming years, therefore an increase of the quality of crude demanded seems inevitable.

Regulation on sulphur content pose challenges to Australia and Korea in the future. Japan already introduced sulphur regulation. Some investments in treating facilities are made. Still, with the expected lighter feedstock the sulphur content will decrease as well.

7.2.4 The other regions

Asia Asia has a fast growing crude demand, mainly due to growing demand in transportation fuels as gasoline and diesel. This demand growth surpasses the demand growth of residual fuel. More light products and less residual fuel need to be produced. This can be done by increasing crude quality or invest in conversion units.

To cope with overall demand an increase of distilling units is needed. *The investments in the refinery industry are not enough to prevent increase of crude oil quality demand.* Still, much capacity is added.

Latin America Latin America is both crude producer as consumer. It produces more crude than it demands and exports most of the crude to North America, who is capable to process these low quality crudes. The conversion ratio will increase at least until 2010, afterwards, with installing big distilling capacity, the conversion ratio will decrease depending on the utilization of the capacity.

FSU The FSU is a crude producer of on average low quality crude. Central Asia (part of the FSU), mostly *the Caspian region has great production potential of high quality crude.*

Conversion ratio in Central Asia is high, mostly due to low utilization of primary capacity.

Russian refinery industry is not complex. It needs to increase its conversion ratio to reduce its residual fuel production.

The FSU exports products and crude to Europe, which is the main export region. New pipelines will make exports to Asia possible. The FSU has an export problem due to: beyond the lifespan pipelines, small amount ice free ports, limited shipping capacity through the Bosporus street near Istanbul.

Middle East The Middle East plays a central role as crude producer. Asia is the major client, followed by North America and Europe.

The Middle East is increasing its diesel production potential and crude distilling capacity. This fits with the demand structure of Europe and Asia.

Africa Africa has a stable petroleum industry from a refinery and product market perspective. Overall refinery complexity is low, but overall demand is low as well.

Africa is of interest for its crude production potential. Crude quality is, in most regions of Africa, high, the potential of increasing production is high. Countries as Lybia, Angola, Chad, Sudan, Algeria etc. are seen as under-explored. Therefore potential in finding new fields is good.

Due to the good quality, African crude can be very interesting for Asia as well as for Europe. Increasing production in this region compensates for the increase of production in other regions which have an overall low quality (Latin America, Canada, Russia and Middle East).

7.2.5 World

Generally speaking, three aspects are of importance in the world:

- European – North American gasoline situation
- Europe and North America domestic crude decline, especially of the higher qualities crude
- Asia – Europe and in a lesser extent North American high quality crude demand, related to the low spare capacity of the refinery industry.

Most of the European surplus of gasoline is exported to North America. North America has a great shortage of gasoline, and is not investing to resolve this. The production of gasoline in Europe could be the reason for this. The deficit of North America gasoline production started in the beginning of the ’80, same as the surplus of gasoline production of Europe (see Figure 75). The rapid increase of gasoline surplus since 1998 in Europe starts just after the fast increase of deficits in North America. This could mean that European refineries are adapting to the North American gasoline deficits and visa versa. Therefore the strategies of the refineries is to import/ export gasoline instead of invest in new gasoline producing equipment, speculating on the demand shift in Europe.

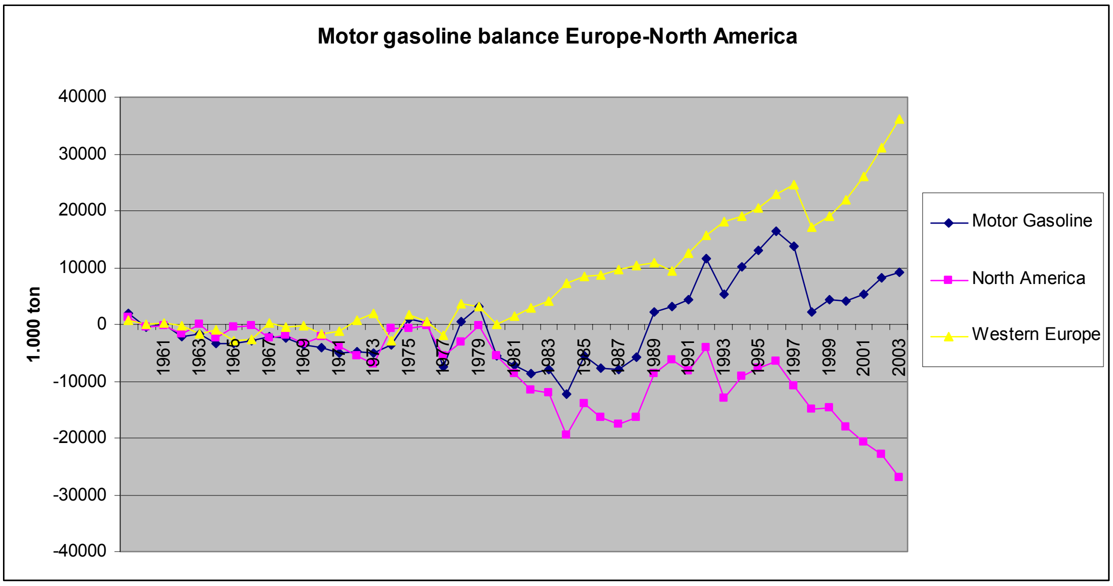

Figure 75: Motor gasoline balance Europe and North America and total balance between the two regions

Crude demand in Asia and Europe will grow lighter. This is not the case in North America, but domestic production of high quality crude is declining. To compensate the decline, high quality crude imports are needed for Europe and North America. Africa and Central Asia are the only two regions with significant production growth potential of light crude oil. Therefore these two regions are or will be of strategic importance.
Asia will need to compensate for the big growth of oil demand and the lack of refinery conversion capacity and distilling capacity.

7.3 The challenges the identified trends pose

This paragraph will answer the third sub-question: *What challenges do these trends pose to the operations of the petroleum industry in the different world regions?* This question will be answered per region as done in the former paragraphs.

7.3.1 Western Europe

The petroleum industry has to cope with five challenges:

1. decrease weight of the refinery output
2. substitute domestic crude with similar quality crude from elsewhere or invest in conversion processes
3. crude demand is getting lighter
4. Fill up diesel deficits and get rid of gasoline surplus
5. cope with sulphur regulation

7.3.2 North America

The petroleum industry has to cope with four challenges:

1. An overall shortage of production of products, especially gasoline

2. crude supply is heavy, product demand is light, therefore a need to keep conversion ratio high
3. High quality domestic crude production is declining, there is need to replace this quality crude
4. high sulphur crude consumption and sulphur regulation challenges the refinery industry to remove sulphur

7.3.3 OECD Pacific

OECD Pacific has three challenges:

1. lighter product market, especially growth in demand of gasoline and naphtha, secure supply
2. Regulation on sulphur content on products challenges the refinery industry to remove sulphur fro intermediate sour crude
3. diversify crude supply to secure supply
4. crude demand is getting lighter

7.3.4 Other regions

In the other regions Asia has the biggest challenges. Still all regions are described here:

Asia	Asia has a fast growing products market, posing capacity problems for the refinery industry. Most of the growth is in transportation fuels as gasoline and diesel. The challenge is to adapt the refinery industry to produce lighter products. To be able to keep up the high demand growth the challenge is to increase distilling capacity and enhance the conversion ratio to preserve current levels of crude quality. Crude demand is growing lighter. The challenge is to lower the crude quality demanded or to keep the crude diet light with other means.
Latin America	The Latin American challenge is to able to process the low quality crude it produces and keep the product market balanced. Next to supplying the product market, crude production is of importance in this region. The ability to increase production and to be able to export these qualities of crude is a challenge (crude is heavy). Diversifying the export to other regions could make them less vulnerable of the US.
The FSU	The FSU has an old petroleum industry infrastructure. To be able to export the crude it produces, the challenge is to enhance its export routes. Almost all export routes are traditionally directed towards Europe, mainly Eastern Europe. There is a need to diversify crude takers. The refinery industry is not capable to reduce the residual fuel production. Because of the little amount of ports, the FSU will have a small bunker market and therefore a small residual fuel demand. The crude quality produced domestically matches the crude consumed, in the future the crude demand will grow lighter.

Central Asia (part of the FSU) produces high quality crude. Their challenge is to export these crudes with out quality loss and interference from Russia.

Middle East The Middle East has more changes than challenges, the challenge is to take advantage of these changes.

The Middle East plays a central role in the crude market and can increase its role on the product market. There is potential of increasing crude production, especially in Iraq.

The Middle East serves the naphtha market of the OECD Pacific. Looking at the investments made they are posing to produce more diesel for the Asian market or the European market.

Africa Africa has great crude production potential. The challenge is to export light crude oil to serve the European and the Asian market. These two regions will compete to acquire high quality oil from Africa.

The refinery industry should focus on processing heavier crude to sell light crudes.

7.4 Answer to the main question

The main question asked was: *What patterns of change can be identified in the regional petroleum product markets and how will this affect the future capability of the refining industry to provide the products in demand and regional crude demand with emphasis on crude quality?* All the aspects in this question were answered in the former questions. Here an overall picture will be presented.

7.4.1 The consumers

Three challenges are posed by the product markets, third is mostly a problem for Europe:

1. *Regulation of sulphur content in products*
2. *Lighter product demand*
3. *Shifting product demand from gasoline to diesel*

From the other side of the refinery industry, the crude supply, challenges are posed. These challenges are as follows:

1. *crude supply is getting heavier*
2. *Domestic production of consuming regions is declining*

The refinery industry is confronted with these challenges. The industry has five strategies to cope with challenges posed by the product market (see chapter 1.1.3):

1. Do nothing and export or import products to balance the market
2. Change crude diet (short term solution)
3. Change operating schemes (short term solution)
4. Revamp refinery processes (medium term solution)
5. Investment in new capacity, distilling as well as conversion capacity (long term solution). Whether early or late investments.

Solutions 2 - 5 can solve the problems in the product market. But challenges of the crude supply limit the options: especially change crude diet. The only option for the refinery industry is do nothing and increase crude runs and produce a surplus of residual fuel, or invest in options 3-5.

For regulation on sulphur content the basic solution is investment in treating facilities, *early investments* come on stream first. The crude demand of most of these regions got some what sweeter, but recovers in the years afterwards due to *late investments*. Vast amounts of treating capacity are added in the regions where regulation is enforced. No problems are projected for this challenge.

Japan has introduced regulation earlier. Overall sulphur content is increasing, but it can be noticed that the sulphur content flattens in the 1997-2000 period. This period is the same period of the first stage of sulphur content regulation in Japan. Japan may function as a good case to predict developments in North America and Europe.

A lighter product demand can be solved by investment or processing lighter crude. Investments in refinery capacity do not suffice, therefore the crude diet is increasingly lighter. This is constrained by the average quality of the crude production. This will pose new challenges, especially to Europe and Asia.

Europe has declining North Sea production which needs to be replaced by about the same qualities to preserve the same product output. Europe is not able to decrease its crude quality demand all though investments in conversion capacity. World demand of light crude will increase.

Adapting the crude diet (making it lighter) may, therefore, be an expensive strategy on the long run, taking that the price differential of low and high quality crude stays high due to a shortage of light crude. Therefore investments in conversion or distilling capacity seem a likely solution. Early investment will increase the benefit of processing cheaper oil relative to higher quality grades.

- Additional distilling capacity is needed to increase crude runs to increase production of light products, with as a side effect more residual fuel production
- Additional conversion capacity to increase conversion and produce less residual fuel and more light products.

Still, too little investments are done with the purpose to process heavier crude. Therefore it could be beneficial to yield profit from the high price differential of low and high quality crude by investing now, and harvest over about 5 years.

7.4.2 Crude supply

Overall the crude quality supply will decline, while the quality demanded will increase. Therefore the projected residual fuel production share will not be reached, as result a residual fuel surplus will be created. Refineries need to find solutions to cope with heavier feedstock:

1. Revamp and/ or Invest to increase conversion capacity
2. find a market for the surplus of residual fuel

The competition to acquire light crudes will increase. The price differential of low and high quality crude will increase as a result of these developments. To cope with this increase it could be wise to invest in new conversion capacity. Some hurry for making these decisions is needed, because of the long period before investments are put into use (about 5 years (Han de Krom)). In the mean time revamping already installed units is very useful.

There is an equilibrium on the crude price and the netback, taking for granted the production of residual fuel. A surplus of residual fuel will be produced to be able to produce more light products from more crude oil to avoid processing expensive light crude. The price of residual fuel will drop, but the demand for heavy crude will rise more than strictly necessary. This has a up driving effect on the low quality crude price.

The demand for crude will increase more than the overall growth in the product market. Because:

- little investment is done in refinery capacity, especially conversion capacity, to cope with the product market.
- To be able to produce the amount of light products demanded, and the conversion capacity is used in full, lighter crude or more low quality crude is needed.
- Taking that the crude quality is declining, the average quality consumed is about the same as the average produced, problems may occur on finding the right quality of crude.
- No more lighter crude can be consumed therefore processing more crude of lower quality is needed, driving crude demand up

Ideally, the spare crude production capacity is of high quality to produce a maximum of light products when peaks or refinery industry disruptions occur. Spare capacity is probably sour and heavy crude because:

- High quality crude yield higher prices and therefore production is maximized to yield maximum profit
- Therefore spare capacity is of low quality
- More crude is necessary to produce the amount of light products needed
- Price of crude rises, as well as for light as for heavy crude
- More spare capacity, as well as of crude production as distilling capacity, is needed to suffice the world product market
- More residual fuel is produced
- More treating is needed to remove sulphur

Conversion capacity is used in full and spare distilling capacity is small in Europe, North America, OECD Pacific and Asia. The problems in the refinery industry is therefore the main driver of problems on the crude market.

To secure future weight of the feedstock of refiners, they can buy crude oil futures. This will increases activity on the paper market. This has an influence on the current oil prices. Crude oil futures will probably increase on light crudes. To balance the feedstock, heavy crudes can be bought on the spot market.

8 Conclusion

8.1 Chapter build up

In this conclusion, the implications of the trends and challenges given in the former chapters will be described. It will be followed by insights it gives on the structure of the petroleum industry as well as the problems within. Then some recommendations will be made on the way the different regions need to cope with the problems they face.

8.2 Implications for the petroleum industry

Most of the developments described in the former chapters have implications on the refinery industry. It can be claimed, overall, that the problems are structural. First of all, the industry is facing a lack of capacity due to lack of investments. Moreover, not enough investments are made; and, therefore, we can predict that the tight capacity will get tighter. Finally, paper markets have a growing influence on the industry, as it has been underscored by Stevens (2005).

The problems, in the context of a lighter product market and heavier crude supply can be summarized in two items:

1. More demand for light crude due to lighter product market;
2. No additional light crude available due to heavier supply and lighter demand.

The increasing demands for lighter crude indicate a shortage of conversion capacity. Because the conversion capacity is used in full, this will be more apparent when demand for products is at a peak or when refinery capacity will be momentarily reduced.

Crude swing production capacity, to cope with fluctuations in demand, is therefore a driver for the short-term crude prices. As we noticed in the introduction, the crude price is very volatile. The following remarks can therefore be made:

1. Crude swing production is small (Stevens 2005, Financieel Dagblad 2006) and of low quality, high quality crude is sold at a premium and not selling is costly;
2. Swing distilling capacity in the refinery industry is scarce: in consuming regions the utilization rate is around 90% or more;
3. Conversion capacity is used in full, no swing capacity is available.

The implications of these problems are as follows:

- Low quality crude swing capacity and total use of conversion capacity leads to more demand of crude to produce the right amount of light products[9], needing more swing capacity, but swing capacity is already small.

[9] Heavy crude yield less light products than light crude, therefore more is needed to produce the same amount. Also more residual fuel is produced.

- Low quality crude swing capacity leads to futures trade in higher quality crudes, which can be balanced with heavier swing crude on the spot market. This increases speculation on the paper market, which drives the crude price up in the longer run.
- Low quality crude swing production pressures the refinery industry to have more spare distilling or conversion capacity, spare distilling capacity is small and swing conversion capacity is not available at all, increasing the urge for high quality swing crude supply, which is, in turn, not available.

To solve these implications, and to reduce the volatility of the crude price, investments are needed in:

1. High quality crude as strategic reserve/high quality crude as swing capacity, and/or
2. More spare distilling capacity, and/or
3. More spare conversion capacity.

The implications of these investments are:

1. Less high quality crude available on the world market when kept as swing capacity.
2. When spare distilling capacity is used, with processing heavier crude, more residual fuel is produced than demanded, and needing more swing crude capacity.
3. Conversion capacity is very expensive, but has no negative implication on product market and the crude market.

Overall, to secure energy supply and stabilize the petroleum industry, a choice needs to be made on the different measures possible. Taking the remarks on the implications made above, it can be concluded that the measures are a trade off between three parameters. These parameters are presented in (Figure 1).

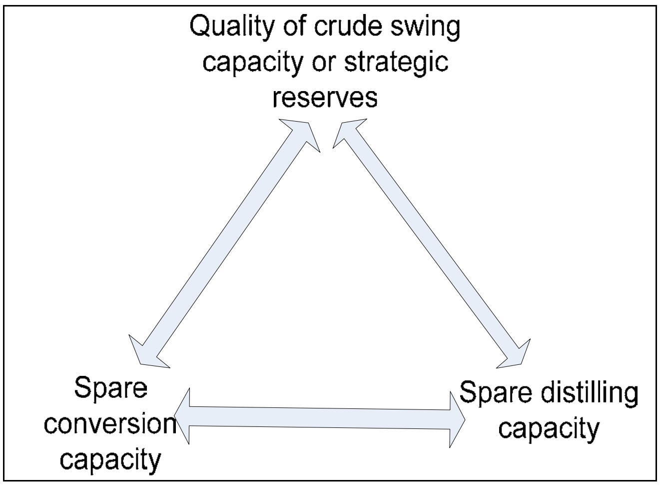

Figure 76: Trade off between distilling and conversion capacity and the quality of crude swing capacity

It can be concluded, with a good level of certainty, that the best way to cope with all these problems is to *increase the conversion capacity*. Since none of the player in the industry is actually engaging in this way, we can predict, therefore, that the problems we have described will stay for the years to come.

8.3 Recommendations

Regions are experiencing specific problems which, in their turn, require adapted solutions. This is due to the different configurations of product market, refinery industry, and crude market. The following recommendations, thus, concern the consuming regions of Western Europe, North America and the OECD Pacific.

8.3.1 Consuming regions

Europe may use domestic high quality crude production as swing capacity to increase security of supply of products. Governments could intervene to control production in order to ensure the security of supply. Therefore, more oil imports are needed, but its quality can be less than the oil used for swing capacity.

It is not expected that new refineries will be build in Europe. The demand growth is too small, and the investment costs stay high. Next to these two factors, environmental regulation makes it even more difficult to obtain a permit from the regulating authorities. Given this situation, it is far more interesting to increase *conversion capacity*:

1. To enhance the flexibility of crude supply due to a bigger mix of possible qualities of crude.
2. To increase the conversion of residual fuel and enhance the production of light products, enough residual fuel will be produced in other regions which can be imported.
3. To increase the ability to process low quality swing capacity crude during peak demand or drop outs.

Whether the North American context is different, solutions provided for Europe may be applicable with some adaptations. North American domestic crude production is relatively of a high quality; but it already processes low quality crude. North America could preserve these qualities for swing crude. Still, this crude is needed to balance the barrel and to decrease the weight of crude.

Residual fuel demand share is small, and, therefore, it may be most beneficial to increase conversion capacity to be able to process even lower qualities of crude. However, the amount of residual fuel produced is already small; much gain can't be found here. Therefore the investments should go in distilling capacity, to process more crude to cope with product deficits. These investments need to come hand in hand with conversion capacity investments to at least maintain current conversion ratio, residual fuel production and crude quality levels.

The OECD Pacific will need both conversion as distilling capacity. The amount of residual fuel produced needs to be reduced, and it would be beneficial to decrease crude quality demand.

Diversifying crude origins will decrease vulnerability to supply disruption in the Middle East.

Overall, the best solution to cope with the main problem of low quality crude supply is to invest in conversion capacity, to lower the quality of crude demanded. This solution needs to be combined with other strategies, depending on the regions specific problems. The advantages of this strategy is, first of all, lower quality crude can be used as feedstock, therefore, lower quality crude can be imported, and/ or, less domestic high quality crude is needed to balance the weight of the barrel. In addition, less crude is needed to produce the same amount of light products, while less residual fuel is produced. Finally, light domestic crude can used as swing capacity to cope with peak product demand or refinery drop outs, which can be a solution to specific regional problems in it self.

8.3.2 Crude producers

The increasing quality of demand gives opportunities for regions producing above world average crude oils. But these regions are also exposed to geopolitics. Basically two export regions are of importance in this respect: Central Asia and Africa.

Export routes from Central Asia to Asia and Europe are under pressure. Russia wants to keep an influence on the neighboring countries, for example Ukraine, Georgia etc.. Therefore, alternative routes from Kazakhstan via Iran to the Persian Gulf, via Turkey i.e. Georgia/ Azerbijan to the Mediterranean, and to the Arabic Sea; through Afghanistan and Pakistan are considered. These routes pose other problems in geopolitics. And finally, the land routes to dense populated regions in China are very long.

Africa is poor, but the high quality crude it produces has changes to increase their wealth. Involvement of China, Europe and the US pose challenges in geopolotics.

West and Central Africa are restless regions. North Africa seems most stable, followed by Central Asia, which mostly has export problems.

Other regions as the Middle East and Latin America are under pressure. The war in Iraq and the high international pressure on Iran, both potentially big crude producers, are good examples. These problems aren't solved in the short run. OPEC (October 2006) is trying to keep the price of crude up by decreasing crude production. Rising taxes on crude revenue and nationalizations of crude production in Bolivia, Venezuela, and Ecuador increase insecurity of supply from Latin America. These regions illustrate the great insecurity of crude supply, which could be one of the reasons for the volatile and high crude oil price.

Recent developments in the petroleum industry initiate changes of all sorts. Therefore it is difficult to predict the outcome. One thing this thesis illustrates is that it is a complex system. The high technology involved increases the risk of investments, constraints by nature on crude quality and climate, could implicate problems. In addition, the petroleum industry is drenched by geopolitics.

8.4 Research suggestions

Residual fuel production share, the conversion ratio and the crude quality (API°) have proved to be good indicators for the structure of petroleum industry in regions (as demonstrated in chapter 5). With these three indicators insight in the state of the industry is comprehendible. To give them more value they need to be researched deeper.

First of all, a better ground for the model is needed by improving knowledge on the quality of the crude used in refineries of known complexity (conversion ratio), and the relation between the notions API° and the residual fuel production share (RFPS), to get better insight in the relation between the two. In addition, statistical analysis on the normalized API° in relation to the conversion ratio is needed to estimate the models worth.
To have a better understanding on the position of residual fuel in relation with the other products, the other products need to be incorporated. Additional research on the product output, by using the typical yields of different types of refineries, as described in chapter 3, will give a deeper insight in the capabilities of refinery industries in different regions.

Different strategies for the refinery industry were given to cope with the changing context. Two were essentially assessed: feedstock change and investment in conversion capacity. Three strategies were not assessed: zero option 'do nothing', revamp existing conversion processes and change operating schemes.

Change operating schemes can be assessed by examining the '*capacity creep'* of refinery capacity. The capacity creep is initiated by optimizing the conversion capacities in place. This can be measured by the trend analysis, but with out the capacity additions by investments. Therefore, the investments in the past needs to be subtracted from the trend identified. After extrapolation the conversion ratio can be calculated and predictions on crude demand may improve.

The next step to expand the model is to incorporate the light fuel oil, the heaviest light product. The price differential of residual fuel and light fuel oil can be used as indicator for the amount of residue produced. Refiners use this indicator to make decisions on the quality of the crude diet.

The amount of extra crude demand, which is due to the lack of conversion capacity/light crudes, may be an interesting topic. Increasing conversion capacity could help reducing the crude demand. The trade offs illustrated by
needs further research.

The possibilities to perform policy to solve the structural problems need to be assessed. Security of energy supply is of national interest. Therefore government involvement may be needed to solve the problems in the petroleum industry. It is wise to take up these problems regionally: European Union, North America and OECD Pacific.But also: China and India for example.

8.5 Evaluation

An attempted to give insight in the demand of crude oil in perspective of the product market, which initiates changes in the value chain, have been made. In addition, events and developments in the crude market have an influence on the product supply.

The three sub-systems in the value chain—the product market, the refinery industry, and the crude market—were brought together in a framework which could model the quality of crude demand. Only two parameters were enough to give insight in the quality of crude demanded; namely the residual fuel production share and the conversion ratio. With this model it was possible to extrapolate the world quality of crude demanded for the future.

By adapting, or improving, the conversion ratio by incorporating the utilization rate of the distilling capacity the notion conversion ratio was improved. This improvement updates the state of the refinery complexity in time, and describes the current possibilities they have.

The model was supported by trend analysis, and the combination gave a good insight on developments in the petroleum market to asses the patterns of crude demand. All questions have an answer and the goal which was set was reached: new insight on the basis of analysis in the petroleum industry.

There is a potential of increasing the scope of the framework of normalized API° by including more products and refinery types next to the conversion ratio and residual fuel. In addition, more specific data on the quality of crude consumed in the assessed regions could increase the models value and increase the worth of the predictions.

The trade offs presented in
can be used for discussion on the developments in the petroleum industry, as well as for physical trade as for price developments of products and crude oil. This report can be a good ground for this discussion.

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Appendix 1 Gasoline and diesel specifications in Europe

Parameters [1]	Unit	Limit [2]	
		Minimum	Maximum
Research octane number		95 [3]	
Motor octane number		85	
Vapour pressure, summer period [4]	kPa	-	60,0 [5]
Distillation:			
- Percentage evaporated at 100ºC	% v/v	46	
- Percentage evaporated at 150ºC	% v/v	75	
Hydrocarbon analysis			
- olefins	% v/v	-	18,0
- aromatics	% v/v	-	35,0
- benzene	% v/v	-	1,0
Oxygen content	% v/v	-	2,7
Oxygenates			
- methanol	% v/v	-	3
- ethanol	% v/v	-	5
- iso-propyl alcohol	% v/v	-	10
- tert-butyl alcohol	% v/v	-	7
- iso-butyl alcohol	% v/v	-	10
- ethers containing 5 or more carbon atoms per molecule	% v/v	-	15
- other oxygenates [6]	% v/v	-	10
Sulphur content	Mg/kg	-	10
Lead content	g/l	-	0,005

Table 68: Environmental specifications for market fuels to be used for vehicles equipped with positive ignition engines, type: petrol.

1) Test methods shall be those specified in EN 228:1999. Member States may adopt the analytical method specified in replacement EN 228:1999 standard if it can be shown to give at least the same accuracy and at least the same level of precision as the analytical method it replaces.
(2) The values quoted in the specification are "true values". In the establishment of their limit values the terms of ISO 4259 "Petroleum products - Determination and application of precision data in relation to methods of test" have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account (R = reproducibility). The results of individual measurements shall be interpreted on the basis of the criteria described in ISO 4259 (published in 1995).
(3) Member States may decide to continue to permit the marketing of unleaded regular grade petrol with a minimum motor octane number (MON) of 81 and a minimum research octane number (RON) of 91.
(4) The summer period shall begin no later than 1 May and shall not end before 30 September. For Member States with arctic or severe winter conditions, the summer period shall begin no later than 1 June and shall not end before 31 August.
(5) For Member States with arctic or severe winter conditions, the vapour pressure shall not exceed 70 kPa during the summer period.
(6) Other mono-alcohols and ethers with a final boiling point no higher than that stated in EN 228:1999.
(7) In accordance with Article 3(2), by no later than 1 January 2005 unleaded petrol with a maximum sulphur content of 10 mg/kg must be marketed and be available on an appropriately balanced geographical basis within the territory of a Member State. By 1
January 2009 all unleaded petrol marketed in the territory of a Member State must have a maximum sulphur content of 10 mg/kg.

Parameter (1)	Unit	Limits (2)	
		Minimum	Maximum
Cetane number		51,0	
Density at 15ºC	Kg/m^3		845
Distillation			
- 95% (v/v) recovered at	ºC		360
Polycyclic aromatic carbons	% m/m		11
Sulphur content	Mg/kg		10 (3)

Table 69: Environmental specifications for market fuels to be used for vehicles equipped with compression ignition engines, type: diesel fuel

1) Test methods shall be those specified in EN 590:1999. Member States may adopt the analytical method specified in replacement EN 590:1999 standard, if it can be shown to give at least the same accuracy and at least the same level of precision as the analytical method it replaces.
(2) The values quoted in the specification are “true values”. In the establishment of their limit values the terms of ISO 4259 “Petroleum products - Determination and application of precision data in relation to methods of test” have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account (R = reproducibility). The results of individual measurements shall be interpreted on the basis of the criteria described in ISO 4259 (published in 1995).
(3) In accordance with Article 4(1), by no later than 1 January 2005 diesel fuel with a maximum sulphur content of 10 mg must be marketed and be available on an appropriately balanced geographical basis within the territory of a Member State. In addition, and subject to the review in Article 9(1), by 1 January 2009 all diesel fuel marketed in the territory of a Member State must have a maximum sulphur content of 10 mg/kg.’

Appendix 2 Residual fuel production share

	1993	1994	1996	1997	2000	2001	2004
NAM	6,9%	6,7%	5,7%	5,5%	5,4%	5,5%	4,9%
US	6,8%	6,6%	5,6%	5,3%	5,2%	5,2%	4,5%
Canada	8,2%	7,5%	7,3%	7,6%	7,0%	7,6%	8,2%
EU-15	19,4%	17,8%	17,2%	17,2%	16,8%	16,4%	16,1%
EU-15+	19,9%	18,3%	17,8%	17,7%	17,2%	16,9%	16,5%
Belgium	21,1%	16,9%	19,5%	20,3%	21,0%	17,6%	19,4%
France	15,4%	13,3%	12,3%	12,1%	12,5%	12,5%	13,2%
Germany	12,3%	11,7%	11,6%	11,0%	11,3%	11,5%	11,7%
Italy	23,9%	22,8%	20,6%	20,2%	20,5%	20,1%	18,6%
Netherlands	20,3%	16,9%	16,7%	16,7%	13,9%	13,2%	15,7%
Spain	27,1%	25,6%	23,3%	24,0%	21,9%	20,4%	15,3%
Turkey	36,3%	34,7%	34,1%	33,2%	33,8%	33,3%	30,2%
UK	16,2%	14,9%	14,3%	14,5%	13,5%	14,5%	14,6%
Japan	21,6%	22,3%	19,3%	19,4%	17,4%	15,6%	15,7%
Korea	39,1%	38,7%	33,3%	29,0%	27,8%	28,0%	25,7%
Austalia	21,6%	22,3%	19,3%	19,4%	17,4%	15,6%	15,7%
Pacific	26,4%	26,7%	23,8%	22,9%	21,3%	20,2%	19,4%

Table 70: Residual production share (IEA 2005)

Appendix 3 Specification of conversion ratio, refinery utility and residue production share

Conversion	1993	1994	1996	1997	2000	2001	2004	2005
NAM	**69**	**69**	**70**	**69**	**70**	**71**	**72**	**72**
US	72	73	73	72	73	73	75	75
Canada	43	44	45	45	45	47	51	52
EU-15	**30**	**29**	**32**	**30**	**33**	**33**	**34**	**35**
EU-15+	**29**	**30**	**31**	**31**	**32**	**33**	**34**	**35**
Belgium	22	23	24	24	21	23	25	25
France	27	27	28	27	26	26	27	27
Germany	37	39	41	39	39	41	41	41
Italy	26	28	30	30	33	34	35	35
Netherlands	27	28	30	31	34	35	38	37
Spain	25	25	25	25	28	28	30	31
Turkey	9	15	15	19	19	19	20	22
UK	42	42	44	43	44	44	45	44
Japan	26	27	30	31	32	33	36	37
Korea	7	7	17	21	24	24	25	25
Austalia	48	51	49	49	52	54	58	58
Pacific	**30**	**33**	**35**	**40**	**48**	**48**	**53**	**54**

Table 71: Conversion ratio (ENI 2005 and 2006)

Utility	1993	1994	1996	1997	2000	2001	2004	2005
NAM	**87%**	**88%**	**91%**	**90%**	**89%**	**89%**	**89%**	**88%**
US	89%	91%	93%	92%	90%	81%	90%	84%
Canada	69%	71%	75%	78%	80%	90%	83%	88%
EU-15	**85%**	**83%**	**89%**	**87%**	**88%**	**85%**	**90%**	**88%**
EU-15+	**84%**	**85%**	**88%**	**88%**	**87%**	**86%**	**89%**	**89%**
Belgium	84%	85%	92%	97%	92%	84%	92%	92%
France	94%	90%	95%	96%	86%	85%	87%	88%
Germany	92%	96%	99%	95%	95%	94%	96%	96%
Italy	69%	69%	71%	75%	88%	76%	80%	78%
Netherlands	91%	90%	95%	92%	92%	91%	97%	95%
Spain	81%	86%	83%	85%	86%	84%	85%	86%
Turkey	72%	69%	74%	75%	67%	72%	78%	81%
UK	90%	87%	91%	90%	90%	84%	90%	85%
Japan	81%	83%	79%	81%	79%	79%	82%	84%
Korea	90%	90%	96%	89%	92%	89%	83%	88%
Austalia	81%	83%	83%	85%	82%	76%	78%	72%
Pacific	**80%**	**80%**	**82%**	**82%**	**80%**	**77%**	**93%**	**89%**

Table 72: Refinery utility (ENI 2005 and 2006)

	1993	1994	1996	1997	2000	2001	2004
NAM	6,9%	6,7%	5,7%	5,5%	5,4%	5,5%	4,9%
US	6,8%	6,6%	5,6%	5,3%	5,2%	5,2%	4,5%
Canada	8,2%	7,5%	7,3%	7,6%	7,0%	7,6%	8,2%
EU-15	19,4%	17,8%	17,2%	17,2%	16,8%	16,4%	16,1%
EU-15+	19,9%	18,3%	17,8%	17,7%	17,2%	16,9%	16,5%
Belgium	21,1%	16,9%	19,5%	20,3%	21,0%	17,6%	19,4%
France	15,4%	13,3%	12,3%	12,1%	12,5%	12,5%	13,2%
Germany	12,3%	11,7%	11,6%	11,0%	11,3%	11,5%	11,7%
Italy	23,9%	22,8%	20,6%	20,2%	20,5%	20,1%	18,6%
Netherlands	20,3%	16,9%	16,7%	16,7%	13,9%	13,2%	15,7%
Spain	27,1%	25,6%	23,3%	24,0%	21,9%	20,4%	15,3%
Turkey	36,3%	34,7%	34,1%	33,2%	33,8%	33,3%	30,2%
UK	16,2%	14,9%	14,3%	14,5%	13,5%	14,5%	14,6%
Japan	21,6%	22,3%	19,3%	19,4%	17,4%	15,6%	15,7%
Korea	39,1%	38,7%	33,3%	29,0%	27,8%	28,0%	25,7%
Austalia	21,6%	22,3%	19,3%	19,4%	17,4%	15,6%	15,7%
Pacific	26,4%	26,7%	23,8%	22,9%	21,3%	20,2%	19,4%

Table 73: Residual production share (IEA 2005)

Appendix 4 Results of the quality of crude produced in barrels instead of tons

Country	Production 2004 (1.000 b/d)		Percentage of total production		API°		Sulphur (wt%)		TAN
	2004	2010	2004	2010					
Algeria	1.900	2.263	24	23	51		0,1		Low
Angola	900	1.747	11	17	35		0,2		Low
Libya	1.607	2.000	20	20	39		1,2		Low
Egypt	700	641	9	6	32		2,2		Low
Sudan	301	533	4	5	32-34		0,1		High
Nigeria	2.508	2.869	32	29	37		0,1		Low
Other Africa	1.216	1.433			40		0,5		
Total/ weighted average	7.916	11.486			'04	'10	'04	'10	
					40	40	0,5	0,5	

Table 74: Crude production and quality in Africa. (BP 2005, Haverly 2005, IEA 2005

Country	Production (1.000 b/d)		Percentage of total production		API°		Sulphur (wt%)	
	2004	2010	2004	2010				
Mexico	3824	4.269	36	32	25		2,1	
Venezuela	2980	3.429	28	26	24		1,9	
Brazil	1542	2.250	15	17	27		0,5	
Argentina	756	897	7	7	29		0,2	
Colombia	551	623	5	5	28		0,7	
Ecuador	535	702	5	5	27		1,2	
Peru	93	81	1	1	23		0,9	
Other	307	444	3	3	25		1,5	
Total/ weighted average	9832	13.139	100	100	'04	'10	'04	'10
					25	25	1,5	1,4

Table 75: Crude production and quality in Latin America. (BP 2005, Haverly 2005, IEA 2005)

Country	Production (1.000 b/d)		Percentage of total production		API°		Sulphur (wt%)	
	2004	2010	2004	2010	2004	2010	2004	2010
USA	7.241	6.628	70%	64%	35		1,1	
Canada	3.085	3.750	30%	36%	30		1,1	
Total/ weighted average	10.326	10.378	100%	100%	'04	'10	'04	'10
					34	33	1,1	1,1

Table 76: Crude production and quality in North America (BP 2005, Haverly 2005, IEA 2005)

Country	Production 2004 (1.000 b/d)		Percentage of total production		API°	Sulphur (wt%)
	2004	2010	2004	2010		
Norway	3.188	2.824	56	57	40	0,2
UK	2.029	1.322	36	27	38	0,5
Denmark	394	661	7	13	35	0,3
Italy	104	115	2	2	33	>0,5
Total/ weighted average	5.715	4.922	100	100	‘04 ‘10	‘04 ‘10
					39 39	0,3 0,3

Table 77: Crude production and quality in Europe (BP 2005, Haverly 2005, IEA 2005)

Country	Production 2004 (1.000 b/d)		Percentage of total production		API°	Sulphur (wt%)
	2004	2010	2004	2010		
Russia	9.285	10.464	84%	81%	31	1,3
Kazakhstan	1.295	1.923	12%	15%	41	0,6
Azerbaijan	318	358	3%	3%	32	0,2
Uzbekistan	152	210	1%	2%	33	>1,3
Total/ weighted average	11.050	12.955	100%	100%	‘04 ‘10	‘04 ‘10
					33 33	1,2 1,2

Table 78: Crude production and quality in the FSU (BP 2005, Haverly 2005, IEA 2005)

Country	Production 2004 (1.000 b/d)		Percentage of total production		API°	Sulphur (wt%)
	2004	2010	2004	2010		
Saudi Arabia	10.584	11.590	43	42	33	2,1
Iran	4.081	4.532	17	17	34	1,7
UAE	2.667	2.910	11	11	39	1,0
Kuwait	2.424	2.782	10	10	32	3,0
Iraq	2.027	3.000	8	7	36	2,2
Qatar	990	1.250	4	5	37	0,9
Oman	785	832	3	3	33	1,0
Syria	536	610	2	2	33	2,6
Yemen	429	658	2	2	39	0,3
Other Middle East	48	47	0	0	34	1,9
Total/ weighted average	24.571	28.202	100%	100%	34*	1,9*

Table 79: Crude production and quality in the Middle East (BP 2005, Haverly 2005, IEA 2005)

***This number represents the value for 2004 as well as for 2010.**

Country	Production 2004 (1.000 b/d)		Percentage of total production		API°	Sulphur (wt%)
	2004	2010	2004	2010		
Australia	541	516	7%	6%	46	0,1
Brunei	211	245	3%	3%	34	0,1
China	3.490	3.490	44%	42%	33	0,2
India	819	869	10%	11%	35	0,1
Indonesia	1.126	991	15%	12%	33	0,2
Malaysia	912	1.032	12%	13%	43	0,1
Thailand	218	284	3%	3%	35	0,1
Vietnam	427	589	5%	7%	36	0,1
Other Asia Pacific	184	217	2%	3%	35	0,1
Total/ weighted average	7.928	8.233	100%	100%	35*	0,1*

Table 80: Crude production and quality in the Middle East (BP 2005, Haverly 2005, IEA 2005) *This number represents the value for 2004 as well as for 2010.

Region	Production 2004 (1.000 b/d)		API°		Sulphur (wt%)	
	2004	2010	2004	2010	2004	2010
Africa	7.916	11.486	40	40	0,5	0,5
Latin America	9.832	13.139	25	25	1,5	1,4
North America	10.326	10.378	34	33	1,1	1,1
Europe	5.715	4.922	39	39	0,3	0,3
FSU	11.050	12.955	33	33	1,2	1,2
Middle East	24.571	28.202	34	34	1,9	1,9
Asia-Pacific	7.928	8.233	35	35	0,1	0,1
Total/ weighted average	77.338	89.315	33,4	33,5	1,2	1,2

Table 81: World crude production with projection on 2010 (BP 2005, Haverly 2005, IEA 2005)

Appendix 5 Model attempts and validation on data

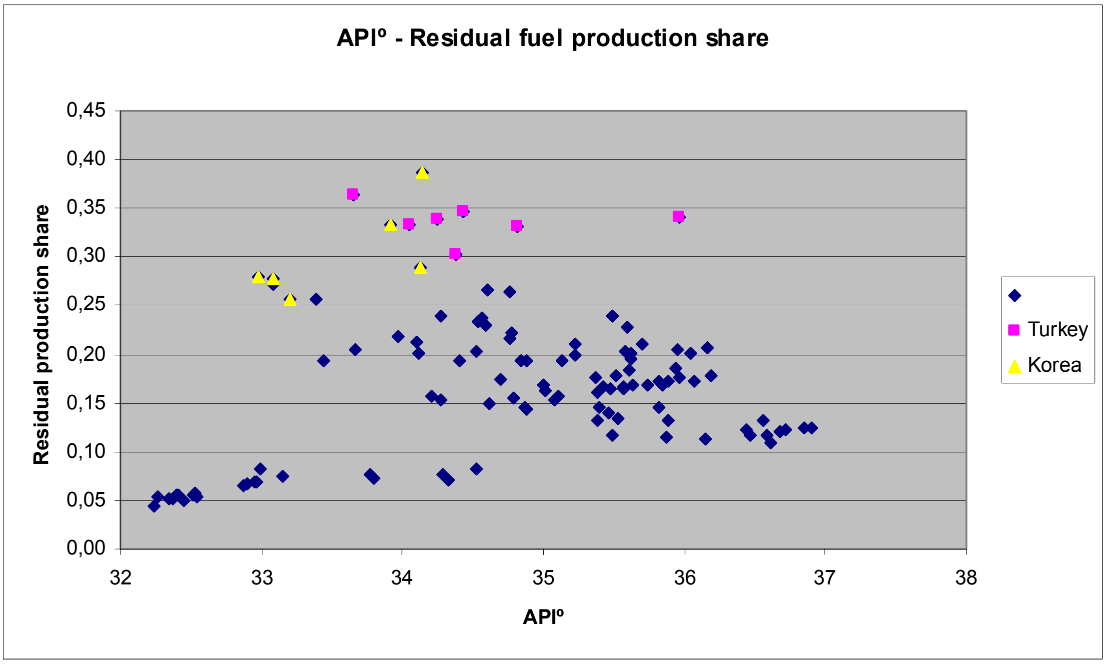

Figure 77: APIº - residual production share

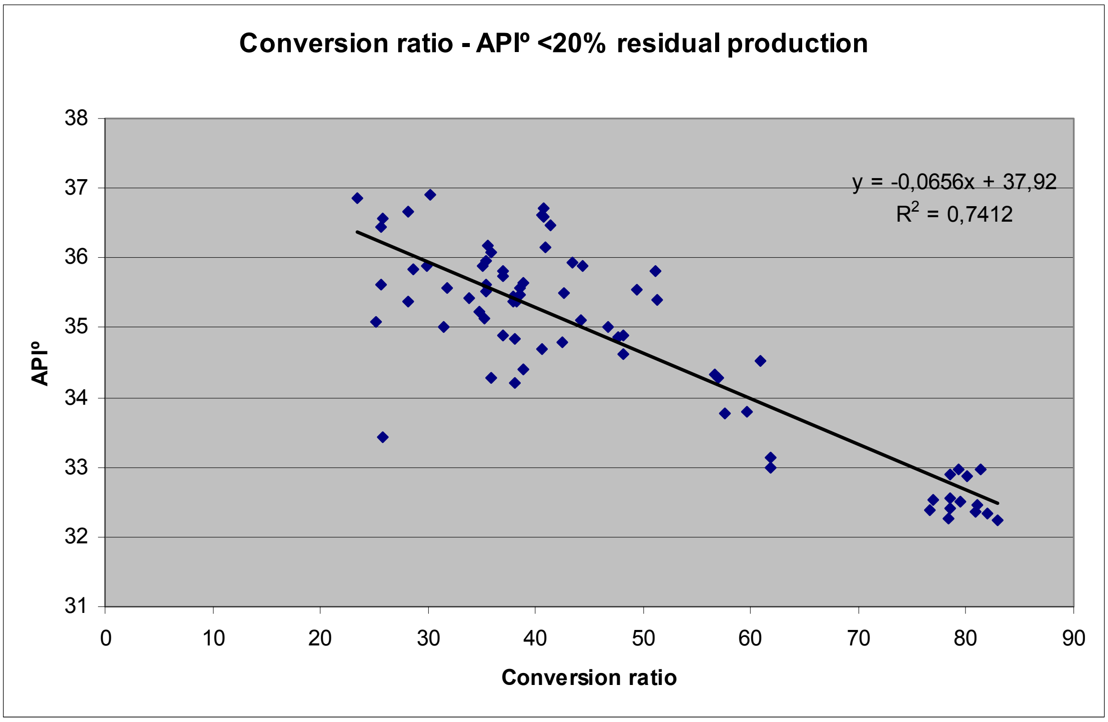

Figure 78: Scatter plot of the conversion ratio and APIº corrected per region and residual fuel production lower than 20% of total

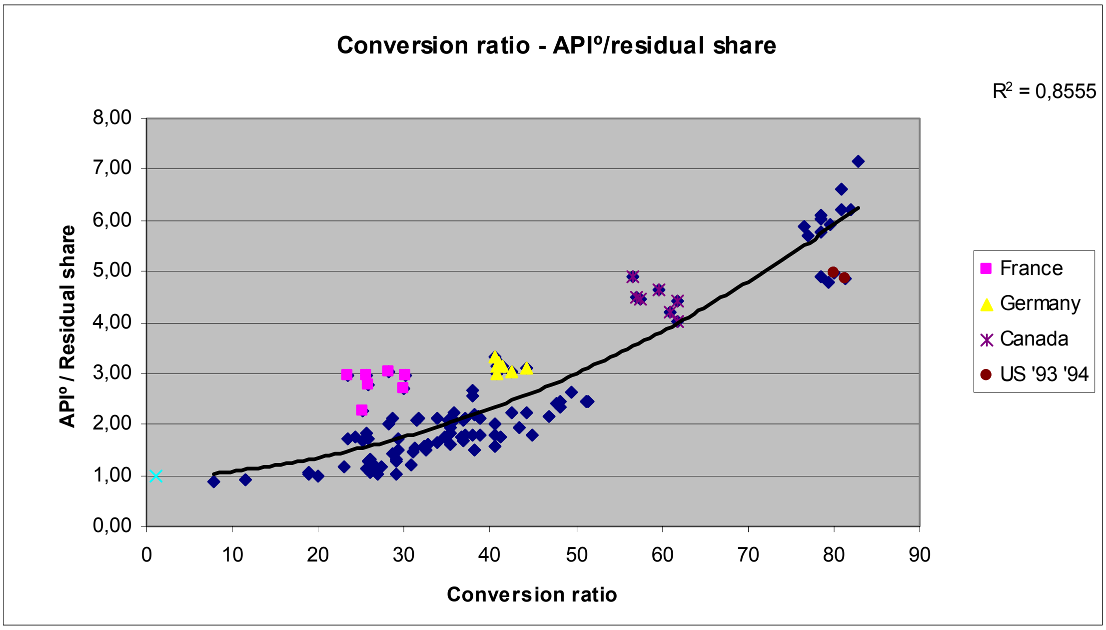

Figure 79: Conversion ratio – APIº / residual fuel production share

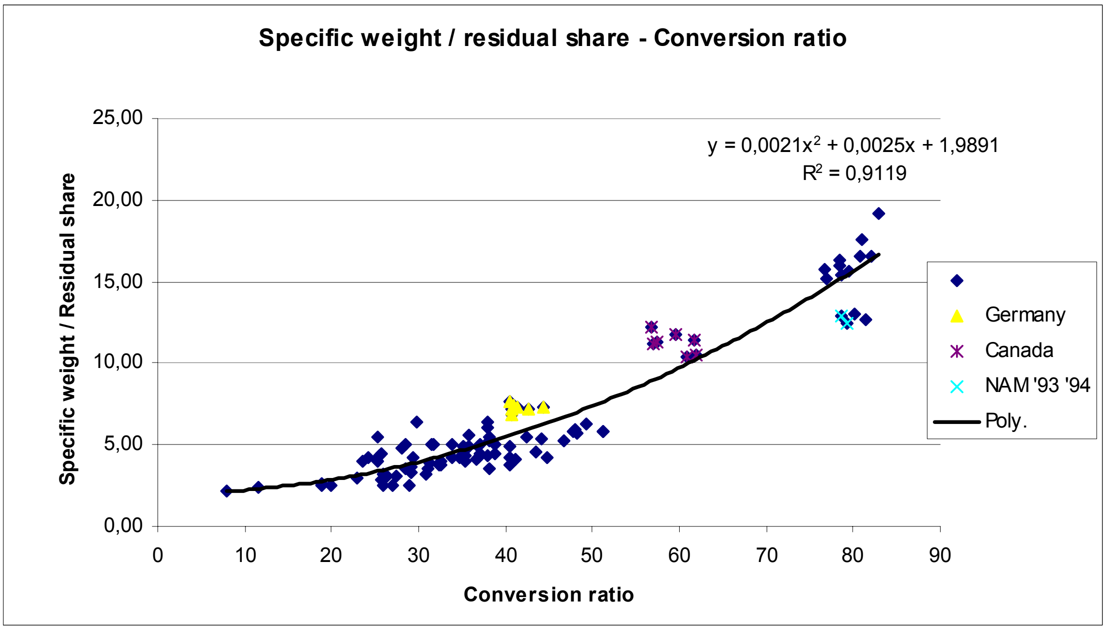

Figure 80: Conversion ratio – Specific weight / residual fuel production share

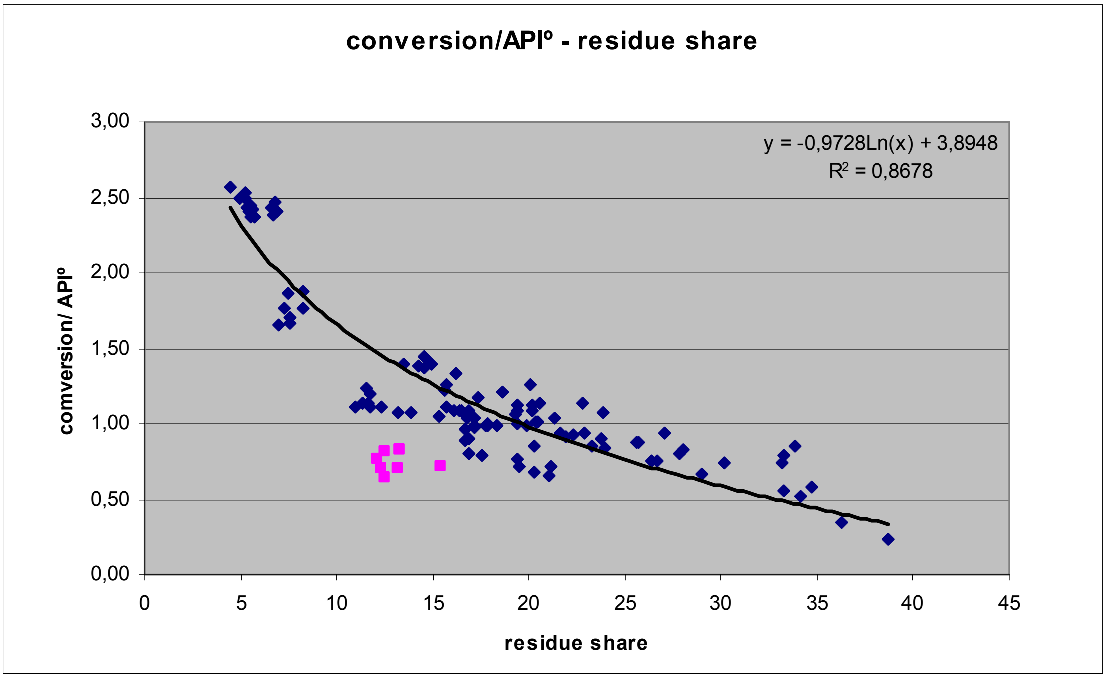

Figure 81: Residual fuel production share – Conversion ratio /APIº

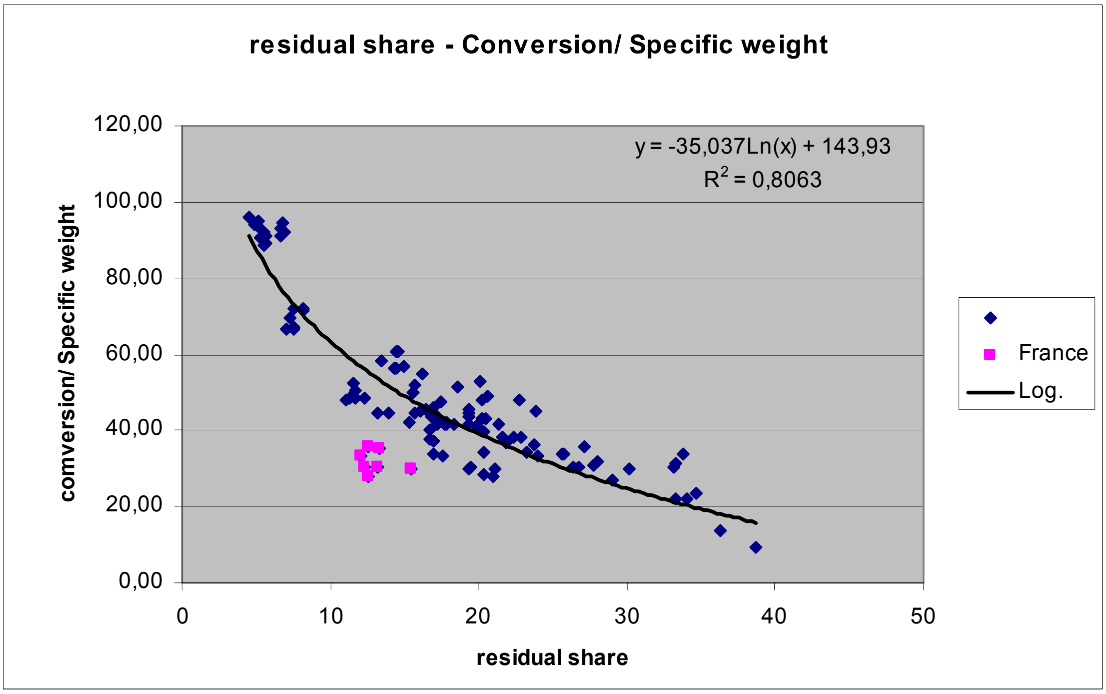

Figure 82: Residual share – conversion ratio / specific weight

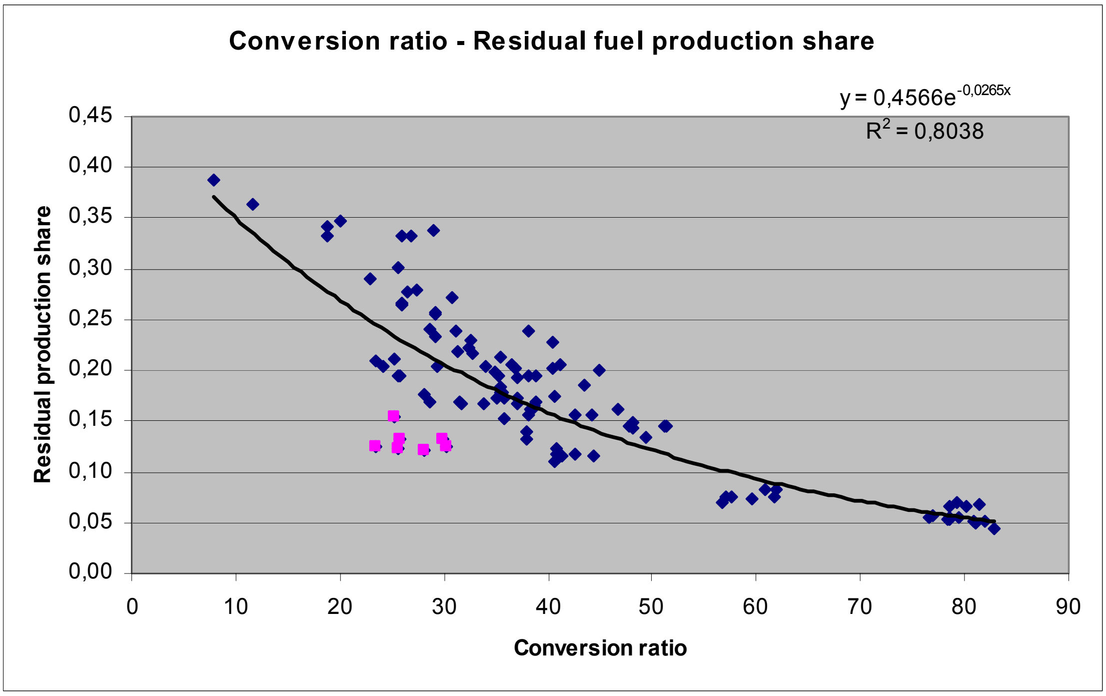

Figure 83: Conversion ratio – residual fuel production share, the purple dots resemble France.

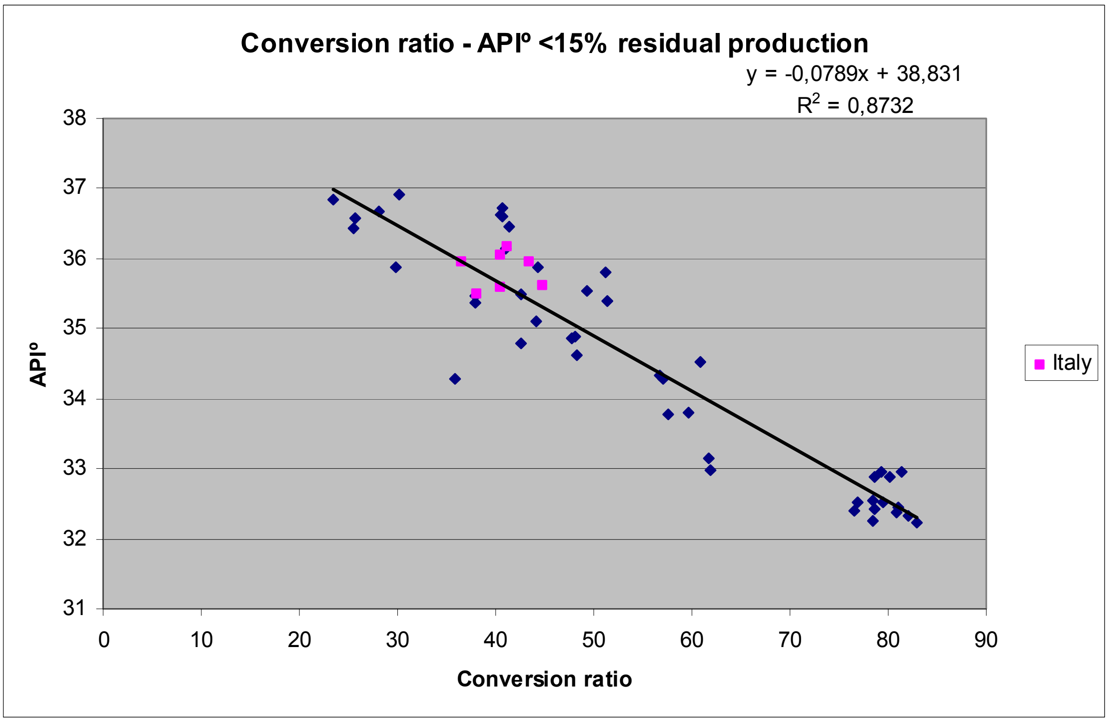

Figure 84: Illustration of the doubt of the Italy data used.

Appendix 6 Model results with all measurements

API° calculated	1993	1994	1996	1997	2000	2001	2004
NAM	**32,19**	**32,37**	**32,93**	**33,04**	**32,77**	**32,58**	**32,54**
US	31,90	32,16	32,70	32,82	32,47	32,29	32,36
Canada	34,47	34,72	35,12	35,34	35,67	35,42	34,64
EU-15	**34,94**	**35,39**	**35,52**	**35,63**	**35,47**	**35,37**	**35,51**
EU-15+	**34,86**	**35,25**	**35,37**	**35,43**	**35,36**	**35,19**	**35,34**
Belgium	35,83	36,64	36,26	36,20	36,09	36,49	36,27
France	37,59	37,61	38,58	38,28	38,82	37,83	38,25
Germany	36,34	36,54	36,48	36,79	36,63	36,07	36,27
Italy	33,30	33,27	33,79	33,99	34,45	33,42	34,03
Netherlands	35,50	36,23	36,25	35,95	36,24	36,47	35,66
Spain	33,40	34,03	34,65	34,54	34,77	34,84	36,11
Turkey	33,50	32,86	33,15	32,49	31,96	32,34	33,27
UK	34,26	34,44	34,64	34,63	34,69	34,11	34,10
Japan	34,67	34,51	34,73	34,56	34,79	35,05	34,78
Korea	33,24	33,36	33,35	33,94	33,79	33,62	34,01
Australia	31,12	30,76	31,62	31,84	31,79	30,83	30,12
Pacific	**34,22**	**34,16**	**34,26**	**34,30**	**34,38**	**34,48**	**34,45**

Table 82: Results of recalculating the API° with the formula given above.

Difference	1993	1994	1996	1997	2000	2001	2004
NAM	0,77	0,53	-0,39	-0,65	-0,23	-0,07	-0,09
US	1,06	0,71	-0,29	-0,56	-0,10	0,05	-0,12
Canada	-1,49	-1,57	-1,32	-1,57	-1,33	-1,14	-0,11
EU-15	0,20	0,13	0,55	0,26	0,27	0,20	-0,13
EU-15+	0,36	0,36	0,82	0,53	0,46	0,45	0,13
Belgium	-0,60	-0,80	-0,64	-0,62	-0,39	-1,11	-2,83
France	-2,52	-1,73	-2,15	-1,61	-1,97	-0,92	-1,69
Germany	0,38	0,05	-0,01	-0,17	-0,48	-0,19	-0,78
Italy	2,20	2,33	2,37	2,05	1,51	2,20	1,91
Netherlands	-0,98	-1,22	-0,68	-0,52	-0,78	-1,09	-1,46
Spain	-0,32	-0,64	-0,12	-0,27	-0,80	-1,17	-1,84
Turkey	0,15	1,58	2,81	2,33	2,29	1,71	1,11
UK	0,76	0,17	0,24	0,23	0,84	1,29	1,71
Japan	0,10	0,27	0,15	0,29	-0,09	-0,27	0,33
Korea		0,79	0,57	0,19	-0,71	-0,65	-0,80
Austalia	10,07	9,74	7,85	7,03	5,83	6,09	8,09
Pacific	0,54	0,45	0,30	0,28	-0,28	-0,37	-0,04

Table 83: Difference between measured and calculated API° equation 1

Difference	1993	1994	1996	1997	2000	2001	2004
NAM	2,34%	1,60%	1,21%	1,99%	0,70%	0,21%	0,28%
US	3,21%	2,17%	0,89%	1,73%	0,31%	0,17%	0,39%
Canada	4,51%	4,74%	3,91%	4,64%	3,89%	3,31%	0,32%
EU-15	0,57%	0,35%	1,51%	0,72%	0,75%	0,56%	0,38%
EU-15+	1,02%	1,01%	2,26%	1,48%	1,27%	1,26%	0,37%
Belgium	1,70%	2,23%	1,81%	1,74%	1,11%	3,15%	8,45%
France	7,18%	4,82%	5,89%	4,38%	5,35%	2,50%	4,62%
Germany	1,04%	0,14%	0,04%	0,48%	1,34%	0,54%	2,20%
Italy	6,19%	6,54%	6,56%	5,70%	4,19%	6,19%	5,31%
Netherlands	2,83%	3,50%	1,92%	1,48%	2,20%	3,07%	4,26%
Spain	0,97%	1,92%	0,35%	0,79%	2,37%	3,48%	5,36%
Turkey	0,45%	4,60%	7,82%	6,69%	6,68%	5,02%	3,23%
UK	2,16%	0,49%	0,67%	0,67%	2,36%	3,64%	4,79%
Japan	0,29%	0,78%	0,43%	0,82%	0,25%	0,78%	0,93%
Korea		2,31%	1,68%	0,54%	2,14%	1,96%	2,42%
Pacific	1,56%	1,29%	0,85%	0,81%	0,82%	1,09%	0,11%
Average	**2,40%**	**2,41%**	**2,36%**	**2,17%**	**2,23%**	**2,31%**	**2,71%**

Table 84: Difference with measurements in percentage without sign (plus or minus) equation 1

Appendix 7 Input data for calculating the world quality of crude demand

Residual fuel production share	1993	1994	1996	1997	2000	2001	2004	2005	2010
Asia	28,3%	26,8%	23,3%	22,1%	17,7%	16,5%	14,0%	13,2%	9,9%
Latin America	29,6%	29,2%	28,1%	27,0%	27,4%	28,0%	27,0%	26,6%	25,0%
Africa	30,6%	31,0%	30,0%	29,8%	29,8%	28,0%	27,8%	27,6%	26,5%
Middle East	33,9%	31,7%	33,0%	32,8%	31,7%	31,1%	30,3%	30,0%	28,4%
Central Europe	32,4%	30,2%	29,2%	29,4%	28,9%	28,7%	28,4%	28,0%	26,0%
FSU	38,2%	37,8%	37,5%	36,5%	31,5%	31,3%	30,9%	30,3%	27,6%
Western Europe	19,9%	18,3%	17,8%	17,7%	17,2%	16,9%	16,5%	16,2%	14,9%
NAM	6,9%	6,7%	5,7%	5,5%	5,4%	5,5%	4,9%	4,8%	4,2%
Pacific	24,1%	24,4%	21,8%	20,9%	19,5%	18,6%	17,7%	17,4%	16,1%
World	**21,9%**	**21,0%**	**19,7%**	**19,2%**	**17,8%**	**17,5%**	**16,1%**	**15,7%**	**13,7%**

Table 85: Residual production share used to calculate the API° of crude consumed (IEA 2004/ 2005)

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

Table 86: Conversion ratio (ENI 2004-2005)

API°	1993	1994	1996	1997	2000	2001	2004	2005	2010
Asia	32,09	31,99	32,77	32,26	31,83	31,86	33,39	33,02	33,43
Latin America	33,25	31,84	31,86	31,77	31,79	31,28	31,19	31,15	32,00
Africa	34,57	34,71	34,62	34,89	34,50	34,74	35,23	34,04	34,37
Middle East	33,09	33,43	32,97	33,10	33,18	33,28	33,21	33,57	33,47
Central Europe	29,88	30,41	30,89	30,67	30,11	29,81	29,29	29,31	29,82
FSU	31,53	31,03	30,54	30,84	32,17	32,40	32,50	32,46	34,06
Western Europe	34,77	35,16	35,28	35,35	35,24	35,14	35,25	35,25	35,40
NAM	32,13	32,34	32,87	33,00	32,81	32,56	32,51	32,34	31,96
Pacific	34,52	34,41	34,69	34,72	34,69	34,45	34,31	34,55	34,88
World	**33,22**	**33,32**	**33,53**	**33,57**	**33,51**	**33,36**	**33,67**	**33,69**	**33,91**

Table 87: Average crude quality in the different world regions

Appendix 8 Interview with Han de Krom of Shell Global Solutions

Han de Krom is a senior consultant crude oil at Shell Global Solution for 5 years now. He used to work with refinery section of global solutions.
Since this thesis is about crude oil from a product market and refinery industry perspective, the expertise of mister de Krom fits.

The conversation was about the complete thesis, but with emphasis on the model on crude oil quality demand. The demarcation of the model as well as the model it self was subject of the conversation.

The conversation started about refineries. Han explained what kind of refineries are available and what kind of processes they have, from simple to complex, to specialized refineries for lubes at bitumen.

After this introduction crude oil was subject opf conversation. Han explained how the decision is made on what crude oil is bought. He explained the different roles of different complexities of refineries within the poule of refineries. He explained that refineries now a day work in poules instead of individual refinery units. Complex refineries are use to increase flexibility and the simple refineries receive a constant 'diet' with a constant output. The diet refers to the crude(s) used as feedstock.

To optimize the crude diet, LP modeling is used. The LP model prescribes a shopping list of crude to be consumed in the coming month. This is shopping list is used to acquire an appropriate crude quality as feedstock. The different crude (5-10) are mixed in such a way the distilling capacity is used optimally for the production of products which can be used for the product market or the other processes (conversion and treating).

Therefore the baskets created in chapter 4 of imported crude oil suffice. It is taken that the crude oil imported are mixed, which is the case.

The shopping list includes a price indication on the worth of certain qualities of crude for the refinery situation. The worth is a derivative of a marker crude (Brent, WTI, Dubai etc.).

The crude diet of a refinery is layered. Some exporting countries require crude sales to be on contract basis and do not sell on the spot market. A part of the diet is therefore fixed to contracts made earlier (long run), a part is fixed by futures and forwards and the last part is filled with crude from the spot market. The complexity of a refinery indicates the flexibility of the refiner. Simple refiners will have a greater amount of fixed feedstock than complex refiners.

The choice of the quality of crude consumed is determined partly by the amount of conversion capacity. *The conversion capacity is used in full*, and therefore need enough feed.

The investments are high for building conversion processes and the gain for using them is high as well. This is an important demarcation for the model.

One of the findings about the refinery industry is the historical fact that Europe has great amount of thermal operations compared to the other regions. The main explanation Han could give was the tradition of North America to install cokers, which can be used to produce gasoline. In essential thermal processes are mild cokers, since the demand in gasoline is not that high in Europe, but demand in diesel, heavy gasoil and bunker oil is, cokers are less necessary. In the North American situation the demand of residue is traditionally lower, central North America for example has little need of bunker oil because of lack of water transport. Destruction of bunker oil is therefore more important in NAM than in Europe, where water transport and therefore the bunker market is more important.

There is no trade of in installing treating processes or HCC processes with reducing sulphur in gasoline and diesel. The gasoline from the HCC should be used as blendstock. This is all very unclear, no further comments are made.

The regions:
There were some doubt about the scale of the refinery poules assessed. The main comment is import and export constraints within a region. When these are low the market should be seen as one. European union and the North America (Canada and US) for example. The interchange of products is high and therefore it can not be presumed that the supply in a country needs to match the demand.
Countries can be taken separately if import and export constraints are big and therefore a independent market.
This would be a problem when the demand of bunker fuel was taken as indicator, this is not the case. The supply is taken as indicator to resolve this question.

Overall it can be said that there is little incentive to transport gasoline across the Atlantic ocean, except when the price difference of gasoline in Europe and NAM is big enough. Han did not know if this was the case. The hypothesis that the European and NAM gasoline market is strongly related is therefore not affirmed.

If heavy fuel oil is too viscous, cutter stock is blended in. Higher quality products production is reduced to be able to sell residue (bunker oil). More constraints on the quality of residue at hand, for inland use, particular seas etc. can influence blending. This is not an issue as of jet.
The residue market is stabilizing, still relatively the bunker market is losing terrain. To cope with this investment is needed in conversion, or process lighter crude.
According to Han refineries are processing crude as heavy as possible, because they are relatively cheap. Refineries are in first instants trying to optimize the existing processes. This is done by using better catalysts, making small modifications of processes (and bigger revamps), and/ or treating to remove sulphur and change feedstock. European refiners are using capacity creep to enhance complexity.

New processes are mostly built to replace old processes; old equipment is kept in use as long as possible until live ends. FCC is replaced by HCC. Treaters are upgraded to mild crackers, mainly hydro treaters in to mild hydro crackers.

Crude oil exploration and production is difficult at this moment. Not much is found, and what is found is of low quality. The price is a good driver for producing these low quality crudes. According to Han the light crudes are produced at maximum capacity.

Another point on the production of crude is enhanced recovery technics. Crude production starts by the natural flow. Mainly, crude gets lighter with maturity of the production field, untill enhanced production methods are used in a later stadium. With these production techniques the heavier end of the field is produced. So, in time the mature fields will get heavier. All in all the crude oil quality is decreasing according to Han, although light crudes from Africa and Central Asia are coming on stream.

Crude quality in a country changes marginally in time. The extrapolation of crude production and the calculation of the weighted average of the crude produced can therefore take the qualities measured in 2004.
When crude quality data in a country is not available, taking the crude quality from a neighboring country or the region is not a problem. This is about true and these countries mostly have small production. Han did not see a problem in this demarcation.

Model:

Three major demarcation were made:
1. Conversion is used at maximum capacity
2. Production of bunker fuel depends on the quality of crude used (API°)
3. API° is a measure for the amount of products it is able to produce

The first demarcation is true, see above.
The seconds is true as well.
The third: according to Han the API° was created as indicator for the volume of fuel the crude has, and is measured between 1-100. This is important aspect of the API° to be able to calculate the normalized API° used in the model.

Insights we got with discussing the model:

- Because the conversion processes are used in full, the crude determines the amount of residue produced (with constant refinery complexity), refineries will be comparable when the API° of crude is corrected to a point that no residue is produced while the conversion processes are used in full.
- The normalized API° is this 0 line of no residue production. Therefore every refinery has its basic quality crude.
- The API° is a measure based on volume, the production share of residue is a measure for volume, therefore these could be used, and the normalized api seem realistic.

A research suggestion is incorporating the fuel oil – gasoil differential, based on price. Gas oil, the heaviest light product, price minus the fuel oil price, the bigger the difference the less residue is planned to be produced (use of lighter crudes)

Note (of wouter): splits in the refinery sector: bigger gasoil-bunker oil differential, more expensive light cruce: invest, process lighter crude, or produce more residual fuel.

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