Oil Refining in the EU in 2015

Prepared by the CONCAWE Refinery Technology Support Group (RTSG):

M. Dastillung (Chairman)

J. Garcia Ocaña
W. Gardzinski
N. Gudde
C. Lyde
A. Mackenzie
P. Nuñez
M. S. Reyes
H-D. Sinnen
R. Sinnen
A. Struck

J-F. Larivé (Technical Coordinator)

M. Fredriksson (Consultant)

Brussels
January 2007

ABSTRACT

In the next decade, the EU refining industry will be facing significant changes in demand both in absolute terms and with regard to the relative calls for its main products. Notably the imbalance between the demand for gasoline and middle distillates is likely to continue to increase. This report explores the possible consequences of these changes on the investment requirement of the EU refining sector as well as the evolution of its energy consumption and CO_2 emissions.

KEYWORDS

Demand, call-on-refineries, energy consumption, CO_2 emissions, capital investment, gasoil/gasoline ratio

INTERNET

This report is available as an Adobe pdf file on the CONCAWE website (www.concawe.org).

CONTENTS

SUMMARY

Changes in demand and crude supply require constant adaptation of the refining tool, taking all factors into account including the availability of dependable import and export sources.

Starting from the existing refining capacities this report explores the changes required in terms of new investments, total economic impact, energy consumption and CO_2 emissions in order to cope with a number of plausible supply/demand scenarios at the 2015 horizon.

From a reference 2015 scenario a number of sensitivities are explored including such factors as, dieselisation rate of the EU car population, improved vehicle efficiency, impact of non-technical measures to reduce demand, introduction of biofuels and availability of gasoline export markets and gasoil/diesel import sources.

The main conclusions are as follows:

> There is adequate primary distillation capacity in Europe to meet the foreseen demand at the 2015 horizon. The way refineries process crude oil must, however, be adapted in order to cope with changes in the product slate, particularly with regards to the relative demands for middle distillates and gasoline.
>
> The gasoil/gasoline production ratio is clearly the single most important parameter determining the process configuration that will be needed. This ratio is affected by many factors such as degree of penetration of diesel cars, relative penetration of alternatives fuels substituting either gasoline or diesel and importantly the continued availability of gasoline export markets and gasoil/diesel import sources.
>
> The main investments required are in hydrocracking and some residue desulphurisation or conversion capacity, particularly in the most extreme scenarios. This has already started as several major conversion projects have been announced in EU refineries.
>
> A continued increase of the gasoil/gasoline ratio would present a very serious challenge to EU refiners in terms of adaptation of their refineries, choice of processes and magnitude of required investments. It would also lead to a further increase of refinery energy consumption and CO_2 emissions.
>
> With the efficiency gap between diesel and gasoline cars set to decrease, there is a possibility that an excessive rate of dieselisation could lead to an increase rather than a decrease of overall CO_2 emissions.

The marginal energy and CO_2 emissions associated with production of road fuels in refineries are dependent on the circumstances, in particular the gasoil to gasoline production ratio. For diesel fuels the variations observed across the three scenarios are small. For gasoline, however, the figures vary a great deal, even becoming slightly negative for high values of the ratio. Under such circumstances, reducing gasoline production does not save any energy or CO_2 emissions in refineries.

1. CONTEXT AND BACKGROUND

Over the years the oil refining system in the EU has developed and adapted to meet the evolving demand, in both qualitative and quantitative terms, while coping with an ever-changing supply of economically attractive crude oils.

The combination of changes in demand and crude supply requires constant adaptation of the refining tool, taking all factors into account including the availability of dependable import and export sources to "balance the books" under acceptable economic terms.

Starting from the existing refining capacities this report explores the changes required in terms of new investments, total economic impact, energy consumption and CO_2 emissions in order to cope with a number of plausible supply/demand scenarios at the 2015 horizon.

We also took this opportunity to revisit the issue of the energy and CO_2 emissions associated with the marginal reduction of road fuels production in Europe. These figures are essential to judge the impact of the introduction of alternative fuels through compared Well-to-Wheels analyses of different fuel pathways.

2. MODELLING THE EU REFINING SYSTEM

This study was conducted using the CONCAWE EU refining model. This model uses the linear programming technique to simulate the European refining system. The model has a library of process units operating modes (yields, product properties, energy use and costs). The EU (+Norway and Switzerland) is represented by 8 regions (see **Table 2**). In each region the actual refining capacity is aggregated, for each process unit, into a single notional refinery. The diversity of actual crude oils is represented by 6 model crudes. Specific other feedstocks can also be imported. The model can produce all usual refinery products. Exchanges of key components and finished products between regions are allowed at a cost. Although ethylene crackers and aromatics production plants belong to the petrochemical rather than refining industry, olefins and aromatics production is included in the model so that the interactions between the two sectors, which is crucial to the understanding and dynamics of the lighter end of the barrel (gasoline, naphtha, LPG) are represented in the modelling.

Given a set premises and constraints (product demands, crude and feedstocks availability, plant capacities and economic data), the model proposes an “optimised” feasible solution on the basis of an economic objective function. The model is carbon balanced and can therefore estimate the impact of changes in terms of CO_2 emissions from both refinery sites and modified fuels when used.

Table 2 The 8-regions of the CONCAWE EU refining model

Region	**Code**	**Countries**
Baltic	BAL	Denmark, Finland, Norway, Sweden, Estonia, Latvia, Lithuania
Benelux	BNX	Belgium, Netherlands, Luxembourg
Germany	GER	Germany
Central Europe	CEU	Austria, Switzerland, Czech, Hungary, Poland, Slovakia
UK & Ireland	UKI	United Kingdom, Ireland
France	FRA	France
Iberia	IBE	Spain, Portugal
Mediterranean	MED	Italy, Greece, Slovenia, Malta, Cyprus

The model was first calibrated with real data from the 2005 base year. The calibration includes small adjustments to the actual plant capacities in order to ensure that the base case is feasible and not over-constrained.

The 2015 scenarios were then run as independent pathways to the future, always starting from the 2005 base case. As a rule the model was required to produce the stipulated demand from a given crude slate, the main flexibilities being crude allocation to each region, intermediate and finished product exchanges and mainly investment in new process units (i.e. beyond the 2005 installed capacities). In line with considerations in section 3.1 the crude diet was kept the same in all cases (45% light low sulphur, 55% heavy high sulphur) only one crude (Heavy Middle East) being allowed to vary to balance the requirements (e.g. for energy).

Comparison of the 2015 reference scenario with the 2005 base case established the need for additional plant capacities, the total cost to refiners of meeting the 2015 demand as well as the impact on energy consumption and CO_2 emissions of the refineries.

The outcome for alternative 2015 cases were compared to the reference case, the differentials giving the extra costs or savings attached to each different future scenario.

This approach assumes that all alternatives can reasonably be envisaged today and that a decision would be made in the short term to go for either one or the other. If, however, one of the cases is likely to be considered as the most probable at least in the short term, there could be “regret” investment if the pathway is changed later on. Note that this would only affect cost and not energy and CO_2 emissions as capacity “installed” in the reference case and not required in the alternative case would simply not be used. Both approaches and interpretation can be equally valid depending on the issue at hand. Wherever appropriate we have flagged whether or not we have taken the regret investment into consideration and for what reasons.

3. EVOLUTION OF OIL SUPPLY AND DEMAND IN EUROPE

In this section we analyse the main historical trends and give a forecast for the next 10 years based on an industry study by Wood MacKenzie (WM). This forecast was used as the reference scenario in the study. Note that all figures are valid for "EU-25+2" i.e. the current 25 EU countries plus Norway and Switzerland.

3.1. CRUDE OIL SUPPLY

Crude oil is a worldwide commodity. Although most grades are traded on a wide geographical basis, consuming regions tend, for logistic and geopolitical reasons, to have preferred supply sources. The favourable geographic location of Europe in relation to light and sweet crude producing regions (North Sea, North and West Africa) has resulted in a fairly light crude diet in the past two to three decades.

North Sea: This is indigenous production for which Western Europe has a clear logistic advantage. Although some North Sea crude finds its way to the US, the bulk is consumed in Europe.

Africa: North African crudes (Algeria, Lybia, Egypt) are naturally part of Southern Europe's “captive” production. West African crudes can profitably go either to North America or to Europe and the market is divided between these two destinations.

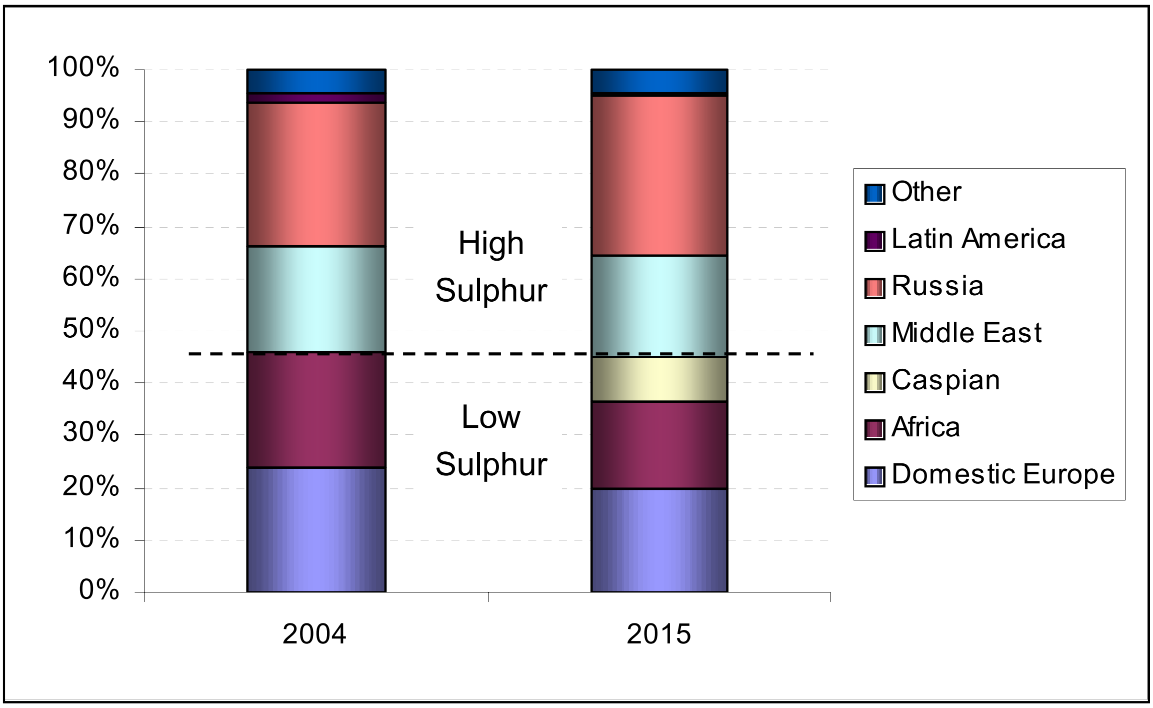
Middle East: The region is an important supplier, mainly of heavy, high-sulphur grades, typically used for the manufacture of bitumen or base oils for lubricant production and by refineries with appropriate desulphurisation and residue conversion facilities.

FSU: Russia is a steady supplier to Europe, partly through an extensive inland pipeline system extending to most former East European block countries. The Caspian basin is poised to become a major producer with Europe as a preferred customer because of favourable logistics.

EU-25+2 consumed about 735 Mt of crude oil an feedstocks in 2005. This is set to grow to 785 Mt in 2015. Although it is considered that supply should be adequate within this timeframe, the sources of supply for Europe will change. North Sea production will decline but other regions such as West Africa and the Caspian basin will take over. These changes in the origin of the crude oil will not significantly affect the average quality and it should be possible to maintain the current proportion of around 45% of sweet (i.e. low sulphur) crudes over the next decade. In the long term though, the quality of world reserves heralds an inevitable trend towards heavier and more sulphurous crudes.

The current and projected European supply is shown **Figure 1**.

Figure 1 Current and projected crude slate in Europe



(Source: Wood Mackenzie)

3.2. PRODUCT DEMAND AND CALL ON REFINERIES

3.2.1. Major demand trends for oil products

Demand for petroleum products is dominated by transport fuels, chiefly gasoline and diesel fuel for road transport and, to a lesser extent jet fuel for aeroplanes. Over the years Europe has seen two main trends.

An ever whiter demand barrel

Europe, like most of the rest of the world, is demanding more and more gasoils and lighter products and conversely less residual fuel oils. This is the result of the tremendous development of land and air transport as well as of petrochemicals while environmental pressures gradually eroded the residual fuel oil market for inland applications (further encouraged by the availability of relatively cheap natural gas).

Marine fuels are the last major outlet for residual fuels although this may in time be affected by legislation to reduce the sulphur content of such fuels (see also CONCAWE report 2/06).

Increasing dominance of "middle distillates" over "gasolines"

The other major trend is the fast growing market for diesel and jet fuel while gasoline demand is gradually eroded. Although it is also noticeable in other parts of the world (e.g. Asia) this trend is particularly strong in Europe where the markets for diesel vehicles and freight transport have been developing apace.

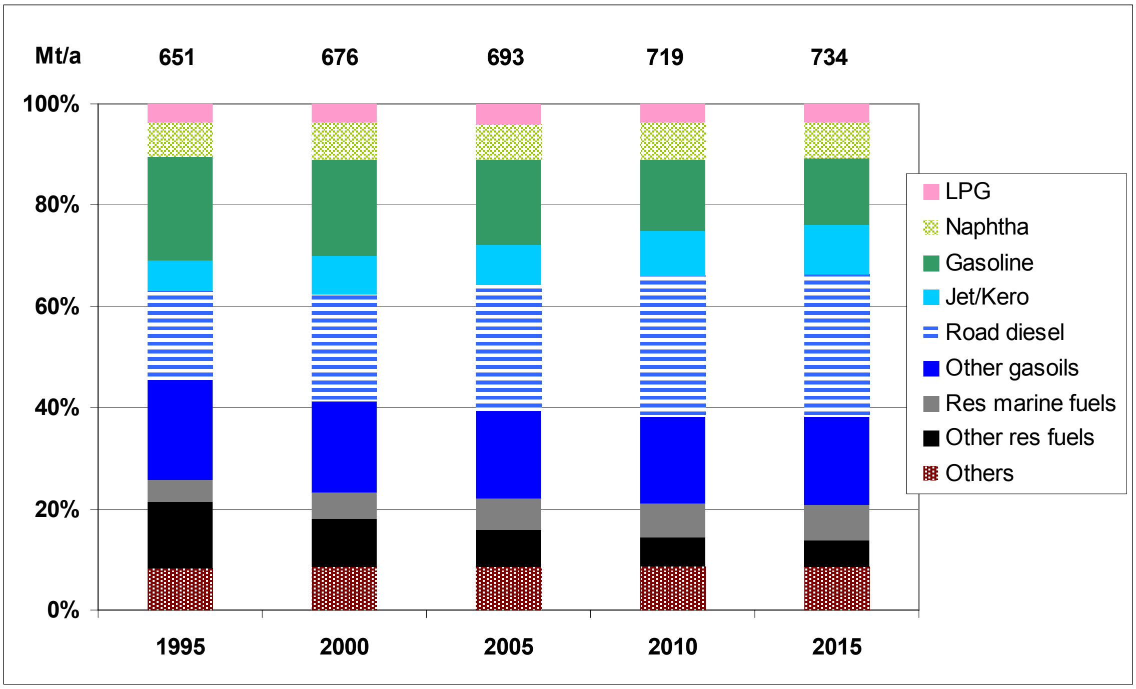
Future demand figures for fuels are impacted by factors such as economic growth but also by public policies in the field of transport and energy. One crucial parameter for the forecasts is the evolution of energy efficiency i.e. how the demand for mobility or heating will translate into a demand for fuel. In this respect the parameter which is subject to the widest forecasts is the rate of improvement of the fuel efficiency of personal cars, indeed a crucial input in view of the dominance of road transport fuels amongst oil products.

3.2.2. Reference scenario

Demand forecast for oil products

We took as reference scenario the forecast in a recent industry study by Wood Mackenzie. **Figure 2** shows the historical demand development over the last 10 years as well as the forecast to 2015.

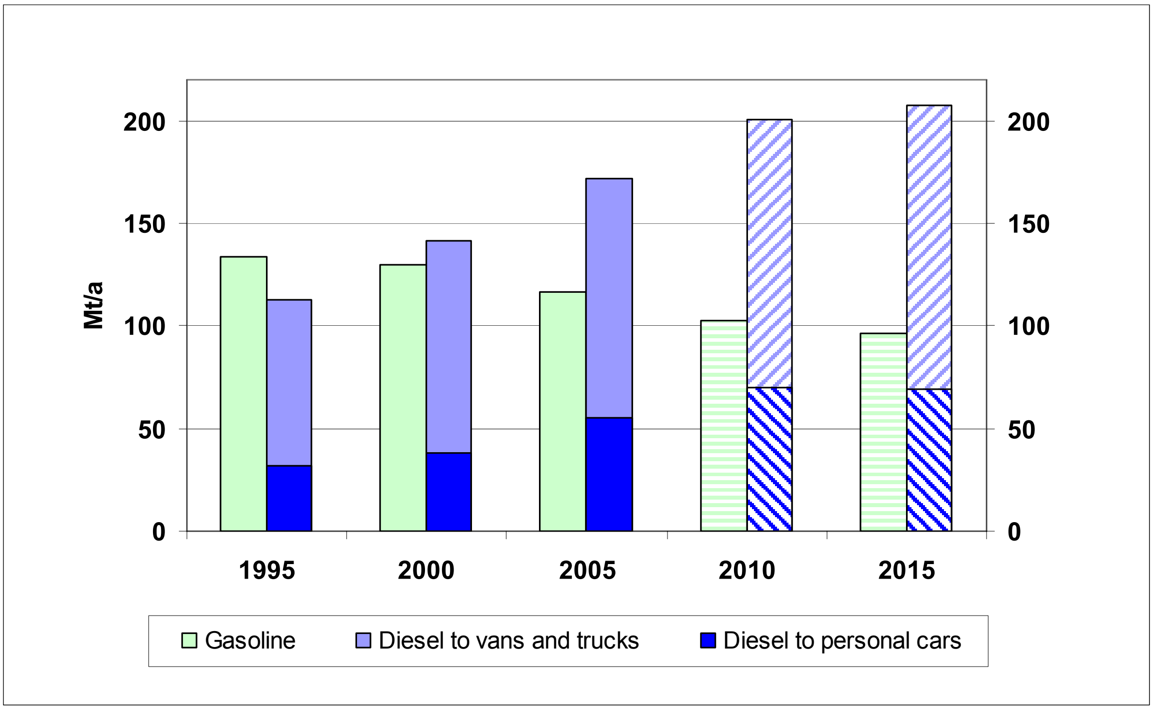
Figure 2 Historical and forecast product demand (EU-25+2)



(Source: Wood Mackenzie)

The figure clearly shows the historical and forecast further "whitening" of the demand barrel, the sharp reduction of the inland residual fuels demand being only marginally compensated by a modest increase in marine fuels. The widening imbalance between middle distillates (gasoils, kerosene, jet fuel) and gasoline is also in evidence with a marked decrease of gasoline demand matched by large increases of the diesel and jet fuel demands only slightly tempered by a slow decline of other gasoils (mostly heating oil). **Figure 3** gives a further split of the diesel demand showing that, although personal cars play a part, a large proportion of the increase is due to freight transport.

Figure 3 Historical and forecast road fuels demand (EU-25+2)



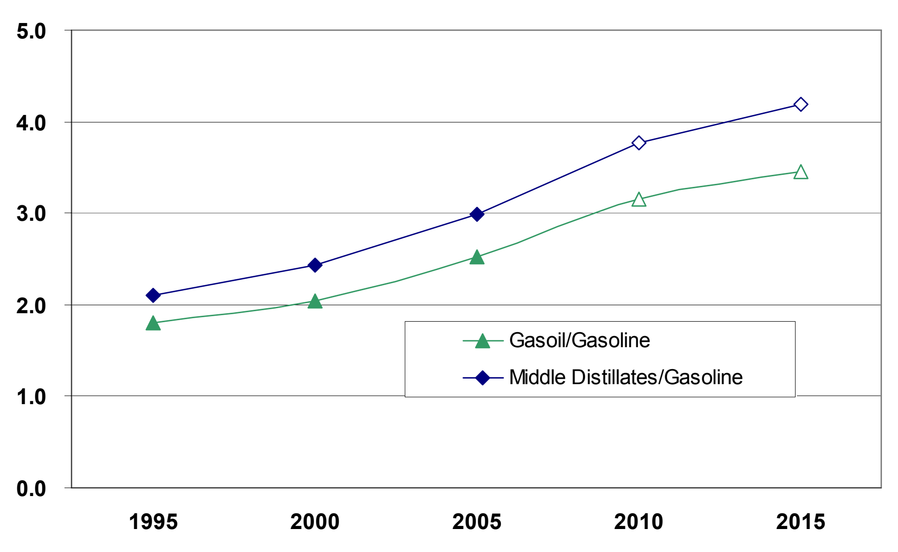
(Source: Wood Mackenzie)

Figure 4 further illustrates the imbalance in the form of relevant ratios i.e. gasoil to gasoline (GO/G) and middle distillates to gasoline (MD/G)[1]. The GO/G ratio has already increased by 50% since 1995 and is set to increase by another 50% through to 2015. MD/G follows the same trend although the rate of change is dampened by the inclusion of petrochemical feed naphtha.

---

[1] "Gasoil" includes automotive marine and off-road diesel, heating and industrial gasoils. "Middle distillates" also includes jet fuel and kerosenes

Figure 4 Evolution of distillate ratios



Call-on-refineries

In order to study the future of refineries one has first to forecast total market demand figures and then to make assumptions as to the proportion of that demand that will need to be met by EU refineries i.e. the "call-on-refineries" (COR). There are two main sources of discrepancy between demand and call-on-refineries.

The first source is trade. The imbalance between middle distillates and gasolines has made it virtually impossible to meet these two demands simultaneously without reverting to trade. The European market for oil products is a subset of a global market in which inter-regional trading is a major activity that allows flexibility responsiveness and economic optimisation. European refiners have therefore been able to "balance the books" by exporting surpluses of gasoline (mostly to the USA) and importing gasoils and jet fuel (from Russia and the Middle East). The continued supply of Europe is crucially dependent on the continued availability of these export markets and import sources.

Based on the most recent IEA final statistics (2003) we have assumed 2005 trade flows as follows:

- 28 Mt/a of middle distillate imports (10 Mt/a finished road diesel, 10 Mt/a heating oil grade, 8 Mt/a jet fuel).
- 22 Mt/a gasoline export (US grade). Note that the 2003 gasoline export figure was lower but, in view of the fast reducing gasoline market we assumed the 2005 figures would be higher.

In the reference scenario we have assumed that these current trade levels are carried forward into the future.

The second source of discrepancy between demand and COR is substitution of refinery products by alternative fuels. The reference scenario does not include any provision for biofuels or other alternatives.

Demand for olefins and aromatics

As mentioned in section 2 our model includes petrochemicals in the form of steam crackers and their associated aromatics separation facilities (producing olefins and aromatics). Demand forecasts for these products, provided by CEFIC[2], are shown in **Table 1**.

Table 1 Demand for petrochemicals

All figures in Mt	2005	2015	Increase
Ethylene	22.7	25.9	14%
Propylene*	14.7	17.6	20%
C4 olefins	2.5	3.2	28%
Benzene	9.4	10.9	16%
Toluene	2.4	2.4	0%
Xylenes	3.2	5.1	59%

* Excluding propylene produced by propane dehydrogenation and metathesis

From the refiner's point of view, the main messages here are:

- Propylene demand is growing faster than ethylene demand. The gap needs to be at least partly filled in by propylene from FCCs. This creates a justification to keep FCC running.

- Demand for xylenes, and to a lesser extent for benzene, is growing while call for toluene is stagnant. As a result some toluene from petrochemicals must be accommodated in the gasoline pool.

3.2.3. Factors affecting demand

The focus of EU energy policy in relation to oil is very much on transport and more specifically road transport fuels. Amongst all oil products, demand for road fuels is also the one that is most likely to be affected by regulatory or societal choices. There are many factors affecting demand

- Fuel efficiency of cars

- "Dieselisation" of the car fleet (i.e. penetration of diesel cars)

- Other technical and non-technical measures to reduce transport demand and/or improve efficiency

On current trends all these factors are likely to lead to a reduction rather than an increase of the COR i.e. the share of the demand that the EU refineries have to produce. Introduction of biofuels, although it does not affect demand in energy terms, has of course a further direct impact on the COR.

---

[2] CEFIC: the European Chemical Industry Council

Accordingly we developed a low road fuel demand scenario based on an analysis of plausible evolution of the above factors. Using both reference and low demand scenarios as anchor points, we then developed sensitivities towards extreme situations in order to test the resilience and robustness of the EU refining system.

The range of variation considered for each factor and corresponding rationale are described below.

Fuel efficiency of cars

The WM study assumed that car efficiency would evolve roughly in accordance with the car manufacturers Voluntary Agreement i.e. approaching the equivalent of 140 g CO_2 /km by 2008. WM further assumed that improvements would continue thereafter, tapering off towards 120 g CO_2 /km in the second half of the next decade.

As an alternative we considered an "accelerated improvement" case whereby 120 g would already be achieved in 2010 and further progress would be made to reach nearly 100 g towards the end of the next decade.

A "slow improvement" case is of course also plausible e.g. including a significant delay in reaching the 140 g target and with a higher ultimate value. This has, however, little relevance in this context as it would simply result in a slower demand decrease and a scenario somewhere in-between the reference and the "low demand".

Penetration of diesel vehicles

In the light of the already existing imbalance between diesel and gasoline the future share of diesel technology in the car market is a crucial parameter that will have a major impact on the future road fuels market.

Today every other car sold in the EU has a diesel engine and diesel cars represent some 30% of the total on-the-road population. If diesel vehicle sales remain at their current level, this will increase to over 40% in 2015. Because cars have a relatively long life time (around 15 years on average on the EU, somewhat more for diesel cars and somewhat less for gasoline cars) the full effect on the fuel demand is delayed at first but it is felt for a long time afterwards.

The WM reference scenario assumes about 35% diesel cars in the total population by 2015 which implies a future reduction of the fraction of new sales compared to today. There is therefore considerable scope for scenarios that foresee higher diesel penetration. For the low demand scenario we have assumed diesel sales increasing to 60% of all new cars by the end of the next decade. This roughly corresponds to a shift of 8 Mt/a from gasoline to diesel. For the extreme scenarios we considered a maximum of 75% diesel sales in 2020.

It is of course also plausible to envisage a serious reversal of the trend towards diesel cars, driven by a/o taxation policy, increasing cost of diesel engines to meet emission limits etc. To gauge the magnitude of the effect we considered an extreme case where diesel sales would slump to 20% of the total by 2015 to stay constant thereafter. This yielded a shift of just under 10 Mt/a from diesel to gasoline compared to the WM reference thereby reducing the diesel/gasoline imbalance.

Other measures

Many measures can be envisaged to reduce transport fuel consumption. They can be from a technical or non-technical nature and aim at decreasing either transport demand or fuel consumption.

Technical measures include efficiency improvement of other road vehicles (particularly trucks), low friction lubricants, low friction tyres as well as driver feedback systems or improved traffic flow management.

Non technical measures include taxation, eco-driving (with voluntary or mandatory training), energy labelling, speed limits etc.

There can be considerable debate as to the potential for such measures to reduce transport demand and eventually fuel consumption. We have based our judgement on a recent report by the Working Group on reduction of energy use in transport under the Joint Expert Group on Transport and Environment convened by the EU Commission [1]. This report considers a wide range of possible measures which, if all successfully implemented simultaneously would result in fuel demand reduction of some 35-40% for cars and 25-30% for trucks. Reasoning that full introduction of all measures was improbable and that some of them may be less successful than foreseen we adopted significantly lower figures as plausible reduction potential viz. 12% for personal cars and 9% for trucks.

Biofuels penetration

Introducing biofuels does not materially affect road fuel demand (at least not in energy terms) but it does have a direct impact on the demand for refinery products. In the next 10 years in Europe, the bulk of biofuels will be provided in the form of ethanol for gasoline engines and FAME for diesel engines. Towards the end of the period, some of the ethanol may be produced from cellulosic material and limited quantities of synthetic diesel may become available. We have assumed maximum availabilities by 2015 of 500 PJ/a of ethanol (18.6 Mt/a or 11.6 Mt/a gasoline equivalent) and 400 PJ/a of bio-diesel (11 Mt/a or 9.3 Mt/a diesel equivalent). Because of the decreasing demand for gasoline and rocketing demand for diesel as well as the limited availability of FAME, the corresponding percentage of ethanol in gasoline is much higher than bio-diesel in diesel. Note that these are not forecasts but very optimistic numbers designed to build a fairly extreme low demand scenario.

Import/export

As in the reference scenario, we have kept the current trade flows also in the low demand scenario. In the sensitivity cases we have included reduction of these trade flows. Note that an increase of these flows is a plausible option but would again simply result in a less stressed case as far as the EU refineries are concerned.

3.2.4. Low Demand scenario

Based on the assumptions described above a plausible Low Demand scenario was built up as shown in **Table 2**.

Table 2 Reference and Low Demand scenarios

Figures in Mt/a	Gasoline	Road diesel			Non-road diesel	Total diesel	Other gasoils	*GO/G ratio*
		Total	*To cars*	*To freight*				
Reference scenario								
Net fossil demand	**96.8**	**206.8**	***68.8***	***138.0***	**30.0**	**236.8**	**96.9**	***3.4***
Low Demand scenario								
Impact of "Accelerated" car efficiency improvement + increased "dieselisation"	-13.8	6.2	*6.2*					
Other policies and measures	-10.0	-23.0	*-9.0*	*-14.0*				
Net demand	73.0	190.0						
Impact of biofuels	-11.0	-9.0						
Net fossil demand	**62.0**	**181.0**			**30.0**	**211.0**	**96.9**	***5.0***
External trade								
Exports	21.9							
Imports						-10.3	-10.0	
Net Call-On-Refineries								
Reference scenario	**118.7**					**313.4**		***2.6***
Low Demand scenario	**83.9**					**287.6**		***3.4***

All other product demands were kept constant. As a result the "conversion intensity" is lower in the low demand scenario than in the reference as the refineries are required to make a smaller proportion of light products.

Clearly this scenario represents a big change in production requirement for the refineries. The GO/G ratio increases from 3.4 to 5.0 in terms of demand. Even with the dampening effect of trade, it increases from 2.6 to 3.4 in terms of COR.

When comparing the Reference and the Low Demand scenarios one can therefore expect to witness the combined impact of lower demand and lower conversion intensity counterbalanced by the higher GO/G ratio.

3.2.5. Sensitivity to gasoil/gasoline ratio

Starting from the two 2015 core scenarios (Reference and Low Demand) we built sensitivity cases geared to studying the impact of the GO/G ratio. In this context the main factors are:

- The rate of penetration of diesel cars (the "dieselisation" of the vehicle park),
- The extent to which the current trade flows can be maintained or increased.

In order to separate the effect of demand level from that of GO/G ratio, we used combinations that resulted, in each series, in an approximately constant total gasoline + diesel call-on-refineries. With regards to changes in dieselisation we consistently considered a 10% decrease in fuel consumption (in energy terms) when changing from gasoline to diesel i.e. a reduction of 1 Mt of the gasoline demand is compensated by a 0.9 Mt increase of the diesel demand (See also section 4.3).

For completeness sake we also added a few sensitivity cases around the 2005 Base scenario. The resulting combinations used for the sensitivity analysis are listed in **Table 3**.

Table 3 Sensitivity cases

Figures in Mt/a	G	GO	G	GO	G	GO	G	GO	G	GO	G	GO	G	GO	G	GO
	Base		B1		B2		B3									
Dieselisation	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0								
Import(-) / export(+)	**22**	**-20**	27	-25	12	-10	2	0								
Demand	**117**	**294**	117	294	117	294	116	294								
COR	**139**	**274**	143	269	129	283	119	293								
GO/G production	***2.0***		*1.9*		*2.2*		*2.5*									
	Reference		R1		R2		R3		R4		R5		R6		R7	
Dieselisation			14.8	-13.4	14.8	-13.4	10.0	-9.0	-13.3	12.0	-4.0	3.6	-13.5	12.1	-13.7	12.3
Import(-) / export(+)	**22**	**-20**	32	-30	22	-20	22	-20	22	-20	16	-14	14	-13	5	-4
Demand	**97**	**334**	112	320	112	320	107	325	83	346	93	337	83	346	83	346
COR	**119**	**313**	144	290	134	300	129	305	105	325	109	323	97	333	89	342
GO/G production	***2.6***		*2.0*		*2.2*		*2.4*		*3.1*		*3.0*		*3.4*		*3.9*	
	Low demand		L1		L2		L3		L4		L5		L6		L7	
Dieselisation			14.0	-12.6	14.0	-12.6	14.0	-12.6	9.0	-8.1	-4.0	3.6	-4.5	4.0	-4.4	4.0
Import(-) / export(+)	**22**	**-20**	42	-40	32	-30	22	-20	22	-20	22	-20	16	-14	12	-10
Demand	**62**	**308**	76	296	76	296	76	295	71	300	58	311	58	312	58	312
COR	**84**	**288**	118	255	108	265	98	275	93	280	80	291	74	298	70	302
GO/G production	***3.4***		*2.2*		*2.5*		*2.8*		*3.0*		*3.6*		*4.0*		*4.3*	

The cases highlighted correspond to a reduction of the GO/G ratio compared to the core scenario. Cases R3/2 and L4/3 depict a future where dieselisation of the car population is reversed (Note that a switch of some 15 Mt/a from diesel to gasoline would require a very quick fall of diesel car sales down some 20% of the total by 2010). In cases R1 and L2/1 the GO/G ratio is further reduced by increasing the trade flows at constant dieselisation.

Cases R4/L5 consider high dieselisation and constant trade flows. Cases R5/6/7 and L6/7 explore the additional impact of reduced trade. In the most extreme cases (R7, L6) total elimination of the trade flows resulted in an infeasible case. Some import/export was therefore reinstated to obtain feasible scenarios.

The sensitivities around the 2005 Base scenario only consider changes in the trade flows.

4. MEETING 2015 DEMAND SCENARIOS

4.1. 2005 BASE CASE: MAIN CHARACTERISTICS OF THE CURRENT EU REFINING TOOL

In a modern refinery, the primary distillation capacity is a poor indicator of the real complexity and capability of the facility. Indeed the function of the refinery is to separate crude oil into various streams but, increasingly importantly, to rearrange the original molecules into those that are demanded by the market. Conversion of heavy molecules into lighter ones is a core component of this process.

The current fabric of European refineries was mostly conceived in the 60s and 70s, in an era when gasoline was dominating transport fuels and growing fast. As a result refineries were geared to gasoline production for which, when it came to selecting a residue conversion technology, (fluid) catalytic cracking (FCC) was the obvious choice. Indeed FCC units were built at the majority of sites in preference to hydrocracking units which would have produced more middle distillates.

With the growing gap between middle distillates and gasoline, this presents an extra challenge for EU refiners. This is also an important point in the context of this work because, when dealing with demand changes particularly when coping with the widening gap between gasoline and diesel demand, a model driven by economics will endeavour to make use of this cheap existing FCC capacity and propose new investments that allow for this. Although reality might be somewhat different, it is likely that refiners will generally try to make best use of their existing and already amortised assets.

4.2. INVESTMENT REQUIREMENTS, ENERGY CONSUMPTION AND CO_2 EMISSIONS IN THE CORE 2015 SCENARIOS

As illustrated by **Figure 2**, the total demand for oil products is only expected to grow by a few percents between now and 2015 in the reference scenario. In the low demand scenario, curtailment of the road fuel market leads to a contraction of the total oil product demand in 2015. As a result it is not expected that Europe will require new primary distillation capacity, any marginal increase being covered by minor revamps of existing units and capacity creep.

The relative demands for the various products will, however, evolve markedly. In this report we focus on the possible evolution of the road fuels demand and, more specifically, to the amount that EU refineries will have to produce, including the share of biofuels and the scope of external trade.

These changes in the "demand barrel" will require adaptation of the refining tool to enable it to make these products from the available crude oil supplies. In practice this will mean modified and new plants and therefore investments. With the highly complex and flexible EU refining system, supply/demand constraints can also be alleviated, at a cost, by intra-European trade of either finished products or intermediate streams. The extent to which this will occur in practice depends on the scope for optimisation within large refining organisations, for mutually advantageous commercial deals between companies and on logistic limitations. Although we do constrain the internal trade opportunities to what appears feasible from a logistic point of view, our modelling represents an economic optimisation of the system's capabilities.

Table 4 summarises the changes to the EU refining system required to migrate from the 2005 to the 2015 situation, for both the Reference and Low Demand scenarios. More complete comparative data is given in **Appendix 1&2**.

Table 4 EU refineries in the Reference and Low Demand scenarios

		2005	2015					
		Base	Reference			Low Demand		
Total production	Mt/a	645.2	699.4			638.2		
Fraction of light products[2]		83.0%	83.2%			81.6%		
Production ratios								
Diesel / gasoline		1.2	1.8			2.3		
Gasoil / gasoline		2.0	2.6			3.4		
Middle distillates / gasoline		2.3	3.2			4.2		
Existing and new process plant capacity utilisation (Mt/a)								
Crude atmospheric distillation		678	747			679		
Vacuum distillation		260	284			264		
Visbreaking		71	83			69		
FCC		123	123			90		
Hydrocracking		77	108			116		
Resid desulphurisation		11	15			18		
Reformate splitting		27	47			38		
Aromatics extraction		9	11			8		
PP splitting		4	5			5		
Middle distillate hydrotreating		214	260			232		
Hydrogen (in kt/a)		796	1244			1169		
Steam cracker		66	77			81		
Investment in new process plants								
Capacity			Mt	% of existing		Mt	% of existing	
Crude atmospheric distillation			68.2	10%		20.3	3%	
Vacuum distillation			23.9	9%		8.0	3%	
Visbreaking			12.5	18%		2.0	3%	
Hydrocracking			31.2	40%		46.1	60%	
Resid desulphurisation			4.3	39%		7.0	63%	
Reformate splitting			20.1	73%		12.0	44%	
Aromatics extraction			2.5	28%		2.3	26%	
PP splitting			1.7	43%		1.4	35%	
Kero hydrotreating			5.9	14%		5.0	12%	
Gasoil HDS (revamp)			30.2	21%		14.6	10%	
Gasoil HDS (new)			10.0	7%		3.1	2%	
Hydrogen (in kt/a)			463	58%		463	58%	
Steam cracker			10.8	16%		15.1	23%	
		Total	Total	Refining	PetChem	Total	Refining	PetChem
Capital cost	G€		15.2	12.9	2.2	16.6	13.2	3.4
Total annual cost[1]	G€/a		4.4			3.2		
Energy consumption	PJ/a	1965	2176	1920	256	1962	1699	263
	% of tot. prod.	7.25%	7.41%			7.32%		
CO_2 emissions	Mt/a	136.7	156.4	141.3	15.1	138.0	122.5	15.5
	t/t of tot. prod.	0.212	0.224			0.216		

(1) Excluding margin effects

(2) Gasoils and lighter, also including petrochemicals

Reference scenario

Driven by the increased transport fuel demand, the total production increases by 8.5%. This of course requires more primary distillation capacity although this level of increase can be covered by capacity creep through minor revamps rather than new units or green field refineries.

The fraction of light products in the total (which characterises the conversion intensity) only increases marginally (the demand for residual does decrease but the current residual fuel oil imports (around 10 Mt/a) are assumed to have ceased by 2015). Production of an additional 47 Mt/a of distillates requires, however, new conversion capacity. As the bulk of the increase is in the form of diesel and jet fuel, hydrocracking is the preferred route. At the same time the model seeks to maximise the economic use of existing assets. FCCs are still fully utilised but the operating mode is changed (**Figure 5**).

In the 2005 base case, FCC are overwhelmingly operated at high conversion, thereby maximising the yield of gasoline components and minimising the yield of low quality diesel components (LCO) characteristic of FCCs. In the 2015 Reference scenario, FCCs are operated in low conversion. The LCO quality is improved partly by using hydrotreated feedstocks from dedicated feed hydrotreaters, mild hydrocrackers and residue desulphurisers (**Figure 6**) but also by deep hydrodesulphurisation. Additional deep gasoil hydrodesulphurisation is also required in order to make sulphur-free road diesel. There is of course a concurrent need for extra hydrogen production. Finally a significant increase of reformate splitting is required to rebalance the various quality requirements of the gasoline pool.

The additional steam cracker capacity is broadly in line with the increased ethylene demand (the larger increase in demand for higher olefins and aromatics is partly met by refineries through investments in PP splitter and aromatic extraction plants). The steam crackers feed composition is only marginally changed (**Figure 7**).

The resulting capital investment cost is 15.2 G€ for an annual cost of 4.4 G€ (including capital charge, extra fixed and variable costs and extra fuel and loss).

All these additional plants consume energy and, not surprisingly, the energy consumption of the refineries goes up in absolute terms and so do CO_2 emissions. Including the steam cracker complexes, the increase represents 5 Mt oil equivalents in energy terms and nearly 20 Mt/a extra CO_2. The energy consumption and CO_2 emissions also go up relative to the total production. As the depth of conversion is not significantly changed, this is clearly the result of the increased GO/G ratio.

Note that this scenario, as well as all others, was run with an assumption of constant energy intensity compared to 2005. Historically, EU refineries have improved their energy intensity by between 0.5 and 1% per year. Although further improvements are gradually becoming more difficult and costly some further reductions are expected in the future. This would partly offset the extra energy consumption (and CO_2 emissions) mentioned above.

Figure 5 FCCs operating mode
(% of feed processed in high or low conversion mode)

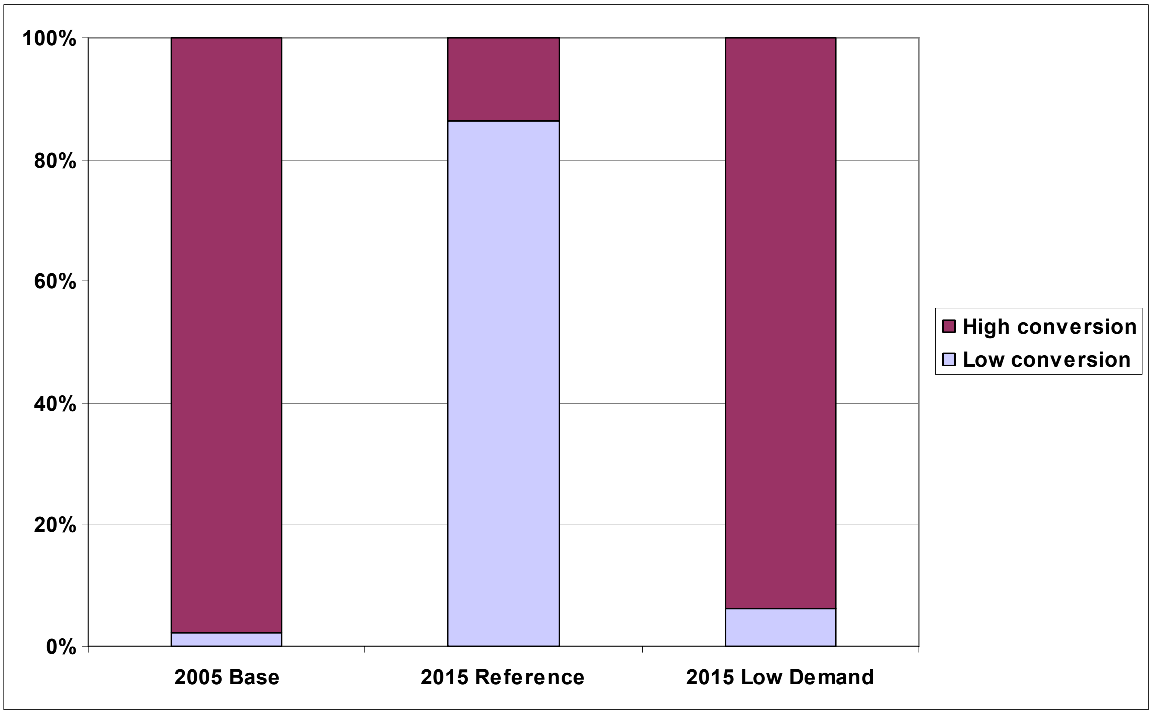


Figure 6 FCCs feed composition

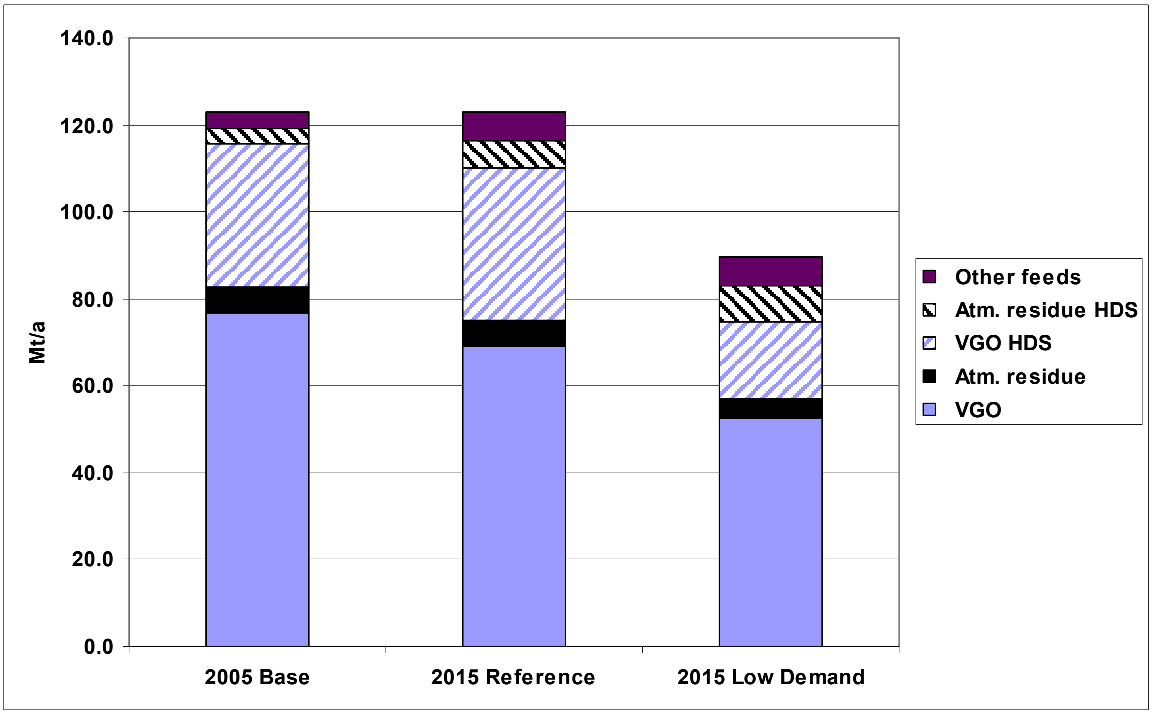
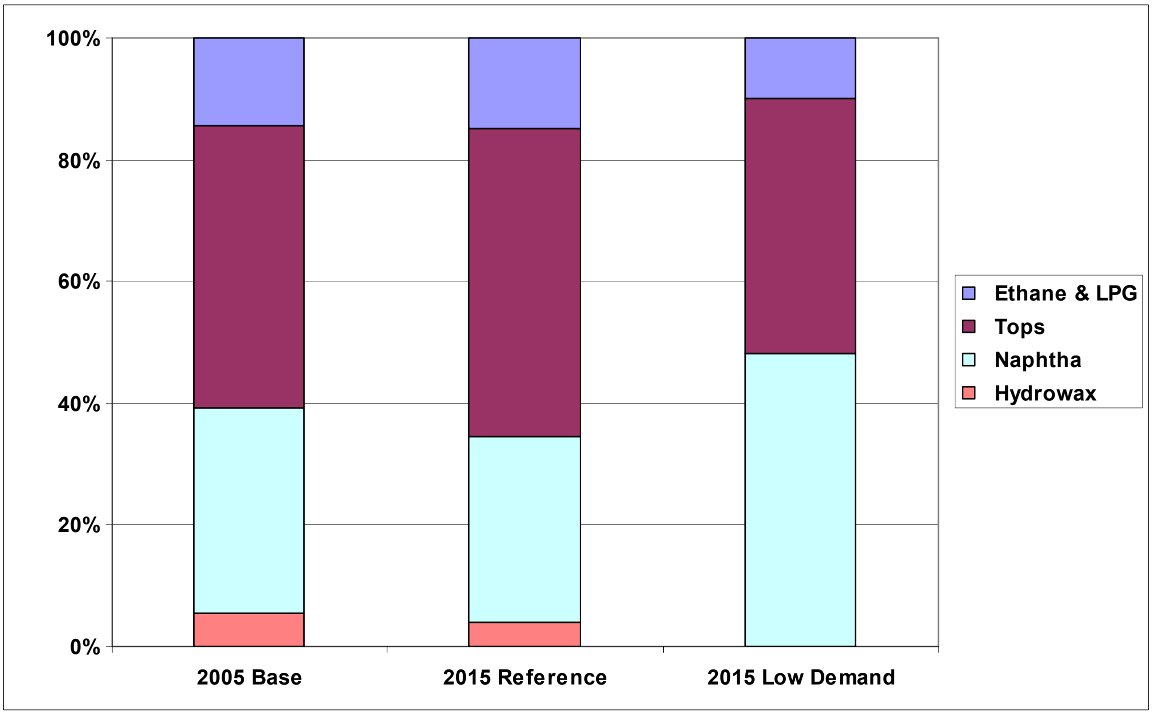


Figure 7 Steam crackers feed composition



Low Demand scenario

The reduction in road fuel demand results in a slight contraction of the total refinery output. Because the demand for all other products has been assumed to remain constant, the conversion intensity is reduced. The middle distillates / gasoline ratio is, however, nearly doubled compared to the 2005 base case. This can only be achieved by a much larger shift from FCC to hydrocracking. Indeed utilisation of existing FCCs is now seriously reduced (72% of available capacity) whereas investment in new hydrocracking and residue desulphurisation capacity is 50% higher than in the Reference scenario (this in spite of the reduced conversion intensity).

The mechanisms used by the model to rebalance the gasoline pool are complex. FCCs are again operated in high conversion mode (**Figure 5**) while more desulphurised residue is used as FCC feed (**Figure 6**) replacing desulphurised VGO used as hydrocracker feed.

The steam cracker feed diet changes significantly (**Figure 7**) with more heavy naphtha as less gasoline is being produced, no hydrowax (it is preferentially used for making middle distillates while a limited amount is also allowed into low sulphur fuel oil) and less LPG as lower FCC runs limit their availability. The average ethylene yield decreases compared to the base case which explains the additional increase in steam cracker feed capacity compared to the Reference scenario.

From the point of view of energy consumption and CO_2 emissions, both effects compensate each other so that the figures are similar to those of the 2005 base case.

The above analysis demonstrates the crucial role of the middle distillates / gasoline ratio in defining the investment strategy of the industry to meet future demand. This is further analysed in the next section.

4.3. SENSITIVITY TO THE GASOIL / GASOLINE RATIO

Results of the model runs for the sensitivity scenarios defined in section 3.2.5 are shown below. More complete comparative data is given in **Appendix 1&2**.

Process plants

Figure 8 shows the changes in the cumulative throughputs of key process plants. In line with what was observed in the comparison between Reference and Low Demand scenarios, FCC utilisation decreases with increasing GO/G ratio. At the same time new hydrocracking and residue desulphurisation capacity comes into play. At very high ratios hydrocracking cannot be further increased by lack of feedstock and massive residue desulphurisation is the only solution. FCC throughput recovers somewhat as more desulphurised residue feedstock becomes available.

Figure 8 Cumulative throughput of key process plants

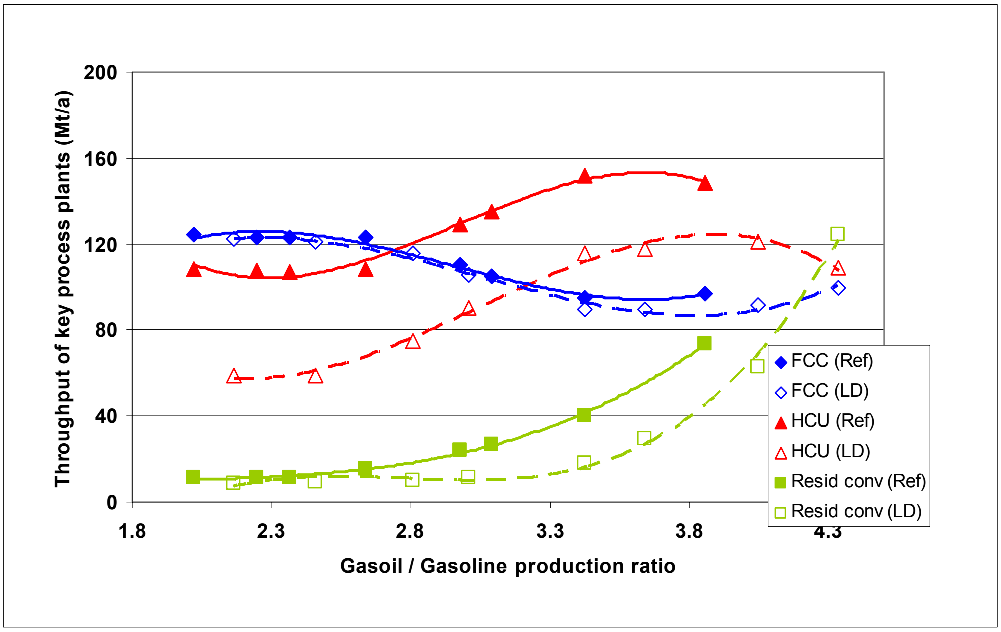
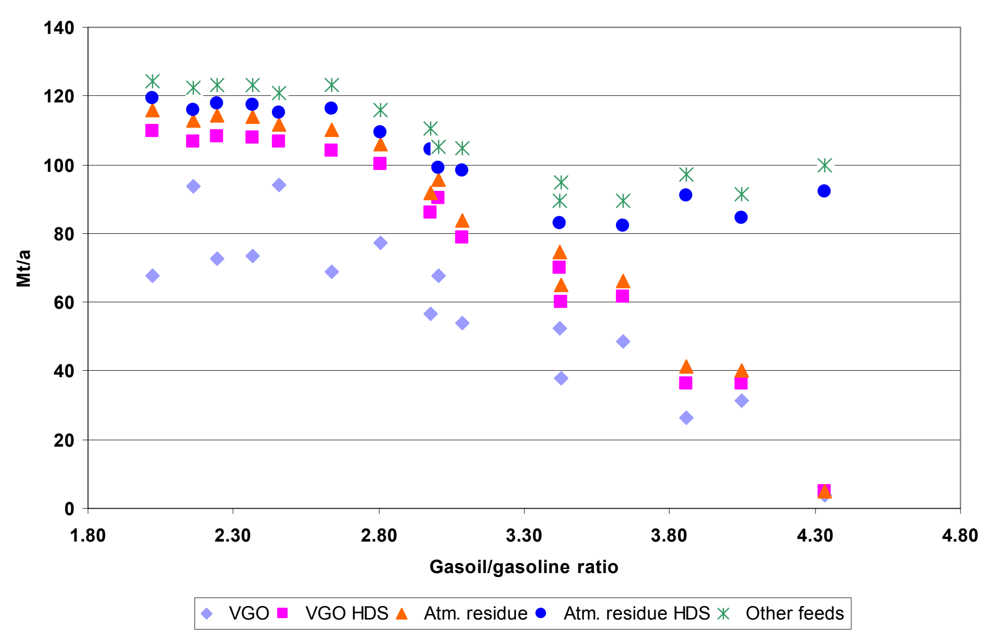


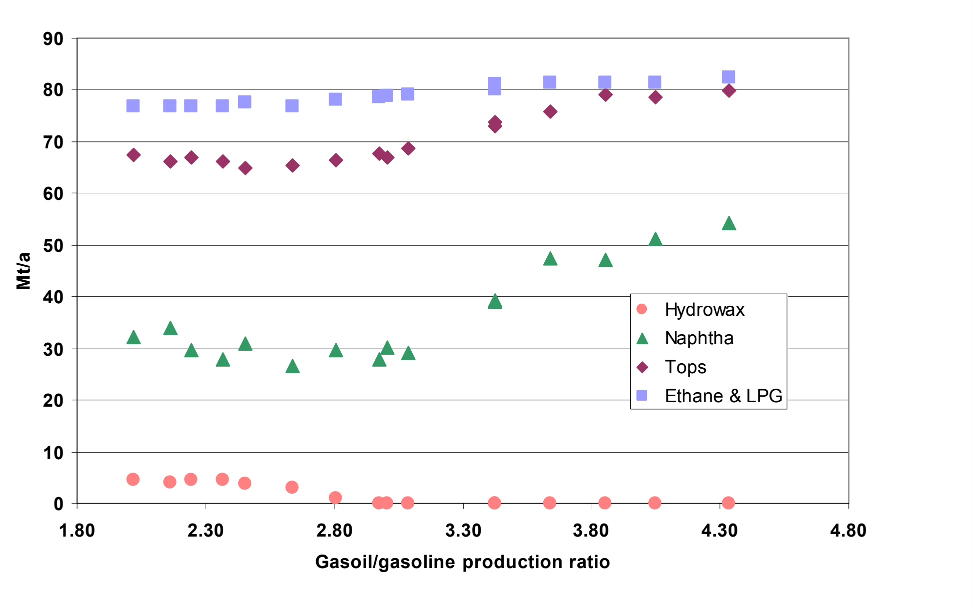
Figure 9 shows the evolution of the FCC feed composition as the GO/G ratio increases. Under normal circumstances VGO (partly hydrotreated) is the main feed, with some atmospheric residue. Beyond a ratio of 3.0 the share of desulphurised residue begins to increase. In the extreme case it represents more than 90% of the feed. Although significant quantities of desulphurised atmospheric residue can be processed in most FCC, this proportion is unrealistic, at least without significant modifications. This model solution is therefore almost infeasible in practice and shows that the level of unbearable constraints has been reached. It is to be noted that at the higher ratios corresponding to the total elimination of import/exports, the model could not find a feasible solution.

Figure 9 Evolution of FCC feed composition



The steam crackers are also affected with some extra capacity required as a result of changes in the feed composition. **Figure 10** shows the gradual increase of the proportion of naphtha to the detriment of all other feed streams particularly hydrowax and LPG.

Figure 10 Evolution of Steam crackers feed composition



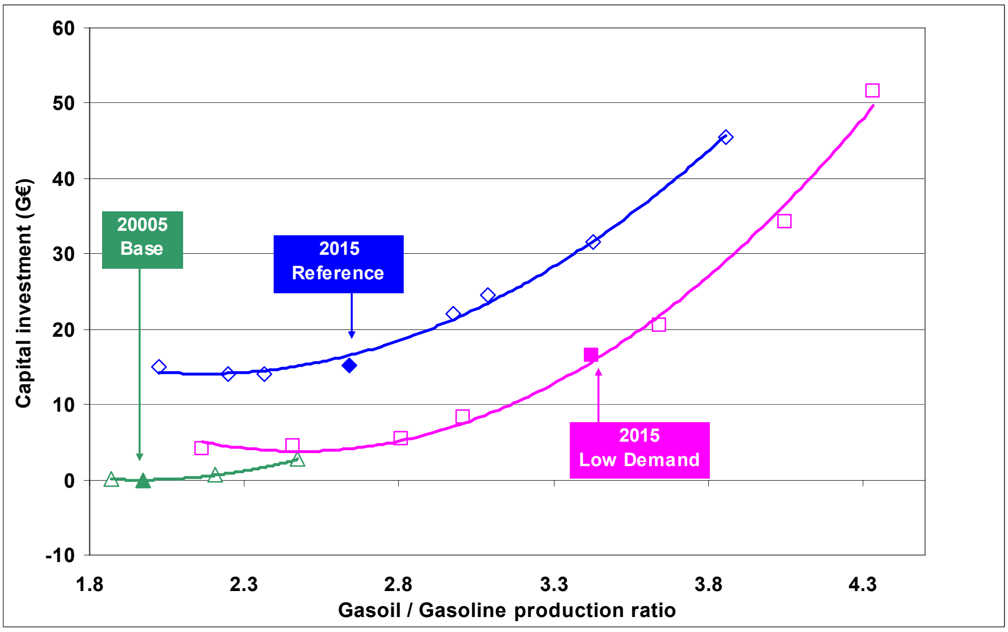
Investment costs

The large investment cost required to install additional capacities correlates remarkably well with the GO/G ratio for a given level of demand (**Figure 11**). Both curves follow the same trend. Noting the Reference scenario requires 15.2 G€ of investment (from the 2005 Base case) increasing the GO/G ratio from 2.6 to 3.4 (case R6 in **Table 3**) virtually doubles this cost. Cases R6 and R7 are of course rather extreme (very high dieselisation and reduced import/export) but, considering that all points on each curve are at constant conversion intensity, this demonstrates the key role played by the GO/G ratio.

The curves appear to show a shallow minimum towards the lower range of GO/G ratios. This suggests there may be an "optimum" value of the ratio, as a function of the demand level, where demand can be met at lowest investment cost.

Note that the trends discussed above are replicated with sensitivity points around the 2005 Base scenario.

Figure 11 Capital investment in new process plants$^{(1)}$ (relative to the 2005 Base case)

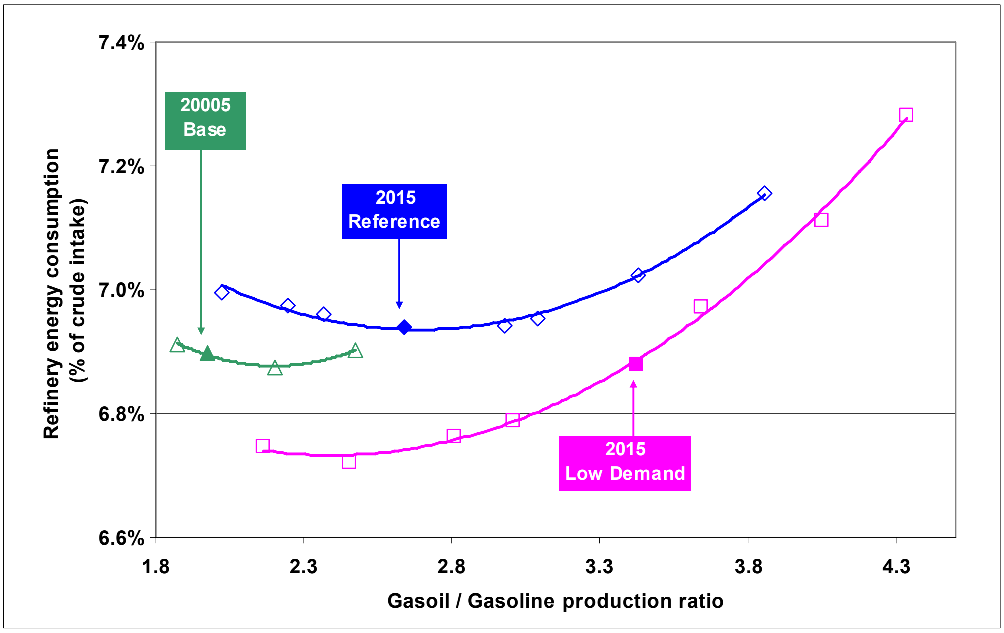


$^{(1)}$ *Including petrochemicals*

Energy consumption and CO_2 emissions

Figure 12 shows a similar correlation for refinery energy consumption. The specific energy consumption increased at high GO/G ratios although the minimum observed with investment is more marked here. At lower GO/G ratios less energy needs to be devoted to conversion plants such as hydrocrackers but this compensated by an increased need for energy-intensive processes associated with gasoline. In line with the lower conversion intensity, the specific energy consumption is lower for the Low Demand scenario.

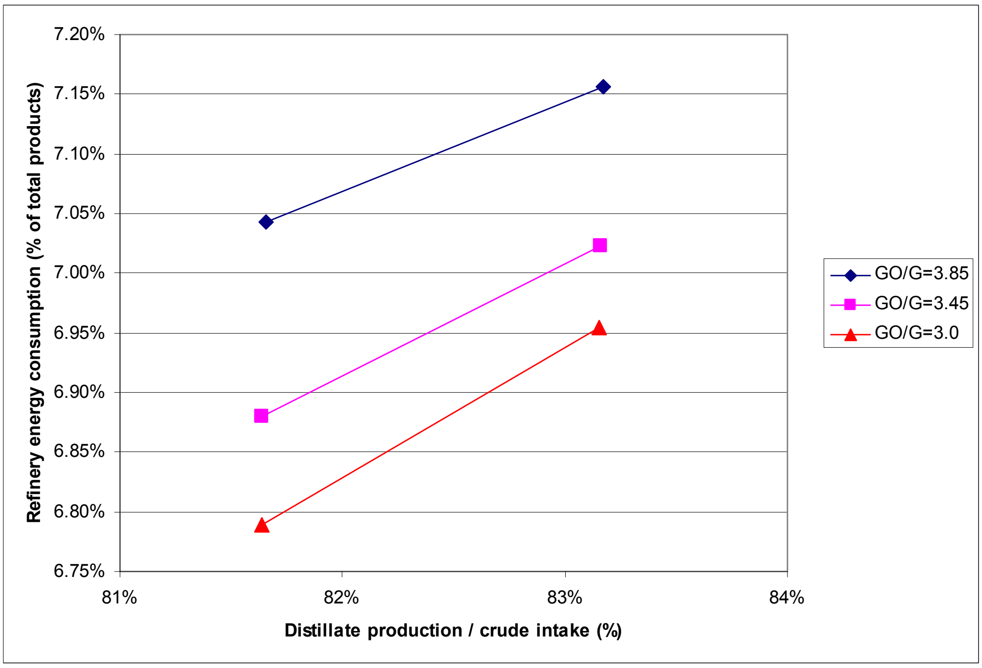
Figure 12 Specific energy consumption$^{(1)}$



$^{(1)}$ *Including petrochemicals*

Figure 13 shows the relationship between the distillate make relative to crude intake and the specific energy consumption, at a given GO/G ratio. 1% more distillate make corresponds roughly to 0.15% extra energy consumption, the relationship being virtually independent of the GO/G ratio.

Figure 13 Relationship between energy consumption and conversion intensity



The energy intensity increase causes additional CO_2 emissions. **Figure 14a** shows the specific CO_2 emissions increase while **Figure 14b** shows the actual CO_2 emissions. In absolute terms the maximum increase of CO_2 emissions over the explored range is about 9 Mt/a from the Reference scenario and 16 Mt/a from the Low Demand scenario. Note that, in the Low Demand series, there is considerable scope to decrease CO_2 emissions by reducing the GO/G ratio.

The minimum observed for energy consumption is less marked for CO_2 emissions as the change in energy requirement is partly compensated by a change in fuel composition.

Figure 14a Specific CO_2 emissions(1)

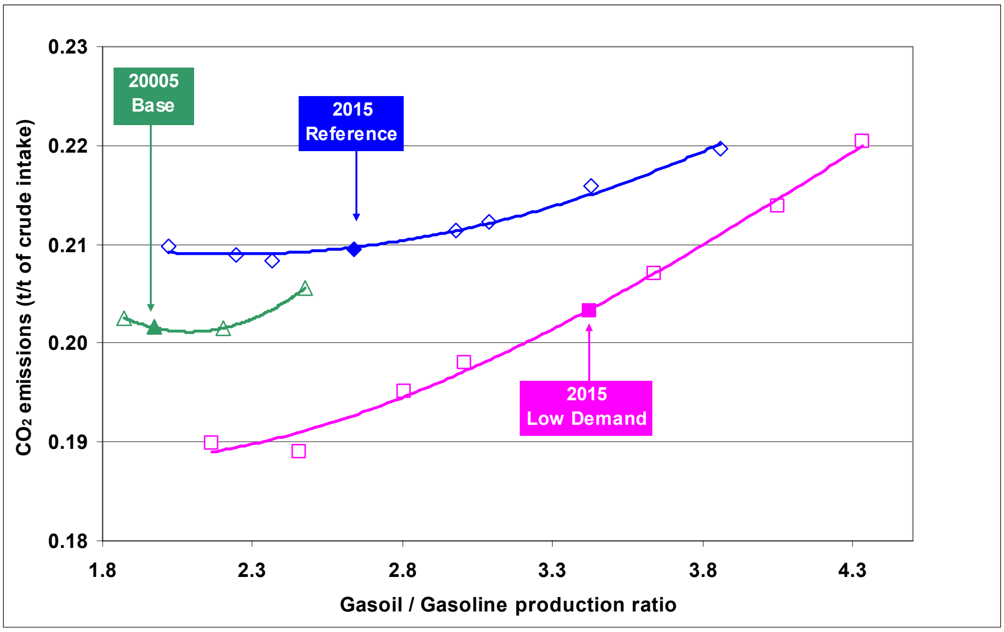
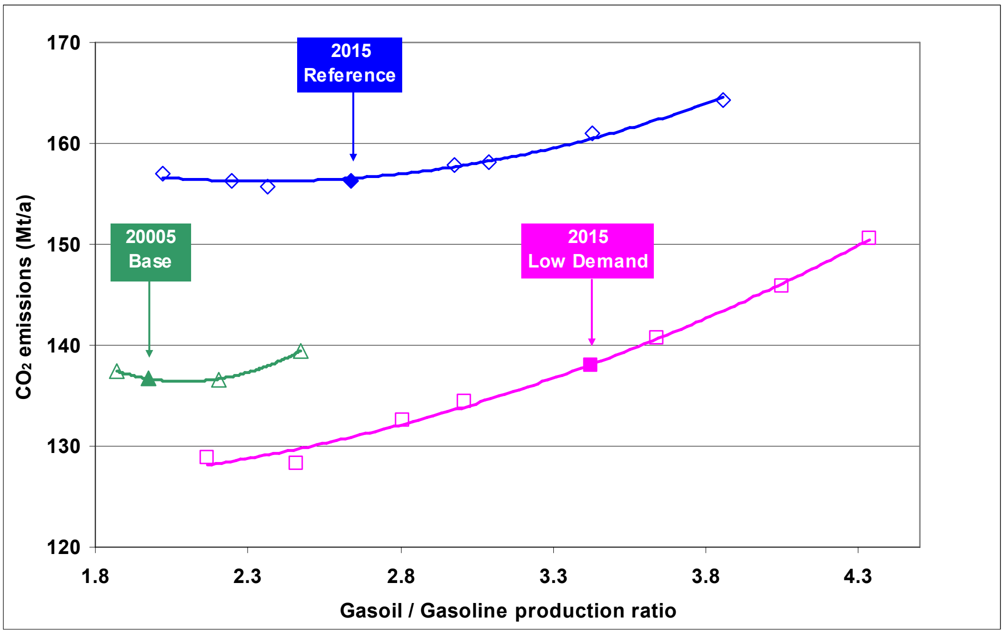


Figure 14b Actual CO_2 emissions$^{(1)}$



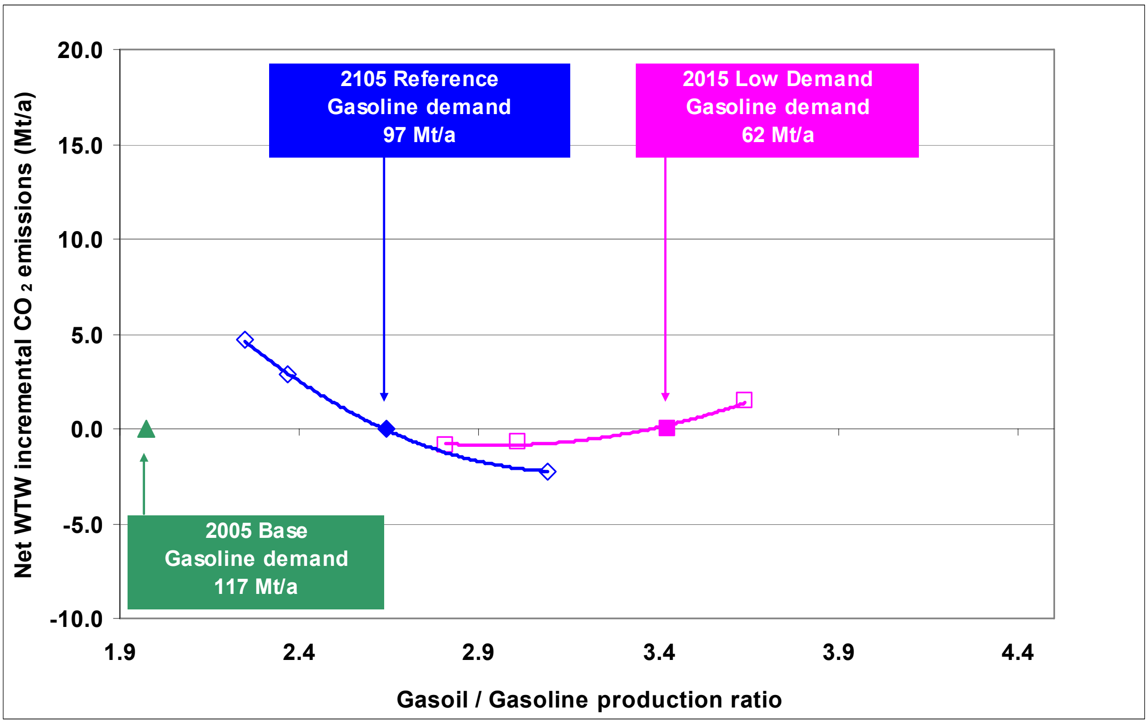
(1) Including petrochemicals

When the change in GO/G ratio stems from increased dieselisation, these significant CO_2 emissions increases can be compared to what would potentially be saved in the car fleet by more efficient diesel rather the gasoline powertrains. At the 2015 horizon, it is generally considered that the efficiency gap between spark-ignited and compression ignition engines will narrow from the current 15-20% to possibly as little as 5% (in energy terms i.e. MJ/km). As mentioned in section 3.2.5 we assumed a mid-range value of 10%. On this basis one can estimate the CO_2 emission savings from cars resulting from a certain rate of dieselisation. The net "well-to-wheels" CO_2 emissions represent the balance of the decrease of emissions from vehicles and the increase of refinery emissions. For those sensitivity cases where the change in demand is solely due to changes in the rate of dieselisation, **Figure 15** shows the net CO_2 impact as a function of the GO/G ratio, compared to either the Reference or the Low Demand scenario.

For the Reference scenario series, increasing dieselisation (i.e. higher GO/G ratio) does result in lower net CO_2 emissions over the studied range i.e. the benefit of the more efficient vehicle fleet is higher than the debit due to additional refinery energy use. **For the Low Demand scenario series**, however, the curve is at best flat or even slightly reversed: **more dieselisation results in the same or slightly higher net CO_2 emissions.**

Although this calculation is only approximate, it highlights the fact that extreme dieselisation of the vehicle population could actually lead to increased overall CO_2 emissions.

Figure 15 Impact of dieselisation of the car population on overall CO_2 emissions



5. ENERGY AND CO_2 EMISSIONS ASSOCIATED WITH MARGINAL GASOLINE AND DIESEL FUEL PRODUCTION

Oil refineries produce a number of different products simultaneously from a single feedstock. Whereas the total amount of energy (and other resources) used by refineries is well documented, there is no simple, non-controversial way to allocate energy, emissions or cost to a specific product. Distributing the resources used in refining amongst the various products invariably involves the use of arbitrary allocation keys that can have a major influence on the results. More to the point, such a simplistic allocation method ignores the complex interactions, constraints, synergies within a refinery and also between the different refineries in a certain region and is likely to lead to misleading conclusions.

Such information is, however, required in a number of cases, for instance when one needs to compare the energy savings or CO_2 emissions avoidance that can be achieved when replacing conventional fossil fuels by alternatives such as biofuels or natural gas.

In such cases, however, one can make a sound estimation by performing a differential analysis between a reference case where a certain amount of fuel is made by refineries and an alternative case where a smaller amount of that fuel is produced, all else being equal. The change in refinery energy consumption and CO_2 emissions (and also cost) can then by solely attributed to the change in the production of the particular fuel. One then obtains the marginal energy consumption or CO_2 emissions associated with that fuel

It is essential to realise though, that the value derived in this way is only valid for the particular reference scenario and also, in principle, for the particular percentage reduction envisaged.

The analysis performed in this study allowed us to derive marginal energy consumption and CO_2 emissions for both gasoline and diesel fuel. Starting from the three core scenarios (2005 Base, 2015 Reference and Low Demand) additional model runs were carried out with a 5% reduction of either gasoline or diesel fuel production. Following the methodology described above, the differential energy consumption and CO_2 emissions were fully allocated to the change in gasoline or diesel fuel production. The results are shown in **Figure 16 and 17** as the marginal energy and CO_2 emissions associated with gasoline and diesel fuel in each scenario. In other words this represents the energy that can be saved and the CO_2 emissions that can be avoided by "not producing" 1 MJ of the fuel in question.

Not surprisingly, the energy and CO_2 graphs are very similar. The remarkable observation, however, is the marked difference between gasoline and diesel. For diesel fuel the numbers stay more or less constant (around 10% for energy) for all three scenarios and therefore across the range of GO/G ratio. For gasoline they vary a great deal, from slightly more than diesel for the 2005 Base scenario to negative for the Low Demand scenario. This means that, at high GO/G ratio, "not making" gasoline can actually *increase* the refinery energy requirement.

This result is in fact in line with the results shown on **Figure 14a/b**. The 2005 Base scenario point is on the down slope before the minimum. Reducing gasoline production increases the GO/G ratio, therefore reduces energy consumption and an energy gain results. The 2015 Low Demand scenario is in the strongly up slope part of the curve and the opposite effect applies. Although there is a small increase in the diesel energy at high GO/G ratio, the effect is much less pronounced.

Figure 16 Marginal energy consumption for road fuels manufacture

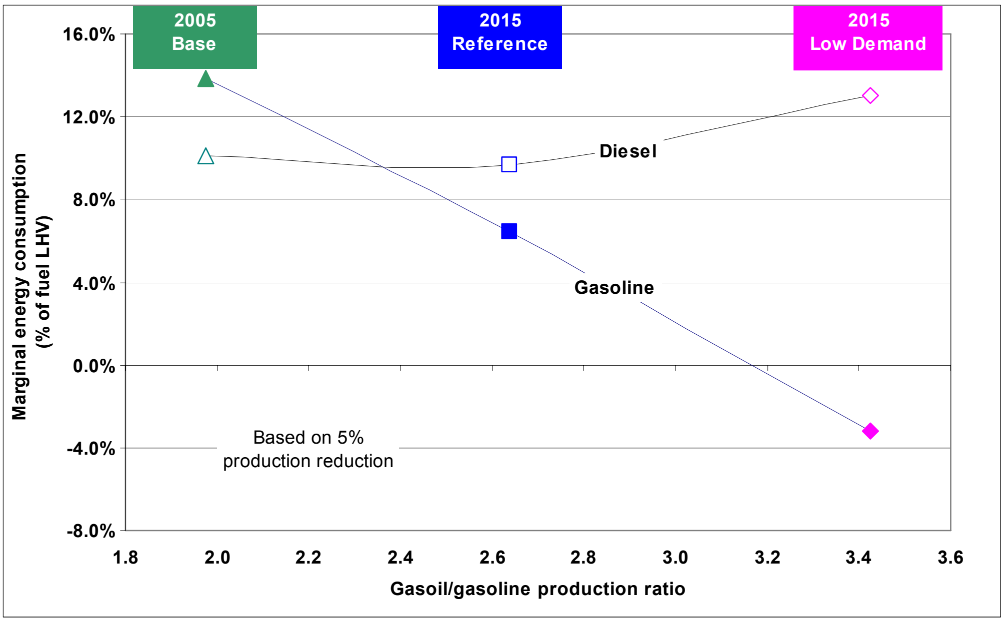


Figure 17 Marginal CO_2 emissions associated for road fuels manufacture

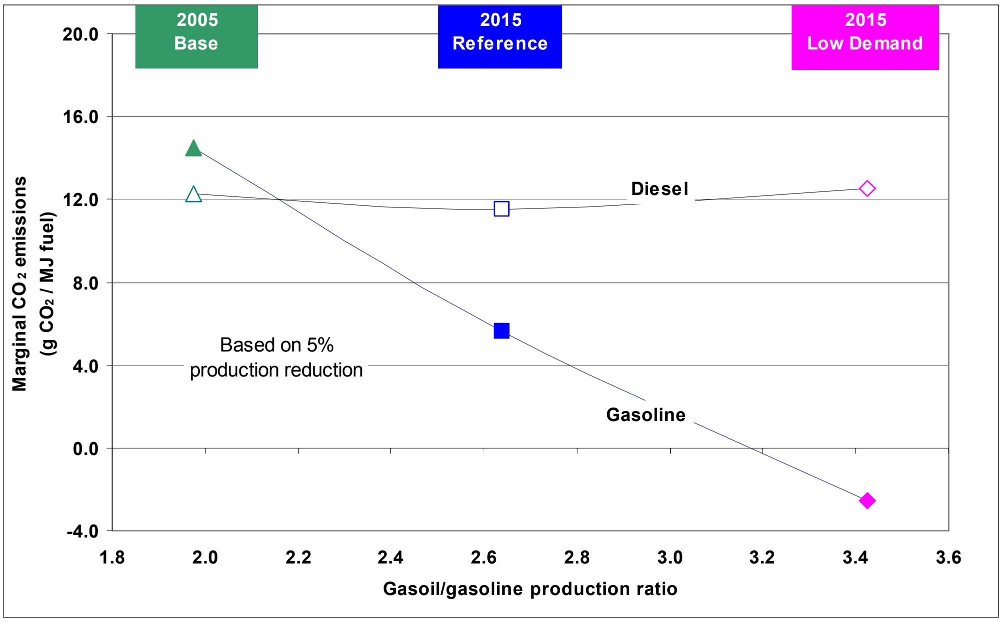
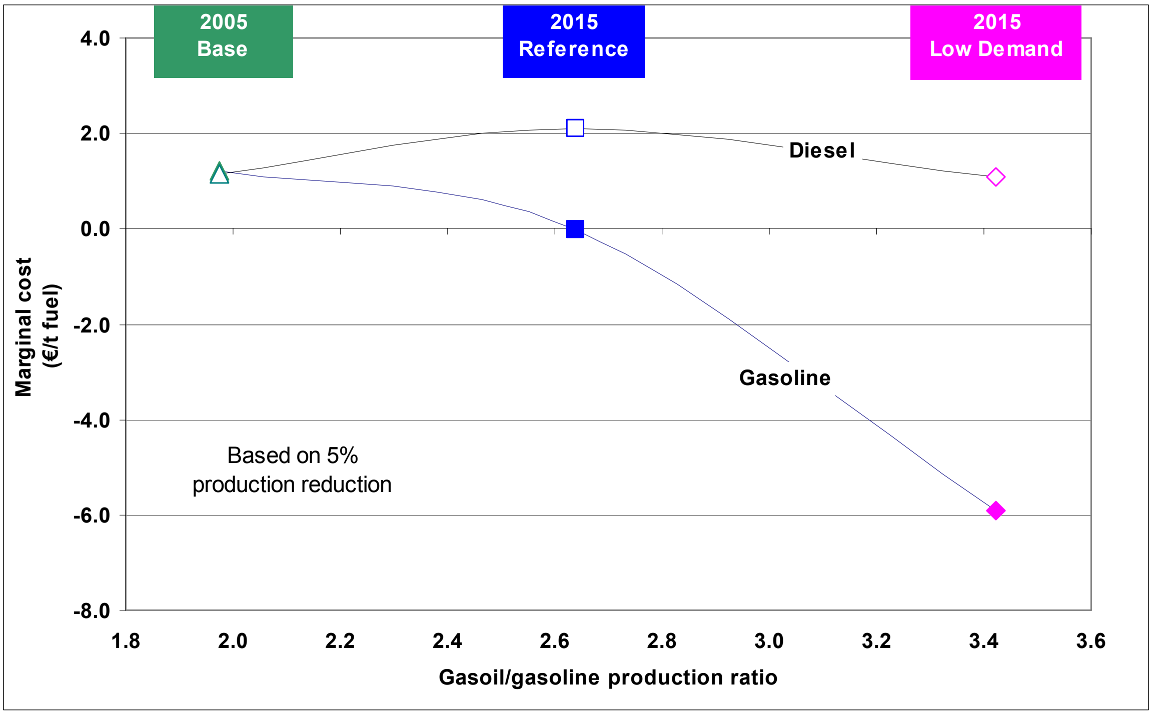


Figure 18 shows the same data points in terms of cost to the refiner i.e. including capital charge and fixed and variable operating costs (mostly energy). Again the picture is very similar to that of **Figure 16** and **17**. Whereas the cost of marginal diesel remains positive, beyond a GO/G ratio of 2.6 the cost of making marginal gasoline becomes negative i.e. one saves money by making more or, conversely one needs more money to make less.

Figure 18 Marginal refiner's cost associated for road fuels manufacture



6. CONCLUSIONS

There is adequate primary distillation capacity in Europe to meet the foreseen demand at the 2015 horizon. The way refineries process crude oil must, however, be adapted in order to cope with changes in the product slate, particularly with regards to the relative demands for middle distillates and gasoline.

The gasoil/gasoline production ratio is clearly the single most important parameter determining the process configuration that will be needed. This ratio is affected by many factors such as degree of penetration of diesel cars, relative penetration of alternatives fuels substituting either gasoline or diesel and importantly the continued availability of gasoline export markets and gasoil/diesel import sources.

The main investments required are in hydrocracking and some residue desulphurisation or conversion capacity, particularly in the most extreme scenarios. Note that this has already started as several major conversion projects have been announced in EU refineries.

A continued increase of the gasoil/gasoline ratio would present a very serious challenge to EU refiners in terms of adaptation of their refineries, choice of processes and magnitude of required investments. It would also lead to a further increase in refinery energy consumption and CO_2 emissions.

With the efficiency gap between diesel and gasoline cars set to decrease, there is a possibility that, an excessive rate of dieselisation could lead to an increase rather than a decrease of overall CO_2 emissions.

The marginal energy and CO_2 emissions associated with production of road fuels in refineries are dependent on the circumstances, in particular the gasoil to gasoline production ratio. For diesel fuels the variations observed across the three scenarios are small. For gasoline, however, the figures vary a great deal, even becoming slightly negative for high values of the ratio. Under such circumstances, reducing gasoline production does not save any energy or CO_2 emissions in refineries.

7. REFERENCES

1. EU (2006) Reduction of energy use in transport. Final report. Brussels: Working Group under the Joint Expert Group on Transport and Environment. http://forum.europa.eu.int/Public/irc/env/transport/library?l=/reducing_transport/reports/transport_1812006pdf/_EN_1.0_&a=d

APPENDIX 1 DETAILED SCENARIO OUTPUT (2005 BASE)

CASE		*2005*			
		Base	*B1*	*B2*	*B3*
Crude intake	Mt/a	678.2	678.3	678.1	678.4
Demand	Mt/a				
Gasoline		116.6	116.5	116.6	116.5
Diesel fuel		183.4	183.4	183.3	183.1
Total road fuels		300.0	300.0	299.9	299.6
Other gasoils		110.4	110.4	110.5	110.4
Trade	Mt/a				
Gasoline exports		22.0	26.9	12.0	2.1
Gasoil imports		20.3	25.3	10.3	0.3
Jet fuel imports		7.6	7.6	7.6	7.6
Production	Mt/a				
Total system		645.2	659.6	644.6	634.3
Refinery		590.3	604.7	589.7	579.4
LPG		21.0	21.1	21.1	21.1
Petrochemicals(1)		54.9	54.9	54.9	54.9
Gasoline		138.6	143.5	128.6	118.6
Diesel		163.1	158.1	173.0	182.8
Gasoils		273.5	268.6	283.5	293.2
Total road fuels		301.7	301.6	301.6	301.3
Jet fuel		47.3	47.4	47.3	47.3
Total Distillates		535.4	535.4	535.4	535.1
(1) C2 to C4 olefins, BTX					
Production ratios					
Distillates/Crude		0.830	0.812	0.831	0.844
Diesel/Gasoline		1.18	1.10	1.35	1.54
Gasoil/Gasoline		1.97	1.87	2.20	2.47
Middle Distillates/Gasoline		2.32	2.20	2.57	2.87
New capacity from	Mt/a				
CDU			0.40	0.40	4.57
HVU			-0.08	0.83	1.07
Visbreaking / coking			-0.21	-0.27	0.21
FCC			-0.04	-0.07	-0.12
HCU once-through			0.00	0.63	7.82
LR HDS			0.00	0.00	0.00
Naph HT			0.05	0.09	0.74
FCC gasoline HT			3.95	0.00	0.62
FCC gasoline sweetening			0.00	0.00	0.40
Cat reforming revamp			0.00	0.00	0.00
FCC gasoline splitter			-0.04	2.43	4.04
Reformate splitting			0.25	8.02	23.81
Isomerisation			0.10	0.00	0.00
Aromatics Extraction			0.00	0.01	0.01
PP splitter			0.00	0.00	0.63
Kero HT			0.04	0.44	0.07
Gasoil HT revamp			0.09	1.18	1.12
Gasoil HT new			0.00	0.00	0.00
Gasoil Hydrodearomatisation			0.00	0.00	0.00
Sulphur recovery			0.00	0.02	0.05
Bitumen			0.00	0.00	0.00
Hydrogen manuf (as hydrogen) (1)			*10*	*26*	*121*
Steam cracker			0.15	0.50	0.59
Hydrodealkylation			0.00	0.00	0.07
(1) as kt/a of hydrogen output					
Plant utilisation	Mt/a				
CDU		678	678	678	678
HVU		260	260	260	260
Visbreaking / coking		71	71	71	71
FCC		123	123	123	119
HCU once-through		77	77	76	83
LR HDS		11	11	11	11
Naph HT		90	90	88	88
FCC gasoline HT		26	30	24	23
FCC gasoline sweetening		0	0	0	0
Cat reforming		90	91	88	86
FCC gasoline splitter		32	32	34	35
Reformate splitting		27	28	36	51
Isomerisation		7	7	5	6
Aromatics Extraction		9	8	8	7
PP splitter		4	4	4	4
MD HT		214	210	215	215
Gasoil Hydrodearomatisation		1	1	1	1
Sulphur recovery		4	4	4	4
Bitumen		20	20	20	20
Hydrogen manuf (as hydrogen) (1)		*796*	*802*	*819*	*904*
Steam cracker		66	66	66	67
Hydrodealkylation		0	0	0	0
Capital Investment	M€		**68**	**590**	**2693**
Capital Charge @ 15%	M€		10	89	404
Opex	M€/a		**5**	**92**	**255**
Fuel & Loss (@LS HFO price)			**29**	**-12**	**104**
Annual cost			**44**	**168**	**763**
Energy consumption					
Total system	PJ/a	1965	1969	1958	1967
	Mtoe/a	46.8	46.9	46.6	46.8
	toe/t product	7.25%	7.11%	7.23%	7.38%
	toe/t crude	6.90%	6.91%	6.87%	6.90%
Refinery	PJ/a	1746	1709	1700	1706
	toe/t product	7.0%	6.7%	6.9%	7.0%
Petrochemicals	PJ/a	219	260	258	260
	toe/t product	9.5%	11.3%	11.2%	11.3%
CO2 emissions		0.070	0.070	0.070	0.071
Total system	Mt/a	136.7	137.4	136.6	139.4
	t/t product	0.212	0.208	0.212	0.220
	t/t crude	0.202	0.203	0.202	0.206
Refinery	Mt/a	123.8	122.0	121.4	124.1
	t/t product	0.210	0.202	0.206	0.214
Petrochemicals	Mt/a	12.9	15.4	15.2	15.4
	t/t product	0.235	0.280	0.278	0.280

APPENDIX 2 DETAILED SCENARIO OUTPUT (2015)

CASE		*2015*															
		Ref.	*R1*	*R2*	*R3*	*R4*	*R5*	*R6*	*R7*	*Low dem.*	*L1*	*L2*	*L3*	*L4*	*L5*	*L6*	*L7*
Crude intake	Mt/a	746.5	748.3	748.1	747.5	745.5	746.8	745.5	747.7	678.9	678.6	678.4	679.0	678.7	679.5	681.7	683.2
Demand	Mt/a																
Gasoline		96.8	111.6	111.6	106.8	83.4	92.8	83.3	83.1	62.0	76.0	76.1	76.0	71.0	58.0	57.6	57.6
Diesel fuel		236.8	223.5	223.5	227.9	248.9	240.4	249.0	249.0	211.0	198.6	198.5	198.4	202.9	214.5	214.7	214.7
Total road fuels		333.6	335.1	335.1	334.7	332.3	333.2	332.3	332.1	273.0	274.6	274.6	274.4	273.9	272.5	272.3	272.3
Other gasoils		96.9	97.0	96.9	96.9	96.9	96.9	96.8	96.8	96.9	97.1	97.1	96.9	96.9	97.0	96.8	96.8
Trade	Mt/a																
Gasoline exports		21.9	31.9	22.0	22.0	21.9	15.9	13.8	5.4	22.0	41.9	32.0	22.0	22.0	22.0	16.0	12.0
Gasoil imports		20.3	30.3	20.3	20.3	20.3	13.8	13.0	4.2	20.3	40.3	30.3	20.3	20.3	20.3	13.8	10.0
Jet fuel imports		7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
Production	Mt/a																
Total system		699.4	697.0	700.9	700.5	697.8	699.2	696.6	697.0	638.2	640.6	640.6	640.1	639.4	637.8	637.6	636.9
Refinery		634.3	631.9	635.8	635.4	632.7	634.1	631.5	631.9	573.1	575.5	575.5	575.0	574.3	572.7	572.5	571.8
LPG		21.0	21.1	21.0	21.0	21.0	21.0	21.0	21.1	21.1	21.1	21.1	21.0	21.0	21.1	21.1	21.1
Petrochemicals(1)		65.1	65.1	65.1	65.1	65.1	65.1	65.1	65.1	65.1	65.1	65.1	65.1	65.1	65.1	65.1	65.1
Gasoline		118.7	143.5	133.6	128.8	105.4	108.7	97.1	88.6	84.0	118.0	108.0	98.0	93.0	80.0	73.5	69.6
Diesel		216.5	193.2	203.2	207.6	228.6	226.6	235.9	244.8	190.7	158.3	168.2	178.1	182.6	194.2	200.9	204.7
Gasoils		313.4	290.1	300.1	304.5	325.4	323.4	332.8	341.6	287.6	255.4	265.3	275.0	279.5	291.2	297.7	301.5
Total road fuels		335.2	336.7	336.8	336.4	333.9	335.2	333.0	333.4	274.7	276.2	276.2	276.1	275.5	274.2	274.5	274.3
Jet fuel		63.3	63.3	63.3	63.3	63.3	63.3	63.3	63.3	63.3	63.3	63.3	63.3	63.3	63.3	63.3	63.3
Total Distillates		581.6	583.1	583.1	582.7	580.2	581.5	579.3	579.7	521.0	522.8	522.8	522.5	521.9	520.7	520.8	520.6
(1) C2 to C4 olefins, BTX																	
Production ratios																	
Distillates/Crude		0.832	0.837	0.832	0.832	0.832	0.832	0.832	0.832	0.816	0.816	0.816	0.816	0.816	0.816	0.817	0.817
Diesel/Gasoline		1.82	1.35	1.52	1.61	2.17	2.09	2.43	2.76	2.27	1.34	1.56	1.82	1.96	2.43	2.73	2.94
Gasoil/Gasoline		2.64	2.02	2.25	2.37	3.09	2.98	3.43	3.86	3.42	2.16	2.46	2.81	3.01	3.64	4.05	4.33
Middle Distillates/Gasoline		3.17	2.46	2.72	2.86	3.69	3.56	4.08	4.57	4.18	2.70	3.04	3.45	3.69	4.43	4.91	5.24
New capacity from	Mt/a																
CDU		68.24	1.04	1.50	0.90	-0.40	0.15	0.39	4.55	20.32	3.94	3.38	4.41	2.58	13.26	18.83	31.88
HVU		23.91	9.94	8.57	7.86	3.55	1.31	-4.39	-19.71	7.96	-8.03	-8.03	-8.03	-3.31	1.69	-8.03	-8.03
Visbreaking / coking		12.53	3.47	4.72	4.32	-4.38	-5.45	-6.34	-9.43	2.04	-2.08	-2.08	-2.08	-1.47	-1.23	-2.06	-1.84
FCC		-0.06	1.40	0.22	0.22	0.00	0.00	0.00	0.00	-0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HCU once-through		31.17	-0.09	0.29	0.08	32.38	22.95	50.76	61.11	46.08	-46.08	-46.08	-44.02	-30.00	4.33	14.15	4.68
LR HDS		4.33	-4.97	-4.33	-4.31	11.16	8.77	24.61	59.64	6.99	-6.99	-6.99	-6.99	-6.99	11.05	49.10	112.03
Naph HT		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.23
FCC gasoline HT		0.42	3.57	1.29	0.31	-0.42	-0.61	-0.40	-0.22	1.13	-1.17	-1.41	-1.41	-0.70	-0.66	-0.82	-1.41
FCC gasoline sweetening		0.00	0.00	0.00	0.00	0.00	0.00	0.88	4.10	0.00	0.00	0.00	0.00	0.00	0.19	1.92	2.85
Cat reforming revamp		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FCC gasoline splitter		1.32	-0.55	0.07	-0.04	-0.75	-0.38	-0.05	0.61	1.46	-1.38	-1.34	-1.22	-0.75	-0.48	-0.53	0.10
Reformate splitting		20.10	-13.90	-11.28	-9.05	3.21	4.39	2.00	-1.32	12.00	-7.06	-4.96	0.14	1.79	-1.12	1.80	1.47
Isomerisation		0.00	0.31	0.00	0.00	0.00	0.00	0.00	6.75	0.00	0.00	0.00	0.00	0.00	0.01	4.40	9.43
Aromatics Extraction		2.49	-0.11	-0.13	-0.07	0.00	-0.09	-0.28	-0.43	2.31	0.08	0.21	0.31	0.22	-0.32	-0.56	0.16
PP splitter		1.68	-0.22	-0.42	-0.38	-0.17	-0.11	-0.06	0.08	1.39	-0.08	-0.12	-0.07	0.06	-0.21	-0.08	0.47
Kero HT		5.91	-1.53	-0.72	-0.56	2.17	1.72	3.12	3.28	5.04	-3.00	-1.93	-0.91	-0.49	-1.53	-0.15	-3.20
Gasoil HT revamp		30.25	-4.44	-4.20	-2.75	-3.55	-4.19	-6.27	-4.35	14.62	1.47	2.75	2.91	2.23	1.01	1.39	9.02
Gasoil HT new		10.00	-1.28	-0.64	0.21	-0.11	-0.25	-1.38	0.29	3.11	0.99	0.89	1.99	0.80	0.52	1.68	3.61
Gasoil Hydrodearomatisation		-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.16	0.00	0.00	0.00	0.99	0.00
Sulphur recovery		0.93	-0.01	-0.01	-0.02	0.27	0.20	0.71	1.49	0.23	-0.24	-0.24	-0.24	-0.23	0.34	0.87	1.63
Bitumen		2.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen manuf (as hydrogen) (1)		*463*	*-62*	*-56*	*-54*	*205*	*142*	*391*	*683*	*463*	*-468*	*-468*	*-364*	*-238*	*157*	*505*	*923*
Steam cracker		10.79	-0.15	0.08	-0.13	2.36	1.78	3.41	4.67	15.11	-4.28	-3.54	-3.17	-2.25	0.12	0.33	1.32
Hydrodealkylation		0.06	0.00	-0.06	-0.06	0.36	0.59	0.30	0.44	0.46	-0.46	-0.46	-0.07	0.24	0.01	0.03	0.07
(1) as kt/a of hydrogen output																	
Plant utilisation	Mt/a																
CDU		747	748	748	748	746	747	746	748	679	679	678	679	679	680	682	683
HVU		284	291	291	291	287	285	279	247	264	249	249	256	261	258	220	161
Visbreaking / coking		83	86	88	88	78	78	75	64	69	64	65	67	68	65	50	16
FCC		123	124	123	123	105	111	95	97	90	122	121	116	105	89	91	100
HCU once-through		108	108	108	107	135	129	152	148	116	59	59	75	90	117	121	109
LR HDS		15	11	11	11	27	24	40	74	18	9	9	10	11	29	63	124
Naph HT		86	85	84	85	81	84	79	82	69	78	75	75	73	68	78	86
FCC gasoline HT		20	29	26	22	19	20	18	17	19	23	20	20	21	20	16	4
FCC gasoline sweetening		0	0	0	0	0	0	1	4	0	0	0	0	0	0	2	3
Cat reforming		86	89	88	78	81	75	71	90	64	69	72	64	63	63	75	77
FCC gasoline splitter		31	30	31	31	25	28	23	23	25	29	30	31	29	25	25	25
Reformate splitting		47	32	36	38	50	51	49	45	38	32	34	38	40	37	40	39
Isomerisation		4	6	6	5	5	4	7	13	5	3	3	3	3	7	11	15
Aromatics Extraction		11	11	10	10	9	9	9	8	8	10	10	9	9	8	8	9
PP splitter		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
MD HT		260	246	252	255	257	258	255	257	232	228	234	238	236	234	239	243
Gasoil Hydrodearomatisation		1	1	1	1	1	1	1	0	1	1	2	1	1	1	2	0
Sulphur recovery		5	5	5	5	5	5	6	6	4	3	3	4	4	4	5	6
Bitumen		22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Hydrogen manuf (as hydrogen) (1)		*1244*	*1182*	*1199*	*1203*	*1415*	*1363*	*1589*	*1857*	*1169*	*715*	*735*	*839*	*952*	*1313*	*1579*	*2009*
Steam cracker		77	77	77	77	79	79	80	81	81	77	78	78	79	81	81	82
Hydrodealkylation		0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	1
Capital Investment	M€	**15165**	**-128**	**-1188**	**-1168**	**9281**	**6832**	**16505**	**30296**	**16556**	**-12486**	**-12030**	**-11079**	**-8241**	**3931**	**17647**	**35000**
Capital Charge @ 15%	M€	2275	-19	-178	-175	1392	1025	2476	4544	2483	-1873	-1804	-1662	-1236	590	2647	5250
Opex	M€/a	**1098**	**81**	**116**	**104**	**268**	**346**	**878**	**2235**	**552**	**-595**	**-608**	**-541**	**-498**	**539**	**2127**	**3496**
Fuel & Loss (@LS HFO price)		**1044**	**63.3**	**15.4**	**-10.8**	**131.3**	**90.0**	**328.0**	**573.5**	**146**	**-489**	**-511**	**-334**	**-237**	**171**	**481**	**801**
Annual cost		**4416**	**4542**	**4370**	**4335**	**6208**	**5877**	**8099**	**11769**	**3181**	**224**	**258**	**644**	**1210**	**4481**	**8436**	**12728**
Energy consumption																	
Total system	PJ/a	2176	2199	2192	2185	2178	2178	2199	2247	1962	1923	1915	1928	1935	1990	2036	2090
	Mtoe/a	51.8	52.4	52.2	52.0	51.8	51.8	52.4	53.5	46.7	45.8	45.6	45.9	46.1	47.4	48.5	49.8
	toe/t product	7.41%	7.51%	7.44%	7.43%	7.43%	7.42%	7.52%	7.68%	7.32%	7.15%	7.12%	7.17%	7.21%	7.43%	7.60%	7.81%
	toe/t crude	6.94%	7.00%	6.97%	6.96%	6.95%	6.94%	7.02%	7.16%	6.88%	6.75%	6.72%	6.76%	6.79%	6.97%	7.11%	7.28%
Refinery	PJ/a	1920	1945	1936	1930	1917	1919	1940	1987	1699	1662	1657	1672	1676	1731	1778	1829
	toe/t product	7.2%	7.3%	7.2%	7.2%	7.2%	7.2%	7.3%	7.5%	7.1%	6.9%	6.9%	6.9%	6.9%	7.2%	7.4%	7.6%
Petrochemicals	PJ/a	256	254	256	256	260	259	259	260	263	260	258	257	259	259	258	260
	toe/t product	9.3%	9.3%	9.3%	9.3%	9.5%	9.5%	9.5%	9.5%	9.6%	9.5%	9.4%	9.4%	9.5%	9.5%	9.4%	9.5%
CO2 emissions		0.072	0.071	0.071	0.071	0.073	0.072	0.073	0.073	0.070	0.067	0.067	0.069	0.069	0.071	0.072	0.072
Total system	Mt/a	156.4	157.0	156.3	155.8	158.2	157.9	160.9	164.3	138.0	128.8	128.3	132.5	134.4	140.7	145.8	150.6
	t/t product	0.224	0.225	0.223	0.222	0.227	0.226	0.231	0.236	0.216	0.201	0.200	0.207	0.210	0.221	0.229	0.236
	t/t crude	0.209	0.210	0.209	0.208	0.212	0.211	0.216	0.220	0.203	0.190	0.189	0.195	0.198	0.207	0.214	0.220
Refinery	Mt/a	141.3	142.0	141.2	140.7	142.8	142.6	145.6	148.9	122.5	113.4	113.0	117.4	119.2	125.4	130.6	135.2
	t/t product	0.223	0.225	0.222	0.221	0.226	0.225	0.231	0.236	0.214	0.197	0.196	0.204	0.207	0.219	0.228	0.236
Petrochemicals	Mt/a	15.1	15.0	15.1	15.1	15.4	15.3	15.3	15.4	15.5	15.4	15.2	15.1	15.3	15.3	15.2	15.4
	t/t product	0.232	0.230	0.232	0.232	0.236	0.235	0.235	0.236	0.238	0.236	0.234	0.233	0.235	0.235	0.234	0.236